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Malvern Hills Igneous Suite

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MALVERN HILLS IGNEOUS SUITE

R Dearnley

A summary of previous petrological and chemical work on the Malvernian crystalline rocks has been given by Lambert and Holland (1971). They considered that diorites and tonalites make up about 70% of the complex, which is exposed mainly in the numerous large quarries along the flanks of the Malvern Hills.

A wide variety of rock types occur, ranging from ultramafics through diorites to granites. Extensive shearing and alteration is common.

The new chemical analyses presented here are intended to supplement those of Blyth and Lambert (1970) and Lambert and Holland (1970) and comprise 36 samples (E58229-58268) collected from the following quarries:
(Figure 1) North Hill (7702 4689, 7690 4700), Earnslaw (7697 4447), Hollybush (7593 3718), Dingle (7654 4567), Gullet (7625 3808), County (7680 4480), 7678 4468), Gardiners (7664 4209) and Westminster (7656 4608).

An attempt was made to collect samples from the whole range of rock types; as can be seen from the various tables of analyses and graphs, a reasonable spread has been achieved. Analyses were carried out by X-ray fluorescence spectometry by Midland Earth Science Associates. Total iron is reported as Fe_2O_3 and loss on ignition at 1050°C is quoted as H_2O+.

The figures quoted in Tables for Feo and Fe_2O_3 have been calculated following the recommendations of Le Maitre (1976) on the adjustment of the oxidation

index according to

$$FeO(Fe_2O_3 + FeO) = 0.88 - 0.0016SiO_2 - 0.027(Na_2O + K_2O).$$

Also, to enable the ~~decimal~~ chemical data to be used in the IUGS mineralogical classification the (CIPW) normative Or, Ab and An values have been recast into alkali feldspar and plagioclase according to the relationships:

alkali feldspar = [Or (Or + Ab + An)]/(Or + An), and

plagioclase feldspar = [An (Or + Ab + An)]/(Or + An).

The plutonic rocks of the Malvern Hills (Blyth and Lambert, 1970; Lambert and Holland, 1970; see also Tables 1 and 2) comprise a calc-alkaline series with significant potassium enrichment (Figs. 1 and 2). On the alkali-silica diagram (Fig. 1) the suite is almost equally scattered on either side of the alkalic-subalkalic boundary. On the potash-silica diagram (Fig. 2) the analyses spread throughout the calc-alkaline series, the high K-calc-alkaline series and into the Shoshonite series. On the AFM diagram (Fig. 3) a typically calc-alkaline trend is evident ranging from ultramafic to alkali-granitic compositions.

Transformations of the chemical data into ideal mineral componants by way of a modification of the feldspar constituents of the CIPW norm (Le Maitre, 1976) allows classification of the rocks on the IUGS system of Streckeisen (1967) and Le Maitre (1989). This is shown on the quartz-alkali-feldspar-plagioclase (QAP) diagram (Figs. 4 and 5) from which it is seen that a wide range of rock types occur with particular concentrations in the monzodiorite-monzogabro, (quartz) monzonite, monzogranite, syenogranite and alkali-feldspar granite groups.

The mineralogy of the suite (see Table 1) differs considerably from the CIPW norms listed in Tables 2 and 3, due largely to the development of hornblende at the expense of normative feldspar, pyroxene and olivine components.

Ultramafics consist almost entirely of hornblende, but on the IUGS classification they fall into the gabbro and monzogabbro groups. Making up the bulk of the suite are the olivine-normative diorites and the quartz-normative diorites and tonalites of Lambert and Holland (1971), here classified as monzogabbros and quartz-monzodiorites and quartz-monozonites.

Relatively minor proportions of felsic rocks are represented by the granites, ranging from monzogranites through syenogranites to alkali-feldspar granites together with rarer quartz-rich granitoids.

Relict igneous textures showing interlocking and ophitic feldspar laths and plates, zoned plagioclase feldspars and pseudomorphs after olivine are to be found in a few specimens of monzogabbro (eg 15) and monzodiorites (eg 9,11,14) but otherwise a metamorphic fabric is apparent, dominated by recrystallised plagioclase feldspar and hornblende. Textures range from equigranular hornblende and feldspar (monzogabbro, 17) to well developed schistose fabrics. Gneissose quartzo-feldspathic types occur including alkali-feldspar granites (eg 31) in some instances with relatively abundant microcline (eg 33,34,36).

Petrogenetic relationships within the series are indicated by the linear covariations of incompatible trace elements Y vs Zr and Nb vs Zr and by the plots of Mg, Ba, Rb, Sr, Zr, and Ni against CaO (Figures 7,8,9).

Of the elements analysed in Table 1 Rb, Y and Nb are the most likely to be effective for the discrimination of intrusive settings and have been used for

distinguishing granitic rocks from various tectonic environments. Pearce, Harris & Tindle (1984) defined a number of such intrusive settings on the basis of Rb vs (Y+Nb) plots, recognising volcanic arc granites (VAG), ocean ridge granites (ORG), within plate granites (WPG) and areas of plate collision (COLG). On this type of plot (Figure 10) the Malvern suite falls mainly in the volcanic arc granite setting with some overlap into the within plate granites. Similarly, on the Nb vs Y plot (Figure 11), spreads are found mainly from the VAG to the WPG regions.

Trace element abundances of the Malvern suite are shown in Figs 12, 13 normalised to mid ocean ridge basalts (MORB), after Pearce (1983).

The spidergrams are arranged in groupings of decreasing CaO percentages from gabbros through monzogabbros and monzonites to granites.

The general trends of decreasing Cr and Ni and increasing K, Rb and Ba are evident through the series. At the intermediate-felsic end particularly the distributions are typical of calc-alkaline sequences

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TABLE 1 MALVERN ANALYSED ROCKS

			PLAGIOCLASE	QUARTZ	ALKALI FELDSPAR	EPIDOTE/ZOISITE	HORNBLENDE	CHLORITE	MICAS (B+M)
	7.	Gabbro	*			*	*		
	6.	Monzogabbro	*			*	*		
	3.	Monzogabbro	*			*	*		
	5.	Monzogabbro	*			*	*		
	2.	Monzogabbro	*			*	*		*
	1.	Monzogabbro	*			*	*		*
	17.	Monzogabbro	*	*		*	*		
	10.	Monzonite	*	*		*	*		
*	15.	Monzogabbro	*	*		*	*		
	13.	Monzogabbro	*	*		*	*		*
	16.	Monzonite	*	*		*	*		
	12.	Monzogabbro	*	*		*	*	*	
*	9.	Monzodiorite	*			*	*		
	19.	Monzogabbro	*	*		*	*	*	*
	23.	Monzodiorite	*	*		*		*	*
	25.	Qtz Monzogabbro	*	*		*	*		
*	14.	Monzodiorite	*	*			*	*	
*	11.	Monzodiorite	*			*	*		
	8.	Monzonite	*	*	*	*			*
	27.	Qtz Monzonite	*	*	*		*		*
	4.	Monzonite	*			*	*		*
	32.	Granite	*	*	*	*		*	*
	26.	Monzonite	*	*	*		*	*	*
	24.	Monzonite	*	*	*	*		*	*
	18.	Monzodiorite	*	*			*	*	
	20.	Monzonite	*	*	*	*		*	*
	28.	Granite	*	*	*	*		*	
	21.	Monzonite	*	*	*	*		*	*
	22.	Qtz Monzonite	*	*	*	*		*	
	29.	Granite	*	*	*	*		*	*
	30.	Granite	*	*	*	*		*	*
	35.	Granite	*	*	*	*		*	*
	33.	Granite	*	*	*	*		*	*
	36.	Granite	*	*	*	*		*	*
	34.	Granite	*	*	*	*		*	*
	31.	Granite	*	*	*			*	*

* Relict igneous textures.

Sequence in order of decreasing CaO% from 7-31.

