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CRYSTALLIZATION HISTORY OF THE KIRANA VOLCANICS, SARGODHA, PAKISTAN.

BY

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Abstract: *The Neoproterozoic Kirana Volcanics represent bimodal volcanism in the Pakistani part of the Kirana-Malani Basin. Rhyolites predominate over the basalts/dolerites andesites and dacites. These volcanics represent the oldest remnants of widespread igneous activity within the so-called Kirana-Malani Basin and mark important Precambrian tectono-magmatic events in Pakistan. The acid volcanics are predominantly potassic; mafic representatives are characterized by the presence of plagioclase, augite and occasional olivine or magnetite. The felsic lavas are dominated by alkali felspar and quartz. Amphibole and augite are also encountered in basalts/dolerites.*

INTRODUCTION

The Kirana volcanics are an integral part of the world's largest felsic volcanic field known as 'Malani Volcanics' occupying tracks along the northwestern flank of the great Aravalli mountain ranges with scattered outcrops extending from Tosham in Haryana to other places in northern districts of Rajasthan. Thus, Kirana Malani may be described as volcanoplutonic province characterized by the widespread Late – Proterozoic tectono-magmatic activity (spanning over 950 Ma to 550 Ma) with distinct rhyolitic flows and associated granites.

The volcanic suites belong to tholeiitic basalt-andesite-rhyolite magma association (Ahmad, 2000, 2004). The volcanics are interbedded with intercalations of volcanogenic sediments and tuffs. The overlying metasedimentary units are Tuguwali phyllites and Asianwala quartzites respectively (Alam, 1987).

The volcanics and associated sedimentary rocks constitute a distinct cratonic rift assemblage and do not represent Indian Shield elements (Chaudhry et al., 1999) as previously believed by many workers (Heron, 1953, Davies and Crawford, 1971; Kochhar, 1984, Alam, 1987; Alam et al., 1992). The Kirana volcanics and volcanoplutonic rocks of Nagarparkar in Sindh were interpreted to have been emplaced in the extensional basins formed as a result of mantle plume activity linked to the break-up of Rodinia Supercontinent. The extensional basin developed within the Late Proterozoic NE Gondwana part of Greater India is named as Malani-Kirana Basin (Chaudhry et al., 1999).

CRYSTALLIZATION HISTORY

Dolerite and Microgabbros Associations

The minerals of some representative samples of dolerites, basalts, rhyolites, ignimbrites and welded tuffs have been analysed by microbe analyzer at GeoScience laboratories, Islamabad.

Chemically these are classified as olivine-normative tholeiitic basalts/dolerites and their mineralogy may be conveniently described on the basis of olivine normative and quartz normative division. All lavas are examined; contain plagioclase, augite, olivine, ilmenite and apatite. Magnetite occurs only in the olivine-normative samples. The olivine normative lavas are aphyric, with some microphenocrystic olivine; plagioclase (up to 5%) and very minor augite are the phenocryst phases in the quartz normative lavas.

Olivine is an accessory phenocryst phase in the dolerite (olivine normative lava) and entirely absent in the quartz normative association of the Kirana Complex. The representative analyses of the olivines of the Kirana

Table: 1.

Microprobe analysis of plagioclase in the Basalts/Dolerites from the Kirana Complex