TABLE 2 CHEMICAL ANALYSES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO^2	42.96	42.74	43.85	44.02	47.97	48.29	48.42	47.11	47.84	47.98	48.81	48.85	49.41	49.94	50.14	50.38	50.77	51.26
Al_2O_3	16.94	17.28	8.77	17.08	13.15	7.61	13.47	16.48	13.52	13.08	13.37	15.31	14.98	13.67	14.80	15.29	15.43	14.19
TiO_2	0.70	0.63	1.49	1.04	0.70	0.68	0.48	1.64	2.85	1.50	3.28	1.33	0.69	2.61	1.40	0.65	1.35	2.68
Fe_2O_3	2.47	2.46	3.20	3.36	2.21	2.18	1.18	4.18	4.39	3.04	4.50	3.50	2.55	4.21	3.17	2.65	3.15	4.25
FeO	7.54	7.49	10.48	7.26	6.12	6.61	6.03	7.45	9.33	6.50	8.98	7.49	6.10	8.33	7.21	5.92	7.35	8.25
MgO	11.60	11.44	12.98	10.47	12.06	15.69	11.45	6.19	5.56	9.77	4.64	5.99	9.32	4.74	5.81	9.35	5.47	4.74
CaO	11.18	11.32	12.47	4.84	11.87	12.77	13.24	5.74	8.36	9.54	6.04	8.61	9.35	6.07	9.16	8.79	9.88	4.39
Na_2O	0.94	0.90	0.94	0.86	1.37	1.19	0.97	2.83	3.79	2.70	4.01	2.98	1.33	3.83	2.53	1.47	2.42	4.09
K_2O	1.20	1.27	0.69	3.79	1.18	0.68	0.28	3.24	0.79	1.82	1.03	1.47	2.23	1.20	1.36	2.54	1.24	1.03
MnO	0.13	0.13	0.42	0.13	0.18	0.19	0.17	0.23	0.24	0.29	0.22	0.28	0.17	0.24	0.22	0.15	0.22	0.16
P_2O_5	0.05	0.05	1.49	0.09	0.05	0.30	0.08	0.94	0.39	0.82	0.65	0.14	0.16	0.33	0.13	0.18	0.12	0.36
H_2O^+	3.44	3.23	2.14	4.62	2.33	1.44	2.97	3.37	1.90	2.07	2.05	1.52	2.30	2.14	1.88	2.18	2.07	3.46
Ba	206	218	176	268	180	136	32	1438	308	784	481	394	418	519	307	453	259	257
Ce	18	12	231	11	18	69	14	147	35	69	84	36	32	44	26	20	19	40
Co	54	57	50	40	47	56	47	42	49	38	29	34	37	37	31	35	35	30
Cr	238	230	688	268	564	1232	598	88	78	479	52	139	300	46	106	290	113	52
Cu	121	105	48	45	70	15	61	58	55	14	19	8	91	22	9	51	12	25
La	0	4	101	0	11	30	9	61	10	40	23	10	13	20	6	0	7	8
Ni	101	95	126	100	173	147	167	40	36	98	26	48	97	22	40	93	39	16
Nb	4	3	21	3	2	12	0	24	8	13	8	7	5	6	5	6	5	8
Pb	5	7	6	9	7	4	10	11	5	6	12	10	8	13	8	7	10	10
Sr	372	382	181	96	182	194	261	499	253	362	218	272	305	272	258	292	307	162
Rb	54	57	12	200	38	15	7	103	26	53	30	48	103	39	44	116	41	21
Th	0	0	3	0	0	0	2	8	0	1	4	0	0	3	0	0	0	5
U	0	3	2	2	4	2	3	0	2	2	0	0	2	0	0	1	1	2
V	255	244	301	281	177	201	135	301	355	235	234	304	197	295	307	193	316	297
Y	12	12	113	26	24	29	25	66	56	36	86	39	18	57	35	16	37	47
Zn	64	62	218	73	73	89	76	168	109	161	151	109	76	129	103	76	105	118
Zr	55	50	89	62	109	96	88	261	240	233	570	89	72	231	91	74	94	225
	58242	58231	58233	58237	58234	58229	58247	58258	58243	58232	58239	58238	58245	58240	58241	58235	58248	58254

TABLE 2 CHEMICAL ANALYSES (cont'd)

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SiO^2	52.19	51.09	51.09	52.60	52.78	54.64	55.67	55.41	57.27	65.15	66.29	69.82	69.44	70.03	70.69	75.33	76.39	82.09
Al_2O_3	14.61	20.76	21.25	16.32	16.09	19.19	15.03	19.29	18.59	15.43	17.14	14.78	14.38	13.16	14.77	10.85	13.15	8.08
TiO_2	0.66	1.29	1.30	1.67	1.75	1.12	1.43	1.13	0.89	0.66	0.45	0.36	0.78	0.08	0.46	0.69	0.13	0.51
Fe_2O_3	2.32	2.80	2.69	3.99	2.84	2.55	2.99	2.49	2.27	1.65	1.44	1.41	1.73	0.44	1.31	1.47	0.49	0.75
FeO	5.23	4.02	3.98	7.00	5.07	3.62	6.23	3.65	3.61	2.65	2.04	2.28	2.59	0.59	1.71	2.19	0.76	1.27
MgO	8.28	3.26	3.23	4.90	3.87	3.40	4.59	3.34	3.15	1.86	1.43	1.29	1.55	0.48	0.96	1.23	0.74	0.68
CaO	8.78	4.30	4.06	3.24	7.11	4.55	6.86	4.59	5.12	4.31	2.93	2.35	0.52	4.66	1.38	0.57	1.79	0.71
Na_2O	2.58	5.38	4.96	3.61	3.91	4.92	2.96	4.25	4.26	3.90	3.93	3.44	2.96	5.08	4.12	2.92	3.76	1.49
K_2O	1.27	2.34	2.47	2.27	1.82	2.71	1.31	3.03	2.19	2.01	2.99	2.14	3.57	2.11	3.32	3.05	1.79	3.01
MnO	0.19	0.10	0.09	0.20	0.14	0.06	0.25	0.07	0.09	0.08	0.04	0.04	0.05	0.05	0.05	0.04	0.01	0.03
P_2O_5	0.10	0.47	0.47	0.17	1.07	0.46	0.21	0.44	0.37	0.19	0.19	0.10	0.08	0.03	0.12	0.05	0.03	0.05
H_2O^+	3.42	2.81	3.08	3.11	2.63	2.36	1.83	1.72	2.12	1.85	1.16	1.34	1.79	3.03	1.24	1.52	0.95	1.42
Ba	179	1134	1213	525	412	655	727	688	741	923	1020	1367	810	448	756	687	752	808
Ce	24	62	62	70	119	44	37	36	35	79	39	46	55	0	31	79	34	55
Co	34	9	8	39	22	19	25	19	19	13	14	15	10	6	9	13	11	10
Cr	273	7	9	151	40	26	79	23	23	16	9	10	86	21	19	76	16	53
Cu	49	15	14	39	21	62	28	24	13	12	11	128	17	5	6	9	25	9
La	5	30	33	32	53	21	16	20	11	37	26	18	31	0	16	45	21	40
Ni	96	4	6	46	26	13	33	7	11	5	3	7	24	8	6	18	5	10
Nb	6	16	16	14	30	6	15	6	5	9	7	5	16	11	7	13	6	10
Pb	9	12	9	9	8	10	9	8	11	12	9	13	45	12	8	61	26	46
Sr	223	848	802	213	1407	1145	279	1168	1187	394	877	618	135	230	239	119	482	100
Rb	47	79	83	72	59	78	45	54	60	56	76	61	97	59	84	88	62	80
Th	3	0	0	7	1	1	0	1	0	6	0	3	11	2	7	13	10	8
U	2	3	0	4	2	2	4	0	0	0	0	2	5	4	0	3	2	0
V	163	46	54	198	128	123	241	135	122	67	54	57	66	22	32	52	22	27
Y	27	36	34	40	24	13	42	12	13	15	7	10	28	15	9	31	8	32
Zn	79	121	135	130	98	97	84	87	86	45	50	41	44	5	34	25	15	13
Zr	82	819	840	233	194	148	140	152	140	197	200	153	331	73	170	394	61	399
	58244	58259	58261	58251	58250	58256	58246	58252	58253	58262	58260	58264	58255	58268	58257	58265	58267	58263

TABLE 3 CIPW NORMS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Qz	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	-	-	-	2.98	-	-	-	0.13	-	-	-	-	-	-	-	-	-	-
Or	7.09	7.51	4.08	22.40	6.97	4.02	1.66	19.15	4.67	10.76	6.09	8.69	13.18	7.09	8.04	15.01	7.33	6.09
Ab	7.54	6.19	7.95	7.28	11.59	10.07	8.21	23.95	32.07	22.85	33.93	25.22	11.26	32.41	21.41	12.44	20.48	34.61
An	38.46	39.36	17.67	23.42	26.25	13.42	31.58	22.34	17.55	18.20	15.44	24.06	28.32	16.57	25.01	27.62	27.58	17.32
Ne	0.22	0.77	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DiWo	6.96	6.88	14.39	-	13.49	20.03	14.03	-	9.49	9.93	4.29	7.41	7.11	4.76	8.18	6.18	8.62	0.88
DiEn	4.70	4.63	9.33	-	9.64	14.68	9.71	-	5.53	7.05	2.50	4.44	4.87	2.77	4.92	4.28	5.02	0.52
DiFs	1.73	1.73	4.08	-	2.65	3.46	3.17	-	3.51	2.01	1.59	2.58	1.67	1.76	2.82	1.40	3.19	0.32
HyEn	-	-	10.15	12.16	7.76	10.30	17.49	5.54	3.79	2.42	9.06	7.67	17.58	9.04	9.55	17.87	8.60	11.29
HyFs	-	-	4.44	4.12	2.13	2.43	5.71	2.70	2.41	0.69	5.77	4.46	6.03	5.75	5.49	5.84	5.47	6.90
Wo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OlFo	16.95	16.73	9.00	9.75	8.85	9.88	0.93	6.92	3.18	10.42	-	1.97	0.53	-	-	0.80	-	-
OlFa	6.89	6.91	4.34	3.64	2.68	2.57	0.33	3.72	2.23	3.28	-	1.26	0.20	-	-	0.39	-	-
Mgt	3.58	3.57	4.64	4.87	3.20	3.16	1.71	6.06	6.37	4.41	6.53	5.08	3.70	6.10	4.60	3.84	4.57	6.16
Ilm	1.33	1.20	2.83	1.98	1.33	1.29	0.91	3.12	5.41	2.85	6.23	2.53	1.31	4.96	2.66	1.24	2.56	5.09
Ap	0.12	0.12	3.46	0.21	0.12	0.70	0.19	2.19	0.91	1.91	1.51	0.33	0.37	0.77	0.30	0.42	0.28	0.84
Q	-	-	-	-	-	-	-	-	-	-	4.11	-	-	5.02	4.79	-	5.90	5.24
A	15.57	16.02	18.75	48.63	21.00	23.05	4.97	46.16	21.02	37.14	27.11	26.53	31.75	28.47	23.15	35.21	19.76	15.09
P	84.43	83.98	81.25	51.37	79.00	76.95	95.03	53.84	78.98	62.86	68.78	73.47	68.25	66.50	72.06	64.79	74.35	42.93
A	10.06	10.28	6.50	20.78	12.30	7.74	6.67	30.80	23.52	21.74	27.01	24.82	18.76	27.79	23.00	20.80	22.21	28.27
F	35.43	35.50	41.77	32.44	29.52	27.35	32.19	37.80	47.92	31.27	48.12	41.77	32.14	46.02	42.64	30.71	44.60	45.55
M	54.51	54.22	51.73	46.78	56.18	64.92	61.13	31.41	28.56	46.99	24.87	33.41	49.10	26.19	34.36	48.50	33.19	26.17

TABLE 3 CIPW NORMS (cont'd)

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Qz	-	-	-	6.04	4.80	0.90	11.37	4.25	7.98	22.51	23.27	33.82	34.43	24.97	29.36	42.98	42.44	59.08
Co	-	2.68	4.16	2.44	-	0.99	-	1.73	0.79	-	2.57	2.77	4.89	-	2.18	1.83	1.85	1.20
Or	7.51	13.83	14.60	13.42	10.76	16.02	7.74	17.91	12.94	11.88	17.67	12.65	21.10	12.47	19.62	18.03	10.58	17.79
Ab	21.83	45.20	41.97	30.55	33.09	41.63	25.05	35.96	36.05	33.00	33.26	29.11	25.05	42.99	34.86	24.71	31.82	12.61
An	24.53	18.26	17.07	14.96	20.98	19.57	23.86	19.90	22.98	18.66	13.30	11.01	2.06	6.88	6.06	2.50	8.68	3.20
Ne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DiWo	7.67	-	-	-	3.05	-	3.68	-	-	0.62	-	-	-	1.90	-	-	-	-
DiEn	5.33	-	-	-	1.99	-	2.21	-	-	0.38	-	-	-	1.20	-	-	-	-
DiFs	1.71	-	-	-	0.84	-	1.28	-	-	0.20	-	-	-	0.59	-	-	-	-
HyEn	15.29	-	8.05	12.20	7.65	8.47	9.23	8.32	7.85	4.25	3.56	3.21	3.86	-	2.39	3.06	1.84	1.69
HyFs	4.89	-	2.94	6.80	3.23	2.69	5.33	2.78	3.28	2.21	1.81	2.43	2.00	-	1.30	1.67	0.78	0.87
Wo	-	-	-	-	-	-	-	-	-	-	-	-	-	4.80	-	-	-	-
OlFo	-	5.69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OlFa	-	2.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mgt	3.36	4.06	3.90	5.79	4.12	3.70	4.34	3.61	3.29	2.39	2.09	2.04	2.58	0.64	1.90	2.13	0.71	1.09
Ilm	1.25	2.45	2.47	3.17	3.32	2.13	2.72	2.15	1.69	1.25	0.86	0.68	1.48	0.15	0.87	1.31	0.25	0.97
Ap	0.23	1.09	1.09	0.40	2.49	1.07	0.49	1.02	0.86	0.44	0.44	0.23	0.19	0.07	0.28	0.12	0.07	0.12
Q	4.28	-	0.09	9.30	6.89	1.15	16.72	5.45	9.99	26.15	26.60	39.06	41.67	28.60	32.66	48.72	45.38	63.75
A	22.42	43.09	46.05	42.88	31.56	44.49	20.41	44.78	32.43	28.73	41.89	32.58	53.15	46.02	51.45	45.03	29.99	30.73
P	73.30	56.91	53.86	47.82	61.55	54.36	62.88	49.77	57.58	45.12	31.51	28.36	5.18	25.37	15.90	6.25	24.63	5.52
A	22.18	51.47	50.75	33.07	39.06	52.08	28.30	51.02	48.83	56.72	66.60	60.98	61.20	87.05	73.59	63.58	78.72	69.77
F	30.13	26.80	27.19	39.37	34.56	24.71	41.29	25.58	27.33	25.43	19.63	24.92	24.27	7.14	16.91	23.32	10.78	19.69
M	47.70	21.73	22.06	27.56	26.38	23.21	30.42	23.41	23.85	17.85	13.76	14.10	14.53	5.81	9.50	13.10	10.50	10.54

TABLES 2 AND 3 - DETAILS OF SAMPLES

1. Monzogabbro (borderline gabbro), Earnslaw Quarry (7697 4447).
2. Monzogabbro (borderline gabbro), Earnslaw Quarry (7699 4447).
3. Monzogabbro (borderline gabbro), North Hill Quarry (7702 4689).
4. Monzonite (melamonzonite), Gullet Quarry (7625 3808).
5. Monzogabbro, Hollybush Quarry (7593 3718).
6. Monzogabbro, North Hill Quarry (7702 4689).
7. Gabbro, Hollybush Quarry (7593 3718).
8. Monzonite (melamonzonite), Westminster Quarry (7656 4608).
9. Monzodiorite, North County Quarry (7673 4477).
10. Monzonite, North Hill Quarry (7702 4689).
11. Monzodiorite, North Hill Quarry (7702 4689).
12. Monzogabbro, Upper County Quarry (7680 4480).
13. Monzogabbro, Dingle Quarry (7654 4567).
14. Monzodiorite, North Hill Quarry (7690 4700).
15. Monzogabbro, Upper County Quarry (7680 4480).
16. Monzonite/Monzogabbro, Dingle Quarry (7654 4567).
17. Monzogabbro, Upper County Quarry (7680 4480).
18. Monzodiorite/Quartz-Monzodiorite, Gullet Quarry (7625 3808).
19. Monzogabbro, Hollybush Quarry (7593 3718).
20. Monzonite, North Hill Quarry (7702 4689).
21. Monzonite, North Hill Quarry (7702 4689).
22. Quartz-monzonite, Gardiners Quarry (7664 4209).
23. Monzodiorite, South County Quarry (7678 4468).
24. Monzonite, North Hill Quarry (7715 4685).
25. Quartz Monzogabbro/Monzonite, Upper County Quarry (7680 4480).
26. Monzonite, North Hill Quarry (7715 4685).
27. Quartz Monzonite, North Hill Quarry (7715 4685).

28. Granite (monzogranite), Swinyards Hill, North of summit (7618 3861).

29. Granite (monzogranite), North Hill Quarry (7715 4685).

30. Granite (monzogranite), North Hill Quarry (7690 4700).

31. Granite (alkali feldspar granite), Gullet Quarry (7625 3808).

32. Granite (monzogranite), Hollybush Quarry (7593 3718).

33. Granite (syenogranite), Upper County Quarry (7680 4480).

34. Granite (syenogranite), Gullet Quarry (7625 3808).

35. Granite (monzogranite), Dingle Quarry (7654 4567).

36. Granite (quartz-rich granitoid), Westminster Quarry (7656 4608).

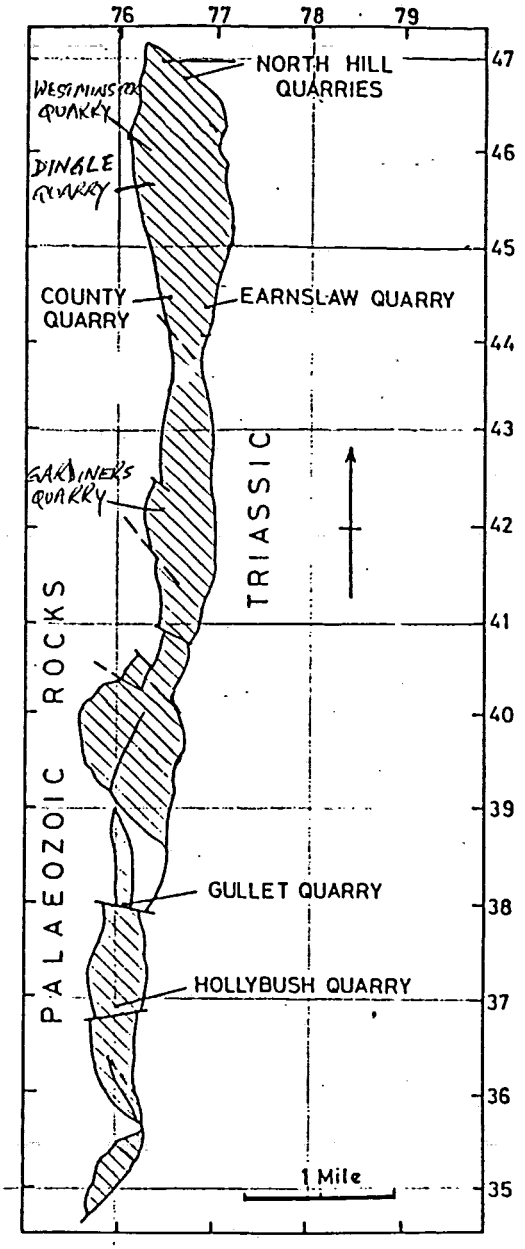


FIGURE 1. Sample collection localities.