Sample#	135-72	134-72	143-72	144-72	149-72	162-72	163-72	177-72	178-72	181-72
Lab No.	C2/1-pl	C3-pl-C	C3-pl-R	C6-pl	C4/2-Pl	C1/2-Pl	C4-Pl	C5-Pl	C1/2-Pl	C2/2-Pl
MAJOR OXIDE PERCENTAGE										
TiO_2	0.072	0.039	0.066	0.089	0.620	0.059	0.072	0.065	0.412	0.051
SiO_2	54.314	54.210	52.970	53.671	51.548	53.980	53.550	51.790	54.290	52.630
Na_2O	4.213	5.310	3.950	4.540	2.995	4.280	3.990	5.160	6.210	3.187
Cr_2O_3	0.034	0.024	0.023	0.019	0.013	0.029	0.018	0.019	0.018	0.024
K_2O	0.150	0.140	0.012	0.140	0.088	0.170	0.149	0.149	0.103	0.130
MgO	0.043	0.021	0.056	0.031	0.038	0.012	0.039	0.114	0.395	0.119
MnO	0.036	0.034	0.000	0.021	0.011	0.052	0.047	0.023	0.019	0.004
CaO	13.350	10.990	12.274	12.690	14.950	13.090	13.090	14.410	12.069	13.260
Al_2O_3	27.723	29.120	29.456	28.504	29.900	28.110	29.150	28.056	25.490	29.410
FeO	0.310	0.371	0.351	0.393	0.550	0.317	0.309	0.519	1.335	1.389
NiO	0.000	0.048	0.001	0.000	0.017	0.000	0.002	0.049	0.089	0.077
Total	100.173	100.268	99.093	100.009	100.110	100.040	100.344	100.289	100.018	100.230
Mol.per cent										
Ab	23.785	32.299	24.329	26.137	16.608	24.401	23.159	26.168	33.783	19.225
An	75.368	66.849	75.597	73.057	82.904	74.629	75.977	73.077	65.657	79.990
Or	0.847	0.852	0.074	0.806	0.488	0.969	0.865	0.756	0.560	0.784
No. of cations on the basis of 32 oxygens										
Ti	0.007	0.005	0.009	0.012	0.085	0.008	0.010	0.009	0.057	0.007
Si	9.849	9.783	9.665	9.747	9.400	9.800	9.684	9.503	9.949	9.557
Na	1.479	1.855	1.395	1.596	1.057	1.504	1.397	1.833	2.203	1.120
Cr	0.005	0.003	0.003	0.003	0.002	0.004	0.003	0.003	0.003	0.003
K	0.035	0.032	0.003	0.032	0.020	0.039	0.034	0.035	0.024	0.030
Mg	0.012	0.006	0.015	0.008	0.010	0.003	0.010	0.031	0.108	0.032
Mn	0.006	0.005	0.000	0.003	0.002	0.008	0.007	0.004	0.003	0.001
Ca	2.594	2.125	2.400	2.469	2.921	2.546	2.536	2.833	2.370	2.580
Al	5.914	6.183	6.323	6.090	6.415	6.004	6.202	6.056	5.495	6.283
Fe	0.044	0.052	0.050	0.056	0.078	0.045	0.044	0.074	0.190	0.196
Ni	0.000	0.007	0.000	0.000	0.002	0.000	0.000	0.007	0.013	0.011
Total	19.936	20.051	19.854	20.004	19.908	19.954	19.917	20.378	20.357	19.815

SHIMADZU EPMA-8705 Q-II System installed at GeoScience Laboratory, GSP, Islamabad.
Conditions: Acc. Volt. = 15 kv Samp. Current = 1 Beam Dia = 10um
Satndards: TiO_2, Quartz, Albite, Cr_2O_3 Sanidine, MgO, Rhodonite, Wollastonite, Al2O3, Fe2O3, Cobatlite, NiSi.

Table:2.

Microprobe analyses of olivines in the Dolerites from the Kirana Complex

Sample #	K-209	K-210	K-211	K-212	K-213	K-214	K-215	K-216	K-217	K-218
Lab. #	C1-ol	C1-ol	C1-ol	C1-ol	C1-ol	C1-ol	C1-ol	C1-ol	C1-ol	C2/1-ol
SiO_2	35.654	36.735	35.560	35.678	35.112	36.225	36.122	35.225	36.445	36.665
Al_2O_3	0.103	0.113	0.114	0.140	0.090	0.050	0.080	0.080	0.060	0.045
FeO	27.570	26.056	26.311	27.786	26.889	25.558	25.489	27.410	25.523	24.470
Na_2O	0.047	0.014	0.014	0.046	0.000	0.021	0.000	0.000	0.015	0.001
Cr_2O_3	0.029	0.005	0.005	0.021	0.000	0.000	0.003	0.014	0.000	0.025
K_2O	0.000	0.005	0.005	0.003	0.000	0.000	0.000	0.004	0.000	0.000
MgO	36.227	36.560	36.763	36.113	37.428	37.072	37.450	36.175	37.145	37.257
MnO	0.589	0.537	0.537	0.457	0.509	0.467	0.528	0.580	0.493	0.528
CaO	0.024	0.068	0.068	0.055	0.036	0.038	0.049	0.020	0.039	0.029
TiO_2	0.000	0.028	0.028	0.019	0.025	0.058	0.022	0.011	0.500	0.060
CoO	0.047	0.030	0.030	0.000	0.000	0.898	0.593	0.073	0.080	0.630
NiO	0.065	0.128	0.128	0.064	0.000	0.006	0.049	0.126	0.029	0.174
Total	100.355	100.279	99.563	100.382	100.089	100.393	100.385	99.718	100.329	99.884
No. of cations on the bases of 4 oxygens										
Si	0.926	0.951	0.927	0.936	0.912	0.943	0.936	0.922	0.937	0.948
Al	0.003	0.003	0.003	0.004	0.003	0.002	0.002	0.002	0.002	0.001
Fe	0.558	0.521	0.534	0.556	0.549	0.511	0.512	0.559	0.511	0.493
Na	0.002	0.001	0.001	0.002	0.000	0.001	0.000	0.000	0.001	0.000
Cr	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mg	1.401	1.395	1.427	1.382	1.446	1.416	1.431	1.409	1.422	1.434
Mn	0.013	0.012	0.012	0.010	0.011	0.010	0.011	0.013	0.011	0.012
Ca	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Ti	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.010	0.001
Co	0.001	0.001	0.001	0.000	0.000	0.018	0.012	0.002	0.002	0.013
Ni	0.001	0.003	0.003	0.001	0.000	0.000	0.001	0.003	0.001	0.004
Total	2.907	2.889	2.910	2.895	2.923	2.902	2.908	2.910	2.897	2.907

Table: 3.
Microprobe analyses of augite in Gabbros and dolerites from the Kirana Complex

Sample #	K-209	K-210	K-211	K-212	K-213	K-214	K-215	K-216	K-217	K-218
Lab. #	C1-aug	C1-aug	C1-aug	C1-aug	C1-aug	C1-aug	C1-aug	C1-aug	C1-aug	C2/1-aug
SiO_2	49.710	52.345	47.106	51.990	49.291	52.490	49.790	48.420	49.215	51.646
Al_2O_3	5.078	4.480	5.345	4.380	3.866	3.280	3.140	3.940	3.556	2.783
FeO	11.820	8.780	11.193	7.840	8.007	8.330	7.750	9.800	8.600	7.124
Na_2O	0.490	0.229	0.483	0.380	0.477	0.270	0.343	0.364	0.480	0.349
$C_{r2}O_3$	0.340	0.150	0.155	0.265	0.357	0.250	0.300	0.184	0.290	0.118
K_2O	0.008	0.110	0.010	0.081	0.000	0.000	0.016	0.010	0.000	0.002
MgO	13.090	14.580	13.699	14.990	15.639	12.940	15.550	14.640	14.870	14.960
MnO	0.148	0.110	0.269	0.169	0.178	0.241	0.210	0.159	0.220	0.315
CaO	17.670	19.223	19.126	18.234	20.860	21.090	20.840	20.970	21.440	22.128
TiO_2	1.550	0.095	2.457	1.374	0.995	1.359	1.380	1.490	1.341	0.852
CoO	0.355	0.149	0.294	0.542	0.640	0.000	0.495	0.016	0.000	0.000
NiO	0.134	0.010	0.146	0.000	0.000	0.000	0.221	0.123	0.000	0.000
Total	100.393	100.261	100.283	100.245	100.310	100.250	100.035	100.116	100.012	100.277
NO. of cations on the basis of 6 oxygens										
Si	1.835	1.835	1.756	1.892	1.823	1.921	1.844	1.804	1.828	1.909
Al	0.165	0.165	0.244	0.108	0.177	0.079	0.135	0.173	0.140	0.091
Al*	0.056	0.056	0.000	0.080	0.000	0.063	0.000	0.000	0.000	0.028
Fe+2	0.371	0.272	0.217	0.243	0.088	0.260	0.133	0.133	0.112	0.171
Fe+3	0.000	0.000	0.133	0.000	0.159	0.000	0.107	0.171	0.154	0.048
Na	0.035	0.035	0.035	0.027	0.034	0.019	0.025	0.026	0.035	0.025
Cr	0.010	0.010	0.005	0.008	0.010	0.007	0.009	0.005	0.009	0.003
K	0.000	0.000	0.000	0.004	0.000	0.000	0.001	0.000	0.000	0.000
Mg	0.719	0.719	0.758	0.812	0.861	0.705	0.857	0.812	0.822	0.808
Mn	0.005	0.005	0.008	0.005	0.006	0.007	0.007	0.005	0.007	0.010
Ca	0.699	0.699	0.775	0.711	0.827	0.827	0.827	0.837	0.853	0.860
Ti	0.043	0.043	0.069	0.038	0.028	0.037	0.038	0.042	0.037	0.023
Co	0.010	0.010	0.009	0.016	0.019	0.000	0.015	0.000	0.000	0.000
Ni	0.004	0.004	0.004	0.000	0.000	0.000	0.007	0.004	0.000	0.000
Total	3.952	3.853	4.013	3.943	4.032	3.926	4.005	4.013	3.997	3.976
Atomic %ages										
Mg	40.211	42.572	40.259	45.973	44.502	39.342	44.543	41.571	42.348	42.803
Fe	20.722	16.068	18.589	13.778	12.776	14.507	12.492	15.573	13.705	11.630
Ca	39.067	41.361	41.153	40.249	42.722	46.150	42.965	42.856	43.946	45.567
mg*	65.992	72.599	68.412	76.941	77.695	73.059	78.098	72.748	75.550	78.635