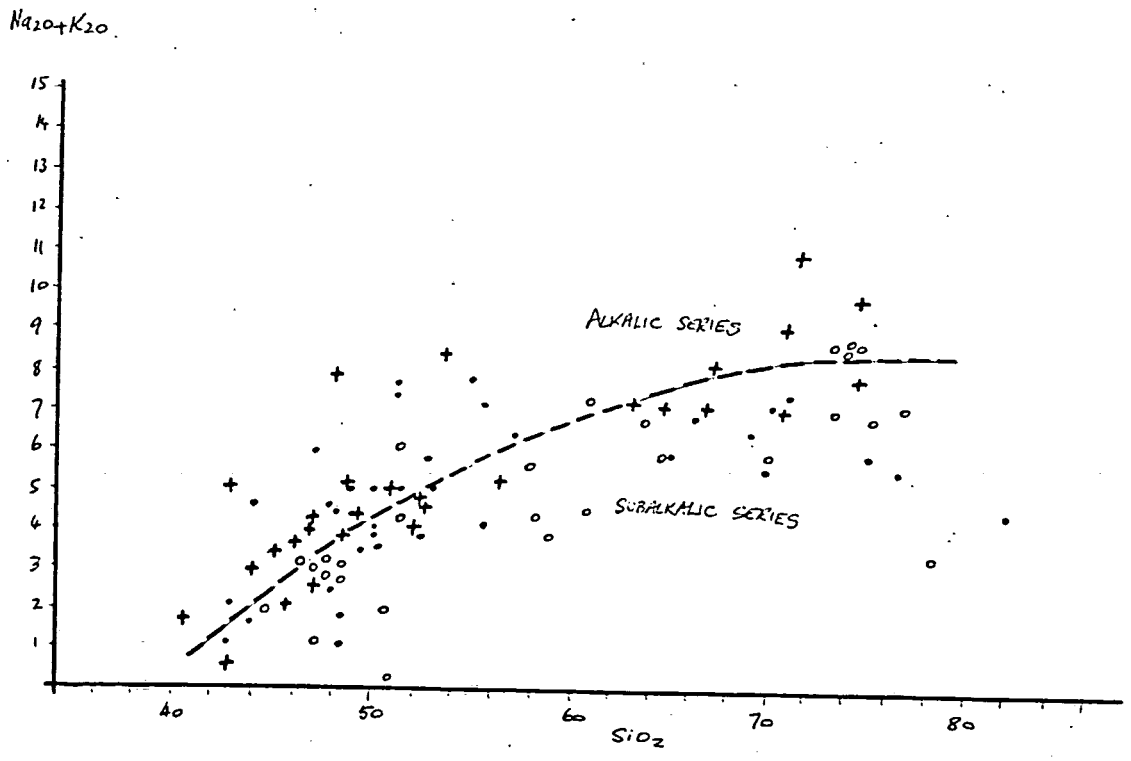


FIGURE 2. Total alkali _ silica diagram of the Malvern igneous suite.

- ● Samples from Table 2.
- o Lambert and Holland (1971)
- \+ Blyth and Lambert (1971).

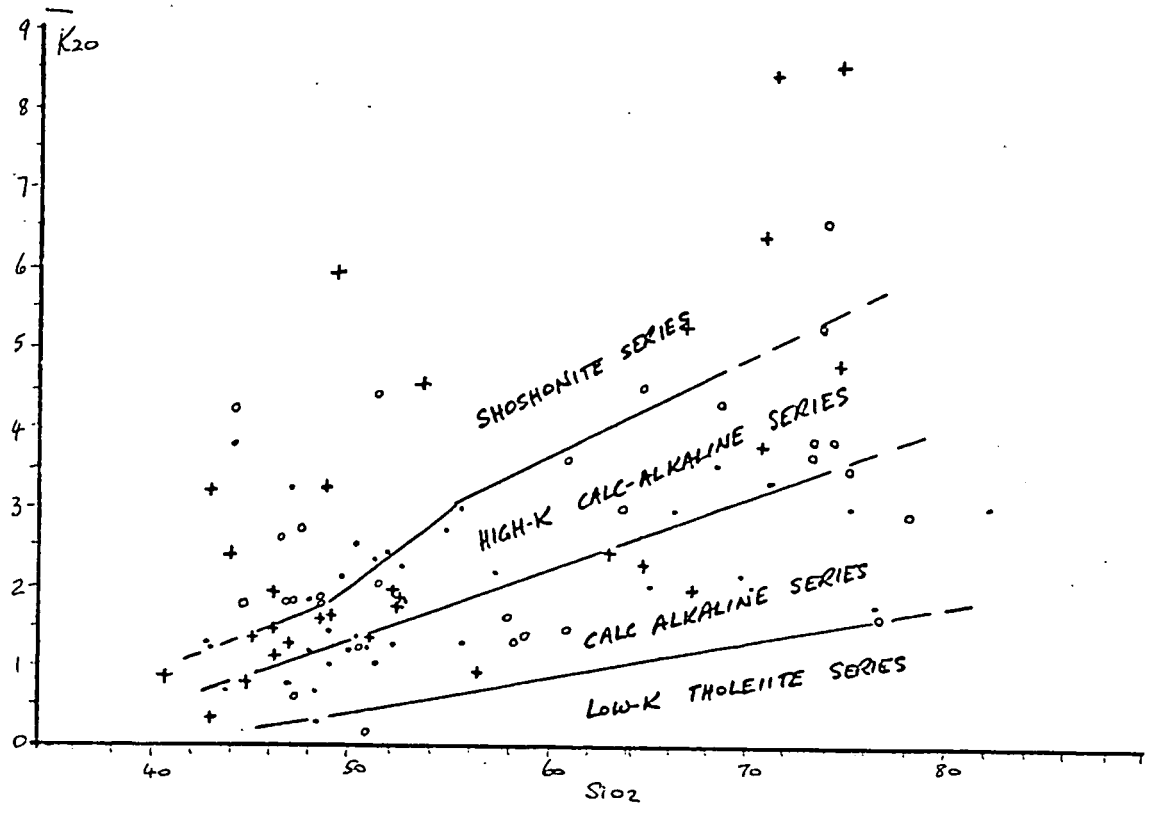
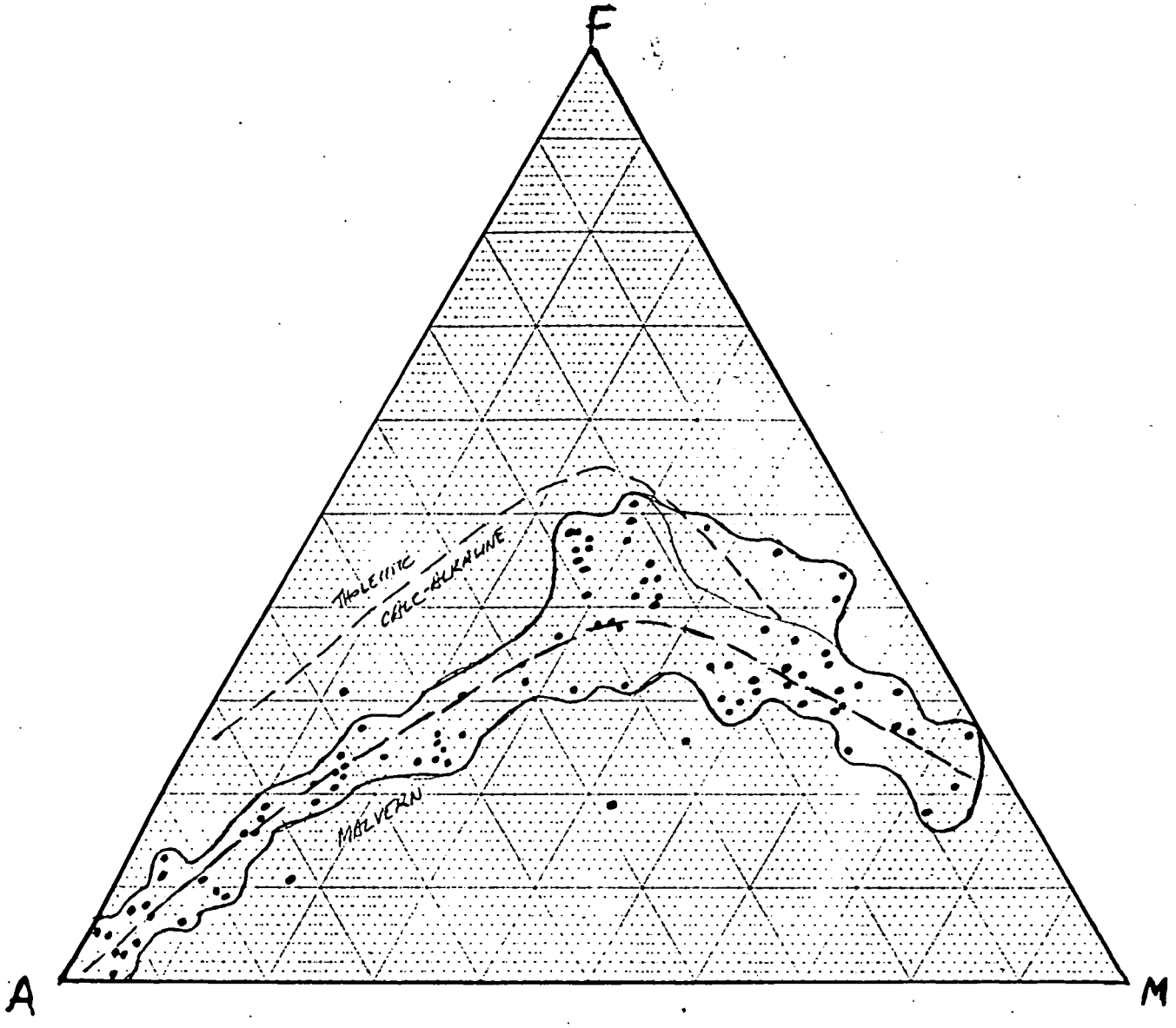


FIGURE 3. Potash _ silica diagram of the Malvern igneous suite.

- Samples from Table 2.
- o Lambert and Holland (1971)
- \+ Blyth and Lambert (1971).



FIGRUE 4. AFM diagram of the Malvern igneous suite.
Samples from Table 2,
Lambert and Holland (1971), and
Blyth and Lambert (1971).