Table: 4.
Microprobe analyses of amphiboles in the dolerites from the Kirana Complex

Sample #	131-72	147-72	150-72	151-72	157-72	158-72	165-72	167-72	172-72	173-72
Lab. #	C3-am-C	C3-am-C	C4/3-am	C5/1-am	C5/1-am	C4–am	C2/1-am	C2/3-am	C4/1-am	C4-am
SiO2	44.120	43.334	43.12	41.25	43.220	41.450	42.889	44.120	43.110	41.330
TiO2	0.000	0.890	0.546	0.590	0.510	0.030	0.070	0.100	0.342	0.432
Al2O3	10.120	9.260	9.34	10.230	9.330	9.780	8.340	8.660	9.340	9.230
Cr2O3	0.010	0.060	0.02	0.420	0.230	0.030	0.000	0.020	0.040	0.080
FeOT	20.340	19.334	19.334	20.560	23.230	22.445	22.445	22.140	23.120	20.230
MnO	0.320	0.330	0.35	0.180	0.190	0.350	0.280	0.260	0.320	0.270
MgO	9.340	12.220	10.34	10.550	9.340	10.220	9.340	10.320	11.450	12.090
NiO	0.040	0.000	0.04	0.000	0.000	0.030	0.010	0.000	0.020	0.050
CaO	15.223	14.221	16.37	16.230	14.230	15.920	15.450	13.950	12.340	16.300
Na2O	0.190	0.330	0.42	0.200	0.250	0.240	0.460	0.370	0.340	0.300
K2O	0.130	0.020	0.08	0.000	0.010	0.070	0.160	0.120	0.000	0.000
Total	99.833	99.999	99.960	100.210	100.540	100.565	99.444	100.060	100.422	100.312
No. of cations on the basis of 23 oxygens										
Si4+	6.571	6.391	6.483	6.191	6.378	6.259	6.530	6.497	6.373	6.333
Al	1.420	1.609	1.517	1.809	1.622	1.741	1.485	1.503	1.627	1.667
Al	0.356	0.000	0.138	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ti4+	0.000	0.099	0.062	0.067	0.057	0.003	0.008	0.011	0.038	0.050
Cr3+	0.001	0.007	0.002	0.050	0.027	0.004	0.000	0.002	0.005	0.010
Fe3+	0.144	0.378	0.000	0.189	0.854	0.114	0.271	0.873	0.608	0.000
Fe2+	2.389	2.007	2.431	2.391	2.013	2.720	2.565	1.853	2.250	2.592
Mn2+	0.040	0.041	0.045	0.023	0.024	0.045	0.036	0.032	0.040	0.035
Mg2+	2.074	2.687	2.318	2.360	2.055	2.301	2.104	2.266	2.523	2.762
Ni2+	0.005	0.000	0.005	0.000	0.000	0.004	0.001	0.000	0.002	0.006
Ca2+	2.429	2.247	2.637	2.609	2.250	2.576	2.501	2.201	1.954	2.676
Na+	0.055	0.094	0.122	0.058	0.072	0.070	0.135	0.106	0.097	0.089
K+	0.025	0.004	0.015	0.000	0.002	0.013	0.031	0.023	0.000	0.000
Total	15.508	15.562	15.775	15.747	15.351	15.850	15.666	15.367	15.518	16.220

Table: 5.
Microprobe analyses of orthoclases in the rhyolites from the Kirana Complex

Sample No	21-vol-166	24-vol-166	26-vol-166	28-vol-166	32-vol-166	45-vol-166	46-vol-166	47-vol-166	50-vol-166	52-vol-166
Rock Name	C2-orth	C2-orth	C2-orth	C1-orth	C1-orth	C2-orth	C1-orth	C –orth	C1-orth	C1-orth
TiO_2	0.150	0.090	0.170	0.150	0.150	0.060	0.190	0.080	0.140	0.190
SiO_2	70.800	79.850	80.690	76.810	79.700	84.650	67.840	81.980	83.610	72.240
Na_2O	0.120	0.100	0.080	0.140	0.100	0.060	0.170	0.130	0.070	0.120
Cr_2O_3	0.000	0.020	0.030	0.010	0.030	0.010	0.040	0.020	0.040	0.020
K_2O	7.250	4.580	4.510	4.960	4.780	4.010	6.750	4.650	3.950	6.690
MgO	0.820	0.550	0.620	0.670	0.570	0.460	0.940	0.480	0.400	0.780
MnO	0.010	0.040	0.020	0.000	0.000	0.010	0.020	0.030	0.020	0.030
CaO	0.000	0.000	0.020	0.030	0.010	0.000	0.000	0.010	0.030	0.010
Al_2O_3	18.230	12.840	11.760	15.200	13.000	9.230	21.980	10.950	9.930	17.980
FeO	1.908	1.269	1.599	1.812	1.482	1.301	1.546	1.215	1.770	1.716
NiO	0.000	0.000	0.000	0.000	0.040	0.000	0.020	0.000	0.000	0.000
Total	99.288	99.339	99.499	99.782	99.862	99.791	99.496	99.545	99.960	99.776
Mol.%age										
ab	2.448	3.204	2.609	4.084	3.069	2.218	3.678	4.059	2.600	2.644
an	0.000	0.000	0.361	0.484	0.170	0.000	0.000	0.173	0.617	0.122
or	97.552	96.796	97.029	95.432	96.761	97.782	96.322	95.768	96.783	97.234
No. of cations on the basis of 32 oxygens										
Ti	0.020	0.012	0.022	0.019	0.019	0.008	0.025	0.010	0.018	0.025
Si	12.470	13.625	13.756	13.171	13.572	14.240	11.929	13.926	14.095	12.594
Na	0.041	0.033	0.026	0.046	0.033	0.020	0.058	0.043	0.023	0.040
Cr	0.000	0.003	0.004	0.001	0.004	0.001	0.006	0.003	0.005	0.003
K	1.630	0.998	0.982	1.086	1.039	0.861	1.515	1.008	0.850	1.489
Mg	0.215	0.140	0.157	0.171	0.144	0.115	0.246	0.121	0.100	0.202
Mn	0.001	0.006	0.003	0.000	0.000	0.001	0.003	0.004	0.003	0.004
Ca	0.000	0.000	0.004	0.006	0.002	0.000	0.000	0.002	0.005	0.002
Al	3.778	2.578	2.359	3.066	2.604	1.827	4.547	2.188	1.969	3.688
Fe^{+2}	0.262	0.169	0.212	0.242	0.196	0.170	0.212	0.161	0.232	0.233
Ni	0.000	0.000	0.000	0.000	0.005	0.000	0.003	0.000	0.000	0.000
Total	18.397	17.550	17.503	17.789	17.601	17.235	18.518	17.456	17.284	18.255

Complex show small compositional variations. Compositions of olivine phenocrysts range from Fo_{73-70}. Slight zoning to more fayalitic composition rims is observed as represented by Table: 1.