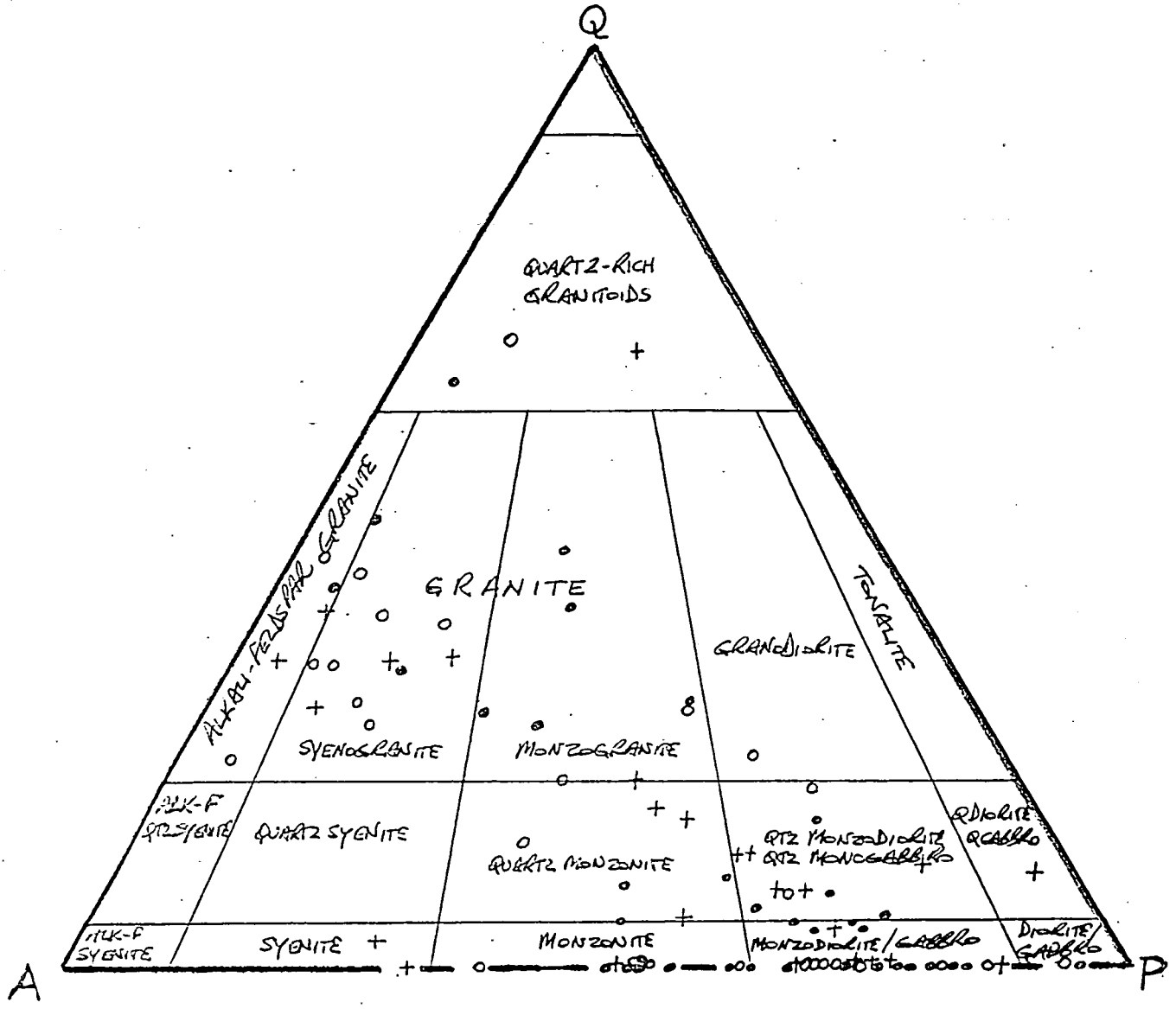


FIGURE 5. Quartz _ alkali-feldspar _ plagioclase (QAP) diagram of the Malvern igneous suite.

- ● Samples from Table 2.
- o Lambert and Holland (1971).
- \+ Blyth and Lambert (1971).

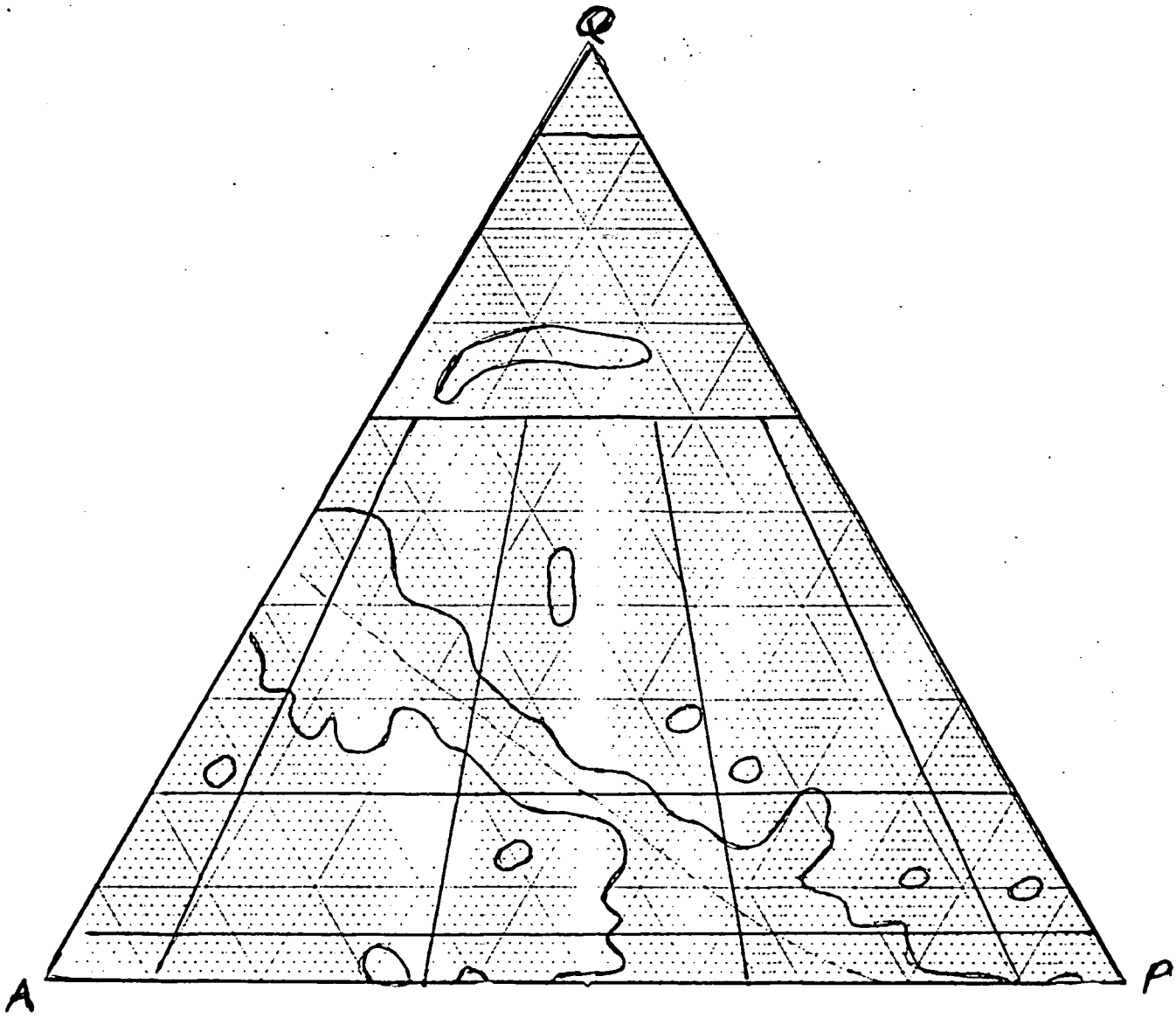
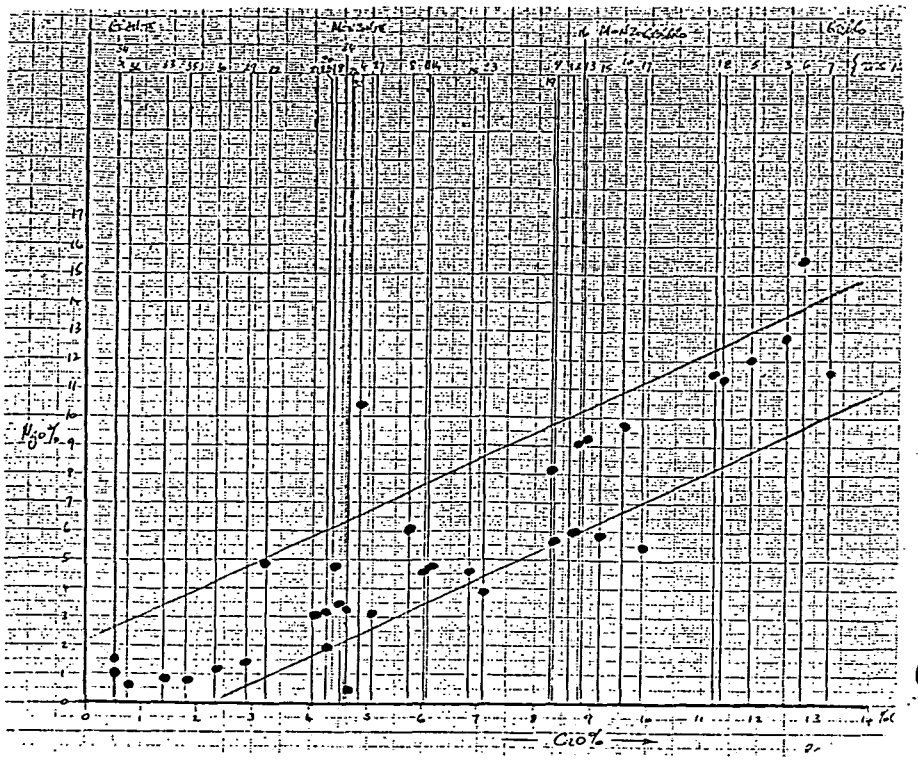


FIGURE 6. Quartz _ alkali-feldspar _ plagioclase (QAP) diagram of the Malvern igneous suite outlining main trend.