Olivine occurs as scattered microphenocrysts, but it is dominantly a groundmass phase in the olivine normative lavas. The microphenocrysts are normally zoned, the total compositional range being Fo_{48-61}. Reaction rims of Ca-poor pyroxene have not been observed. Granular groundmass olivine is, within a given sample, compositionally similar to the coexisting microphenocryst rims, the observed range being Fo_{47-68}. Al was detected only in a few samples. The trace element spectra are also similar. Cr is not detectable where as Ni and Co is detected in some samples. The CaO content in olivine is dependent on silica activity of magma; high silica activity promoting Ca poor olivine. Thus the most Ca-poor olivines in plutonic rocks should be expected in low-level undersaturated rocks.

The composition of plagioclase in basalt plots in the labradorite/bytownite field (Fig: 1). The structural formula of plagioclase is determined on the basis of 8 Oxygens. The Calcium contents in plagioclase vary from 67% to 79% and all felspars are deficient in Al. The plagioclase from groundmass does not show any appreciable variation from the phenocrystal composition and plots in the labradorite field. The core of one of the phenocrysts plots near the boundary of labradorite-bytownite while the rim of the same is essentially of labradorite composition. As the composition of plagioclase in the groundmass does not show any appreciable variation, it is tempting to conclude that the magma ascended immediately after the formation of plagioclase phenocryst, allowing no time for further crystal fractionation in the residual melt.

Plagioclase represents phenocryst as well as groundmass phase in the dolerite, exhibiting relatively small compositional changes. Plagioclase crystals are slightly zoned and restricted in composition to labradorite to bytownite (An_{67} to An_{82}) field, however in the altered dolerites only albite is present (Fig. 1) The plagioclase from groundmass does not show any appreciable variation from phenocrystic composition and plots in the same fields.

The olivine normative lavas are characterized by a distinctly pink, granular groundmass of calcium rich augite, which shows rather restricted solid solution.

Microprobe analyses of the pyroxene from the Kirana basalts/dolerites clearly indicate that all the analysed samples fall within the field of augite, when plotted on the Ca-Mg-Fe diagram (Fig: 2) after Morimoto, et al (1988). Calcic augite is the dominant phenocryst and groundmass phase following plagioclase in the dolerites of the Kirana Complex. Analyses of pyroxenes (Table: 3) calculated on the basis of 6 oxygens and 4 cations. The chemical data indicates that the clinopyroxene mainly formed under low pressure conditions as documented by their low Al^{+6} value as represented in Table: 3.

The microprobe analyses of the amphibole are given in Table: 4. All the samples fall in “Fe-hornblende” to “Mg-hornblende” fields, when plotted on the Si versus Mg/(Mg+Fe2) diagram (Fig: 3) after Leake et al (1997). It occurs as phenocrysts as well as in the groundmass. The amphibole is rich in Ca to be hornblende enriched in Fe and Mg to be classified as Fe-hornblende to Mg-hornblende. The chemistry of the amphibole follows the parameters of Ca-amphibole i.e. $Ca^{2+} > 1.50$; $(Na+K) < 0.50$ (after Leake et al, 1997). All the samples fall in the “Magmatic amphibole” field, when plotted on the Si versus Ca+Na+K diagram (Fig: 4) after Leake et al (1971).

Felsic and Silicic Associations

Rhyolites are phenocryst free (5% total volume of samples) with two-felspars plus quartz. Orthoclase, (the dominant felspar, generally in excess of plagioclase in at least 5:1 proportion) ranges in composition from 95% to 98% (Table: 5). Individual crystals show minor oscillatory zoning of plagioclase. Plagioclase is predominantly sodic oligoclase and individual phenocrysts show oscillatory normal zoning typically with less than 5% total variation. Samples from the different flows show small variations in their total compositional range.

Wide variation exists in the K-Na content of the alkali felspar in the different samples. The two phenocrysts of alkali felspars from rhyolite represent almost end members with 94% $K\ Al\ Si_3O_8$, and 98% $Na\ Al\ Si_3O_8$ (Fig: 1). The maximum albite contents of K-felspar from rhyolite is 45%, with less than 2wt% anorthite, K-felspar is found to co-exist with pure albite.

The maximum albite content of k-felspar in the granites is 3% with <0.5% anorthite (Table:5). The iron contents of the K-felspar ranges from 1.26% to 1.91% as FeO. Wide variations exist in K-Na content of the alkali felspar in the rhyolites of the Malani volcanics (India). Bhushan (1989) presented analyses exhibiting 94%$KAlSi_3O_8$.

DISCUSSION

It is a generally accepted fact that felsic volcanics predominate over the mafics within bimodal complexes (e. g. Yellowstone and Medicine lake in Western, USA, Iceland, Western Scotland and Southern Queens land of Australia, Malanis, India; Nagarparkar Complex, Pakistan). Ahmad (2000) and Ahmad (2004) based on geochemical constraints suggest that the rhyolites of the Kirana and Nagarparkar complexes are not differentiated products of

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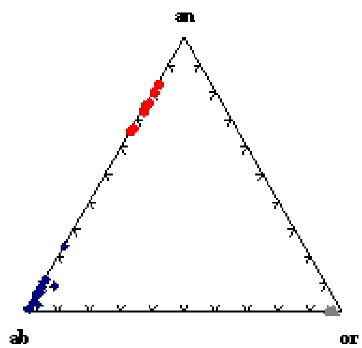

Fig: 1

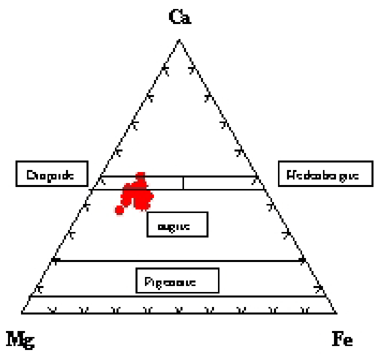

Fig: 2

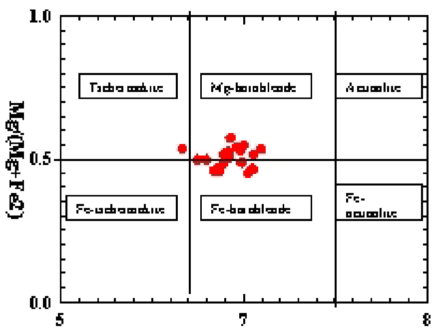

Fig: 3

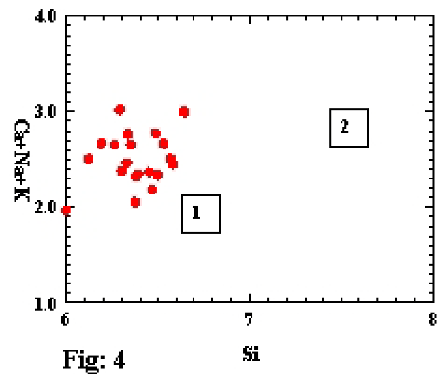

Fig: 4

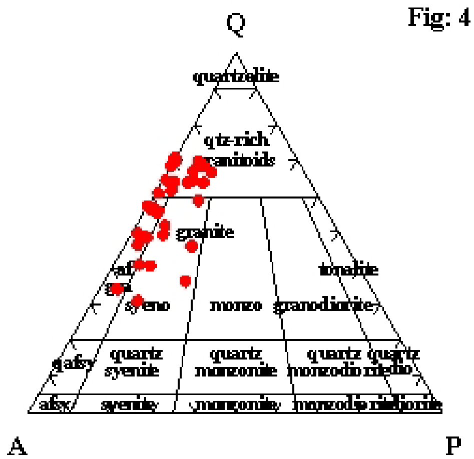

Fig: 5

Fig: 1. Plots of microprobe analyses of felspar (mol per cent), from the rhyolites and dolerites of the Kirana Complex. Dolerites/basalts (rounded) show bytownite to labradorite composition. Rhyolites contain orthoclase (triangle). Filled diamonds are albitised plagioclase from altered dolerite.

Fig: 2. Microprobe plots of clinopyroxene in the dolerite from the Kirana Complex (Mg-Ca-Fe diagram) indicating augite to diopside composition (after Morimoto et al, 1988).