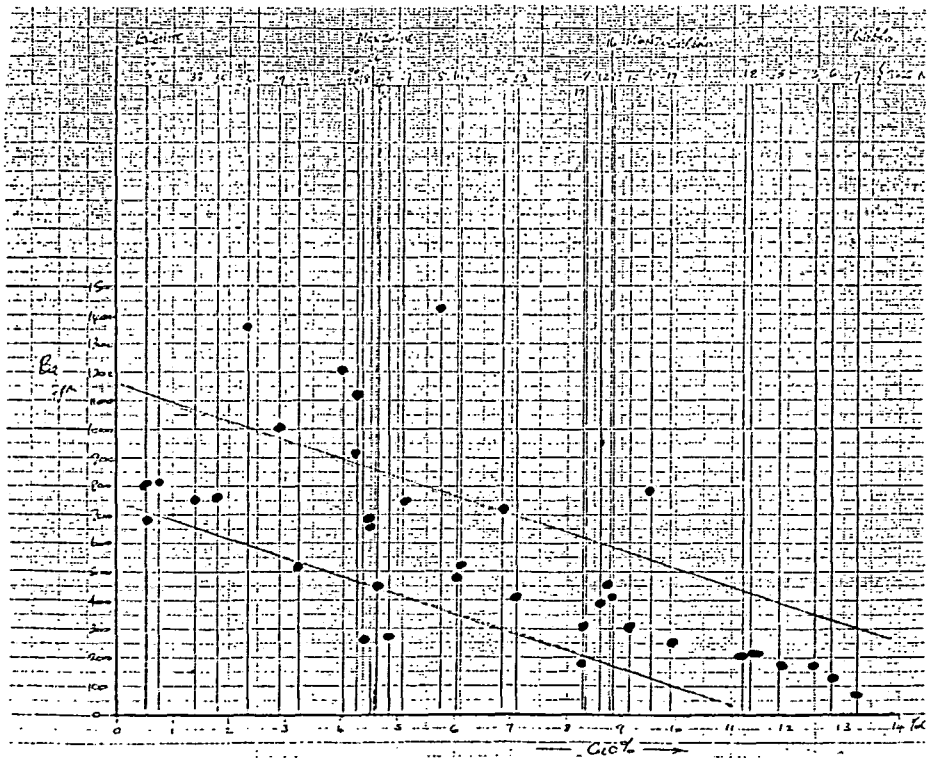
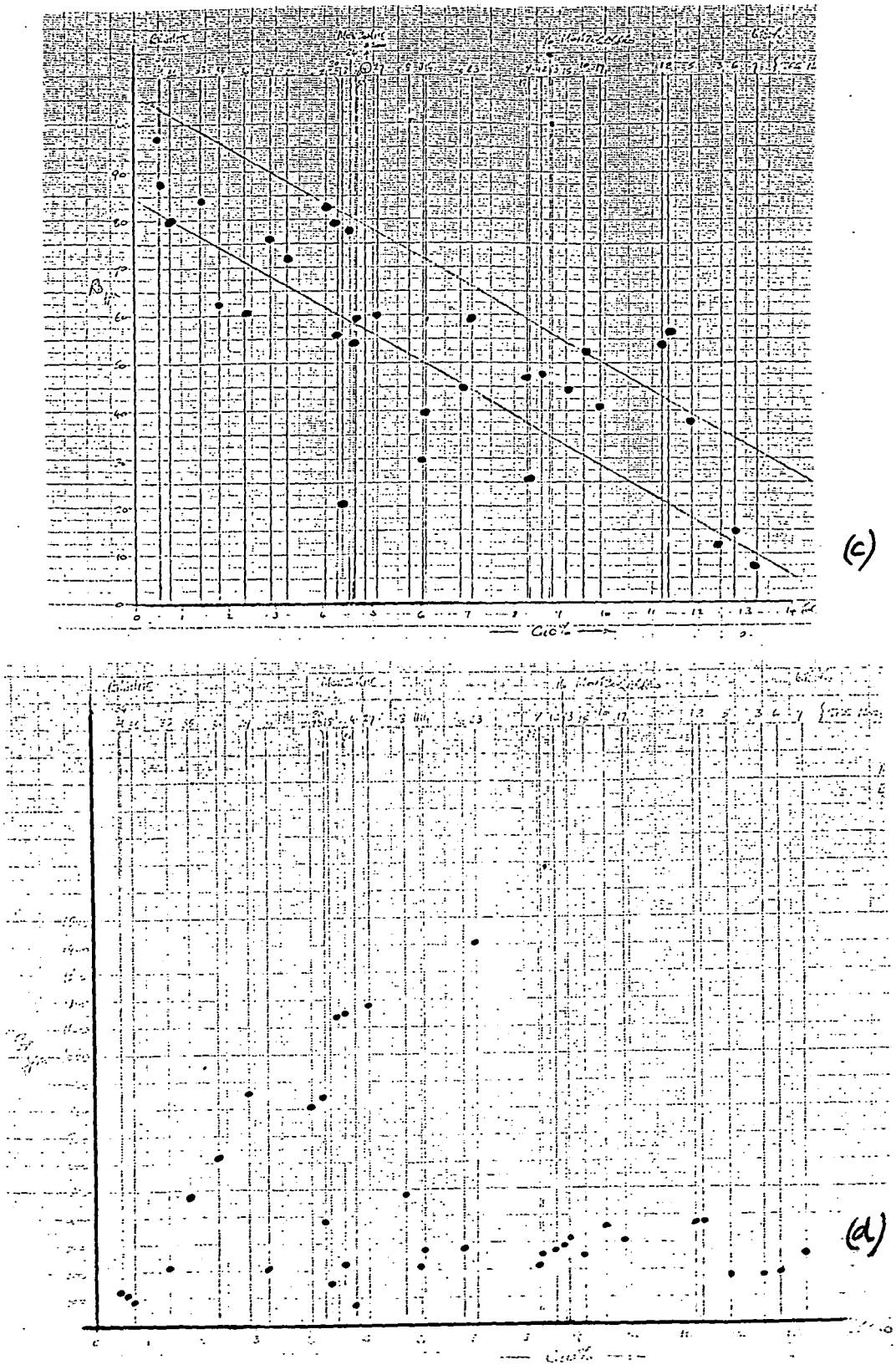


FIGURE 7. Element variations with CaO content of the Malvern igneous suite: (a) MgO-CaO, (b) Ba-CaO, (c) Rb-CaO, (d) Sr-CaO.



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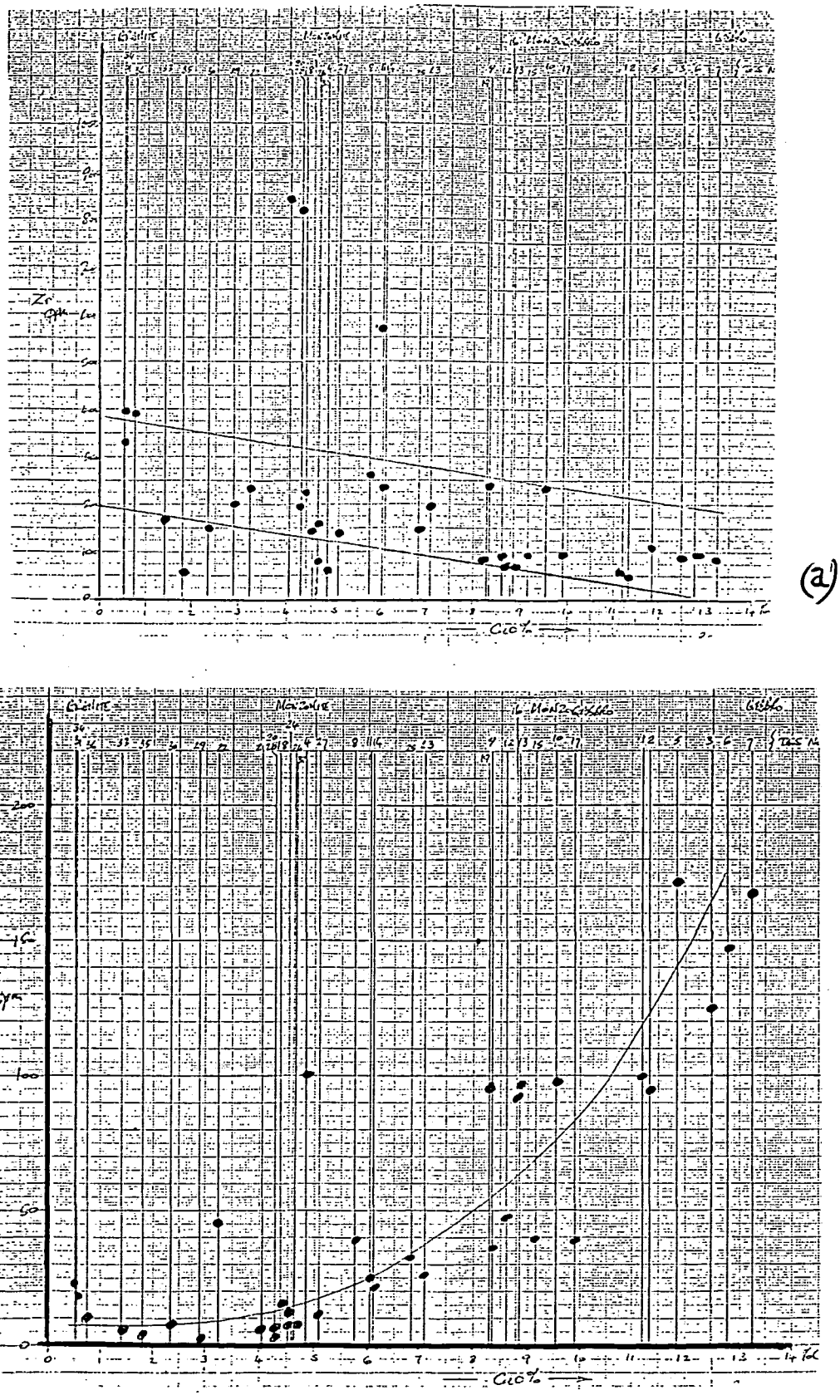
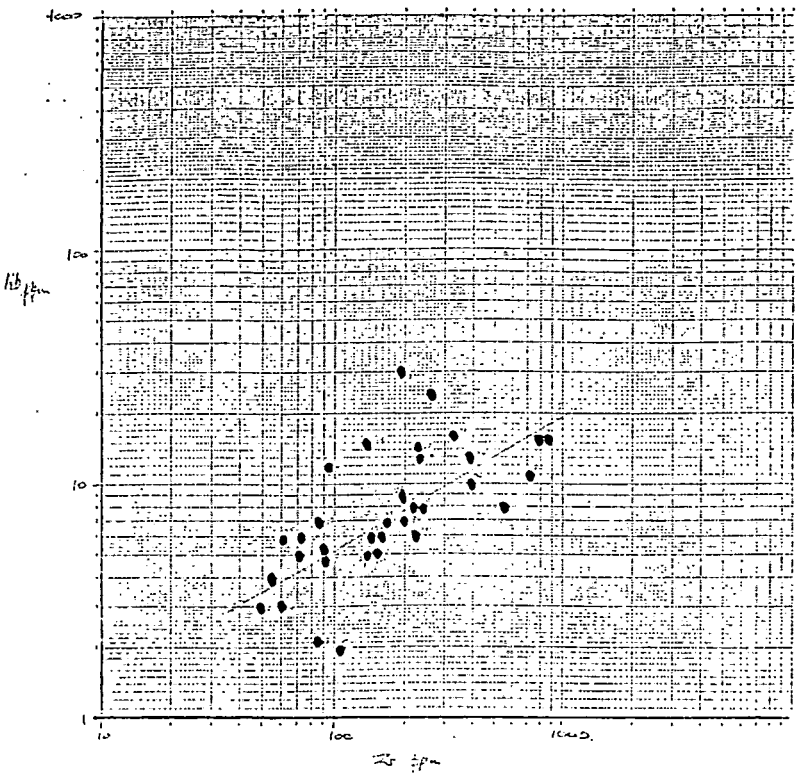
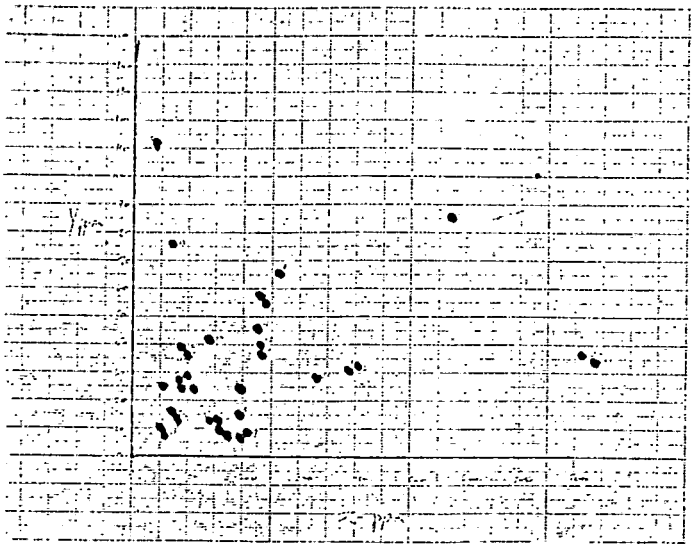