Fig: 3. Amphibole composition (plotted after Leake et al., 1997) from dolerite of the Kirana Complex. Composition of the representative samples fall in Ca-amphibole from Fe-hornblende to Mg-hornblende.

Fig: 4. Plot of Si versus Ca+Na+K for amphibole from the Kirana Complex. Fields after Leake (1971), 1 = magmatic amphibole, 2 = metamorphic amphibole. All the representative samples fall in the field of magmatic amphibole.

Fig. 5. Plots of Q-Ab+Or-An normative data of rhyolite from the Kirana Complex, plotted on the Q-A-P diagram, using fields established by Streckeisen (1976) for his modal Quartz-Alkali felspar-Plagioclase plot. The rhyolite of the Kirana Complex is falling in the fields of Alkali granite (alkali rhyolite), Granite (rhyolite) to Quartz rich granitoids (quartz rich rhyolite) fields.

basaltic magmatism. Near absence of intermediate members between the basaltic and rhyolitic flows and presence of voluminous rhyolitic rocks suggests that the rhyolites are not differentiated products of basaltic magmas (Bhushan, 1989). Only a small proportion of rhyolitic material as a fractionate may be generated by the differentiation of basic magma. Hence their formation by fractionation from basalt is not considered feasible. Evidently the generation of silicic magma should be related to partial melting of a preexisting crust, enriched in silica, alumina and alkalies (McBurney, 1984). The presence of bipyramidal quartz and K-felspar as phenocrysts is indicative of high temperature of crystallization (Deer et al., 1992). The long-lived magmatism in the Neoproterozoic Kirana-Malani Basin necessitates the geochemical and geodynamic conditions that enable melting and igneous activity for extended periods of time. The observed variations in the chemical compositions of Kirana volcanics require that they be derived by different degrees of melting from heterogeneous mantle source.

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REFERENCES

Ahmad, S. A., 2000. Geology and geochemistry of Neoproterozoic Kirana Volcanics, Sargodha district, Pakistan. *Geol. Bull. Punjab Univers*, **35**: 59-71.

Ahmad, S. A., 2004. Geology, Petrology and Geochemistry of the Neoproterozoic Indian Shield rocks extension in Pakistan, Ins. Geol. Lahore, Pakistan. *Ph. D thesis.*, 478.

Alam, G.S., 1987. Geology of Kirana Hills, Sargodha, Punjab, Pakistan. *Information release no.201. GSP. Quetta, Pakistan*:1-37.

Alam, G.S., Jaleel, A. and Ahmad, R. 1992. Geology of the Kirana area, District Sargodha Punjab, Pakistan. *Acta Miner. Pak* **6:** 93-100.

Bhushan, S.K., 1989. Mineral chemistry and petrogenetic aspects of Malani Volcanics, Western Rajasthan. *Indian Minerals.*, **43**: **3&4:** 325-338.

Chaudhry, M.N., Ahmad, S.A. and Mateen, A., 1999. Some postulates on the tectonomagmatism, tectonostratigraphy and economic potential of Kirana-Malani-Basin, Indo-Pakistan. *Pakistan. Jour. Hydrocarbon. Res. Islamabad, Pakistan.*, **11**: 52-68.

Davies, R.G. and Crawford, A.R., 1971. Petrography and age of the rocks of Buland Hills, Sargodha Districts West Pakistan, *Geol. Mag.*, **108: 3:** 235-246.

Heron, A. M., 1953. The Geology of Central Rajputana. Mem. *Geol. Surv. Inida.*, **79:** 1-339.

Kochhar, N., 1984. Malani igneous suite: Hotspot magmatism and Cratonization of the northern part of Indian Shield. *Journal of Geological Survey of India.*, **25**, **(3)**: 155-161.

Leak, B.E., 1971. On aluminous edenitic and hornblendes. *Mineral. Mag.*, **42**: 389-407.

Leak, B.E., Wooley, A. R., Arps. C.E.S., Birch. W. D., Gilbert, M.C., Grice, J.D., Hawthorne, C., Kato, A., and others.,1997. Nomenclature of amphiboles: Report of the subcommittee on amphiboles of the International Mineralogical Association, Commission on new minerals and mineral names. *Amer. Mineral,*. **82**: 1019-1037.