FIGURE 8. Element variations with CaO content of the Malvern igneous suite: (a) Zr-CaO, (b) Ni-CaO.



(a)



(b)

FIGURE 9. Covariance of (a) Ni and Zr and (b) Y and Zr in the Malvern igneous suite.

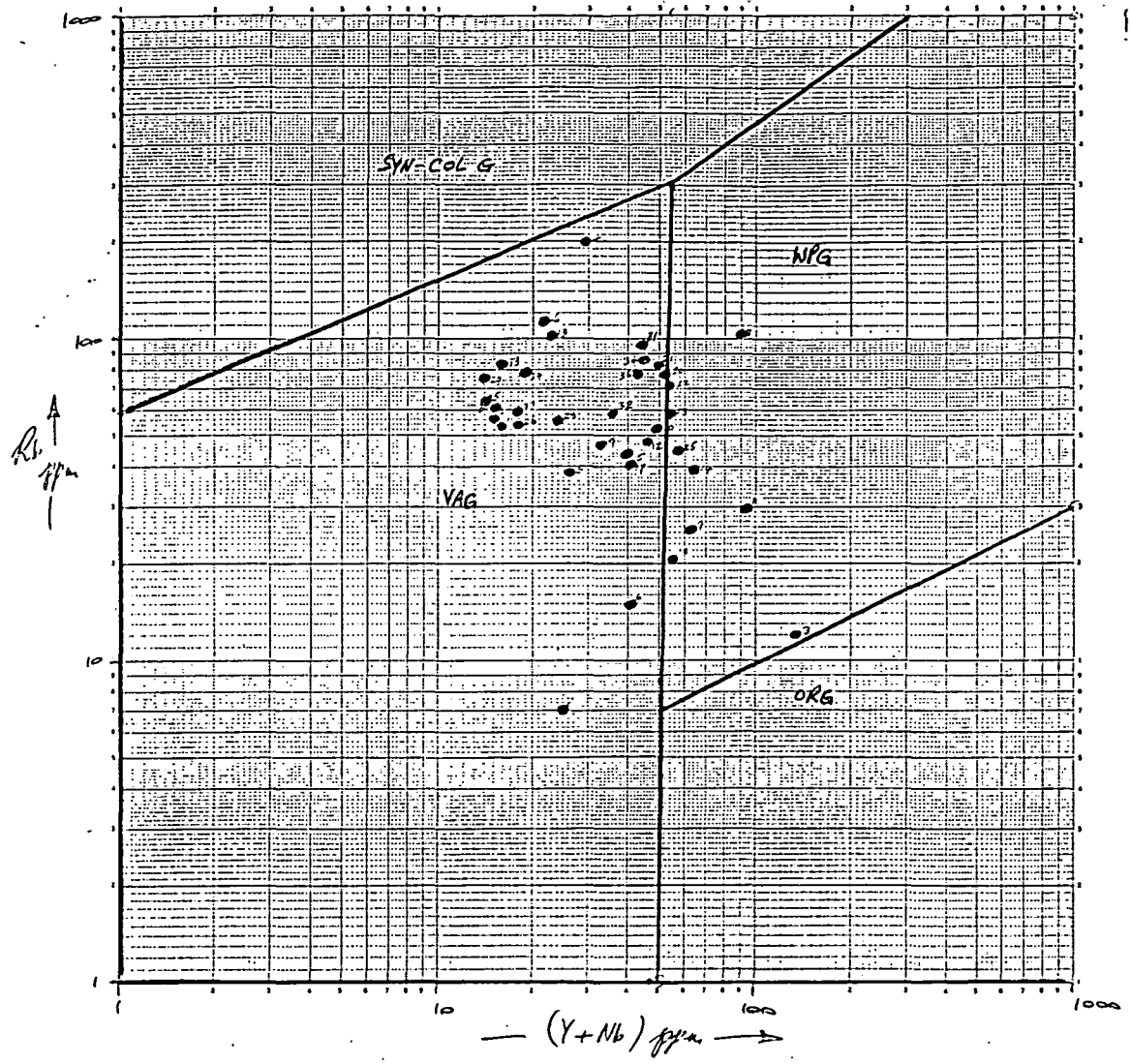
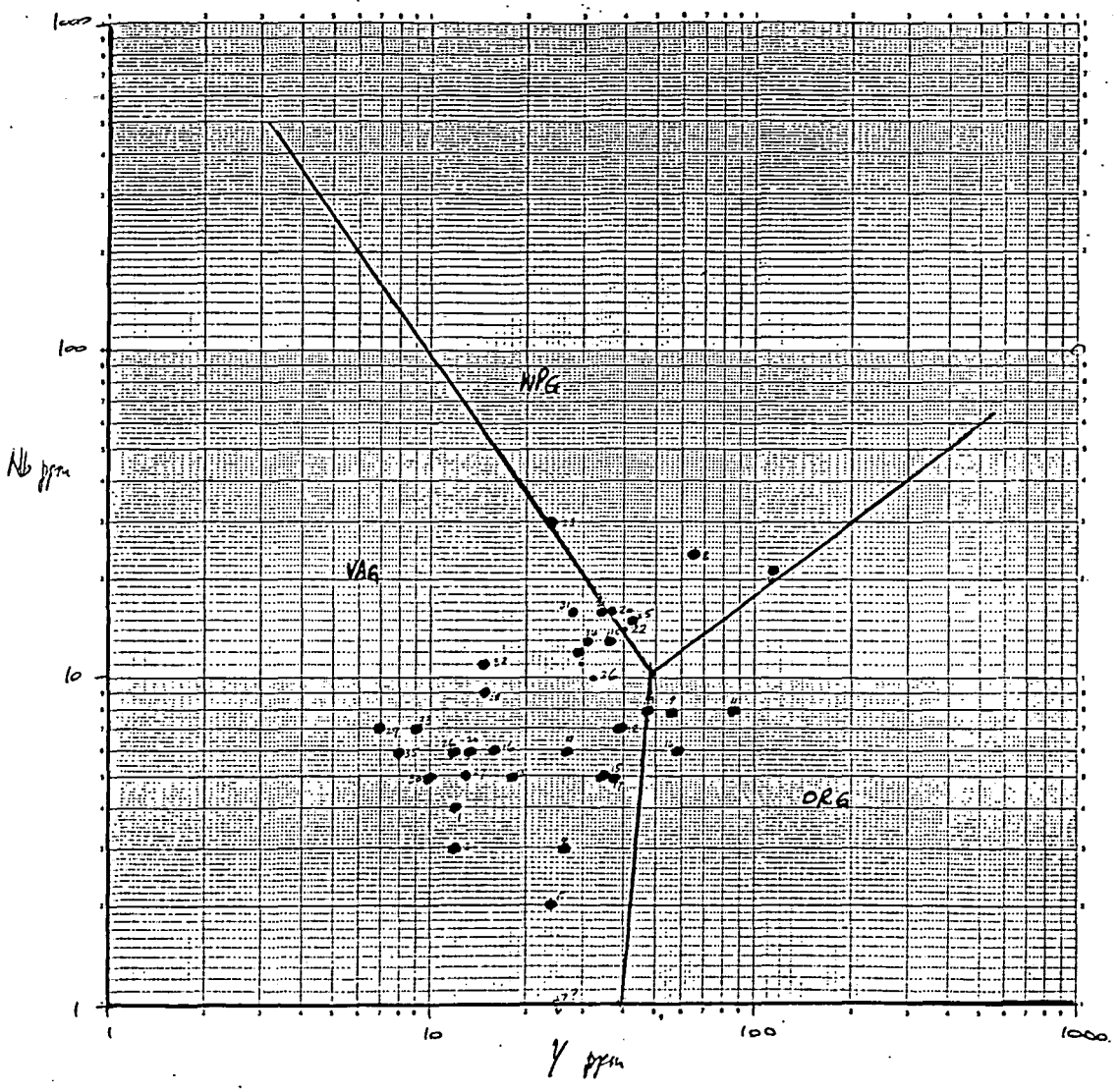


FIGURE 10. Covarience of Rb and (Y + Nb) in the Malvern igneous suite. Field boundaries of syncollision granites (SYN-COLG), within plate granites (WPG), volcanic arc granites (VAG) and orogenic granites (ORG) from Pearce, Harris and Tindle (1984).



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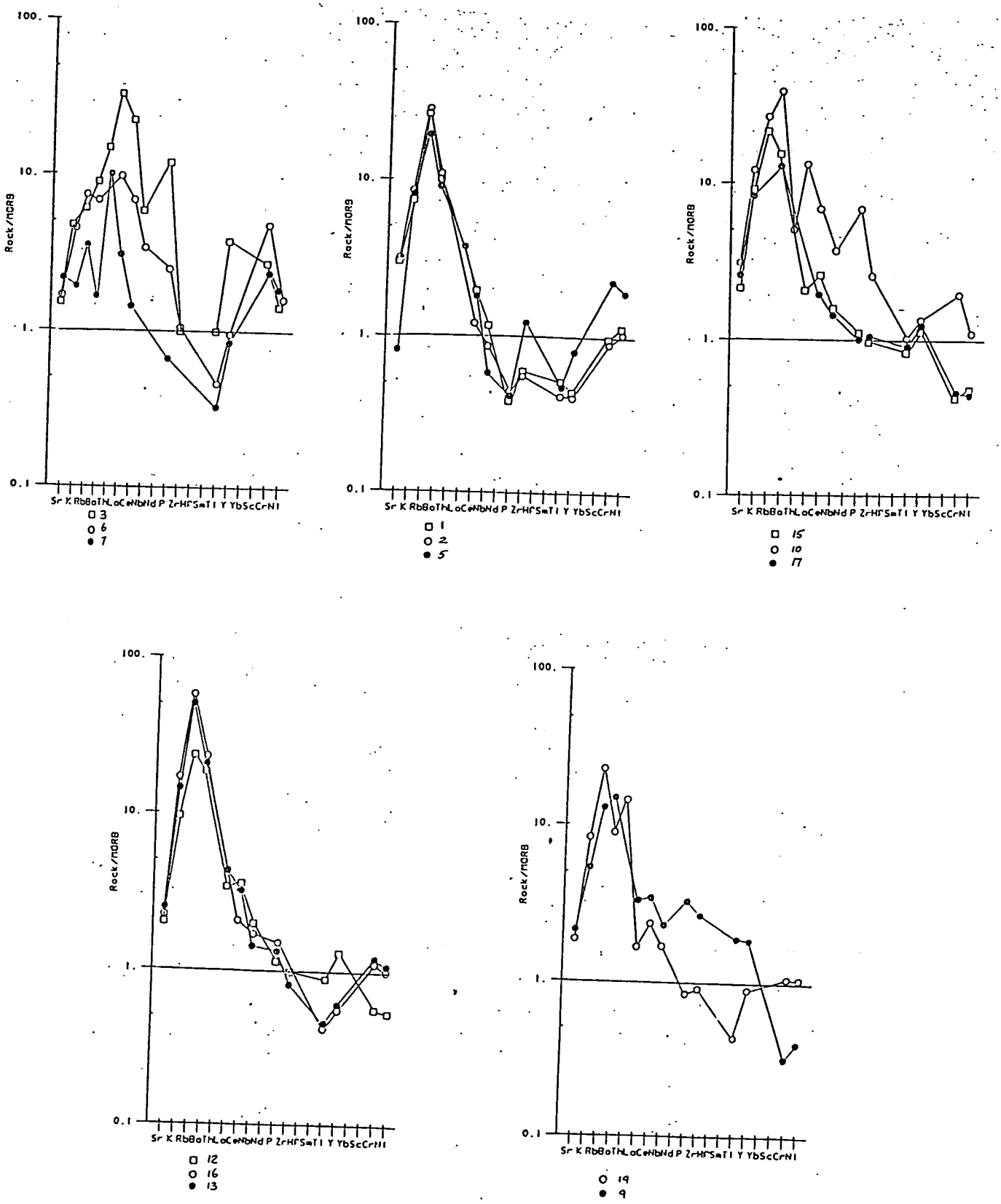
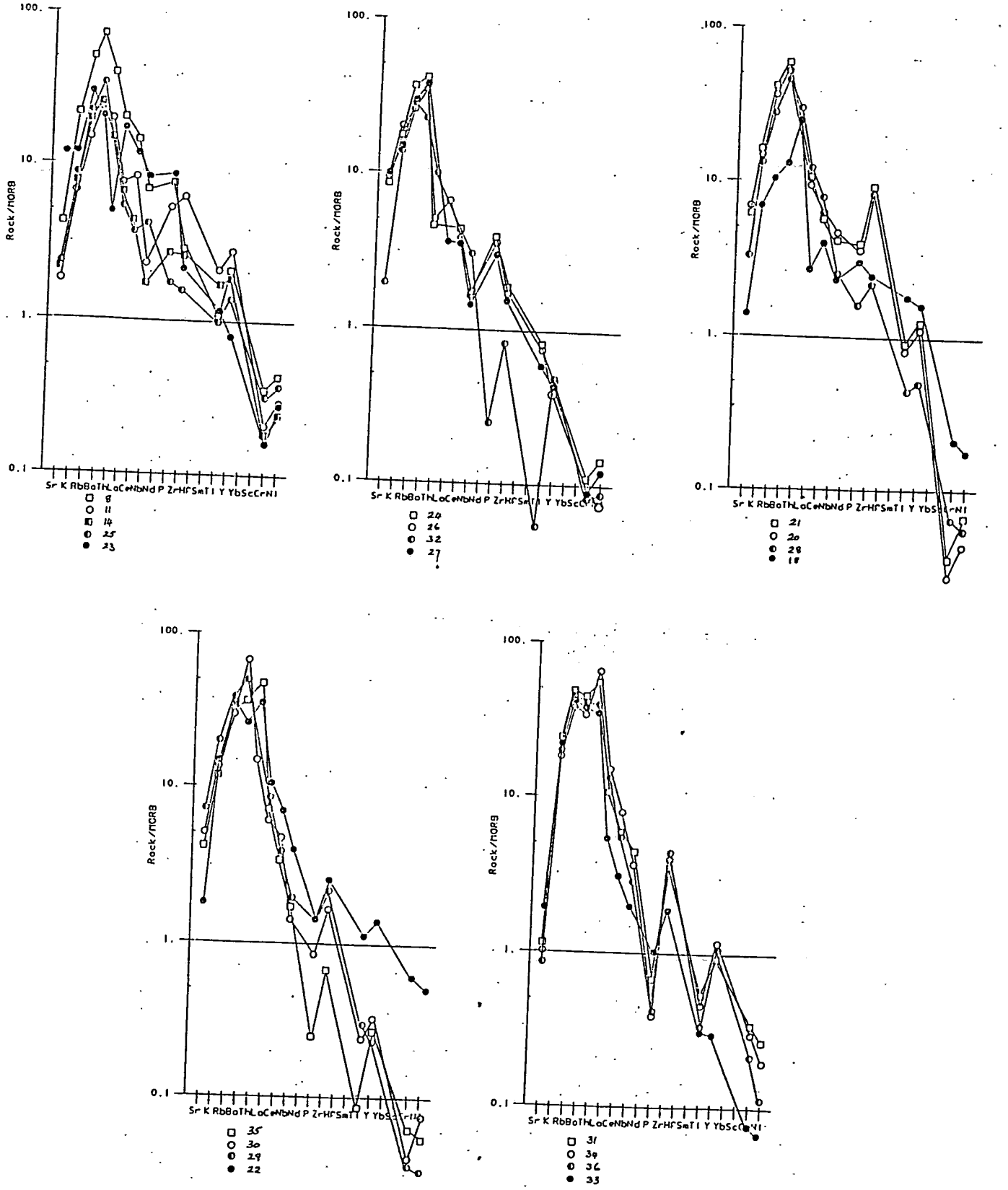


FIGURE 12. MORB normalised element variation spidergrams of the Malvern igneous suite. Numbers correspond to rocks listed in Tables 1,2 and 3. Sequence in order of decreasing CaO%; as in Figures 7 and 8.



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