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Provenance of the Ottnangian Sands as Revealed by Statistical Analysis of their Heavy Mineral Content (Austrian Molasse Zone, Upper Austria and Salzburg)

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With 5 Figures and 5 Tables

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Upper Austria
Molasse Zone
Ottnangian
Heavy Minerals
Multivariate statistics
Correspondence factor analysis

Contents

Zusammenfassung

Aus Sanden des Ottnangiens der oberösterreichischen und Salzburger Molassezone wurden 118 Schwermineralproben statistisch untersucht. Das Datenmaterial entstammt drei Probengruppen, den Atzbacher Sanden der Bohrung Kemating K1, Oberflächenproben aus dem Robulusschlier s.l. (hauptsächlich Atzbacher Sande) und aus der Sand-Schottergruppe (Oichtental, Salzburg). Jede Gruppe ist statistisch unterschiedlich aufgebaut. Da die Verteilung der Schwerminerale nicht der Gaußschen Normalverteilung folgt, konnten nur parameterfreie statistische Verfahren angewendet werden. Die „Korrespondenz-Faktorenanalyse“ – eine verteilungsunabhängige Technik – läßt drei Schwermineralkomponenten erkennen.

1) Granat-Staurolith, welche relativ stabile Minerale aus Glimmerschieferkomplexen repräsentiert.
2) Epidot-Hornblende, eine Komponente aus weniger stabilen Mineralen, welche sich vorwiegend von basischen Metamorphiten ableiten lassen.
3) Apatit-Zirkon; diese Komponente wird teilweise von der Korngröße des Sediments beeinflußt.

Die Ergebnisse dieser statistischen Analyse (Fig. 3, 4) können dahingehend erklärt werden, daß die mehr instabilen Minerale, wie Hornblende und Epidot, in den Fandelta-Ablagerungen der Sand-Schottergruppe, welche als Liefergebiet für die marinen Atzbacher Sande in Frage kommt, eine postsedimentäre Lösung erfahren haben. Dieser Lösungsprozeß muß nach der Bereitstellung und Verteilung der Atzbacher Sande stattgefunden haben.

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Abstract

Heavy mineral data from 118 samples from sands of Ottnangian age were statistically analyzed. Three groups of samples: Atzbach Sands (well Kemating K1); Robulus Schlier s.l. with Atzbach Sands (surface data) and "Sandschottergruppe", each one statistically different from the other two are shown. Because the distribution of the heavy minerals is not normal (non Gaussian) only non-parametric statistic could be performed. Correspondence factor analysis (a distribution free technique) shows the existence of three heavy mineral components: the Garnet-Staurolite component, representing relatively stable minerals from a mica schist provenance; the Epidote-Hornblende component, unstable minerals originating prevailingly from basic metamorphic rocks and the Apatite (Zircon) component influenced partly by the grain-size of the sediment. The results of this statistical analysis (Figs. 3, 4) could be explained by post-sedimentary dissolution of the more unstable minerals in the "Sandschottergruppe" (fan-delta), the possible source of the material of the marine Ottnangian Sands. This post-sedimentary dissolution in the fan-delta environment took place after the supply of the Atzbach Sands sediments i.e. in post-Atzbach Sands time.

1. Introduction

In order to get all the possible information from heavy mineral analysis in sands concerning the distributory province, the dispersal system and post-sedimentary processes, especially in complicated geological regions multivariate statistical procedures are often used (IMBRIE & VAN ANDEL, 1964; MAURER, 1983; STATTEGGER, 1986; TOURENQ et al., 1978).

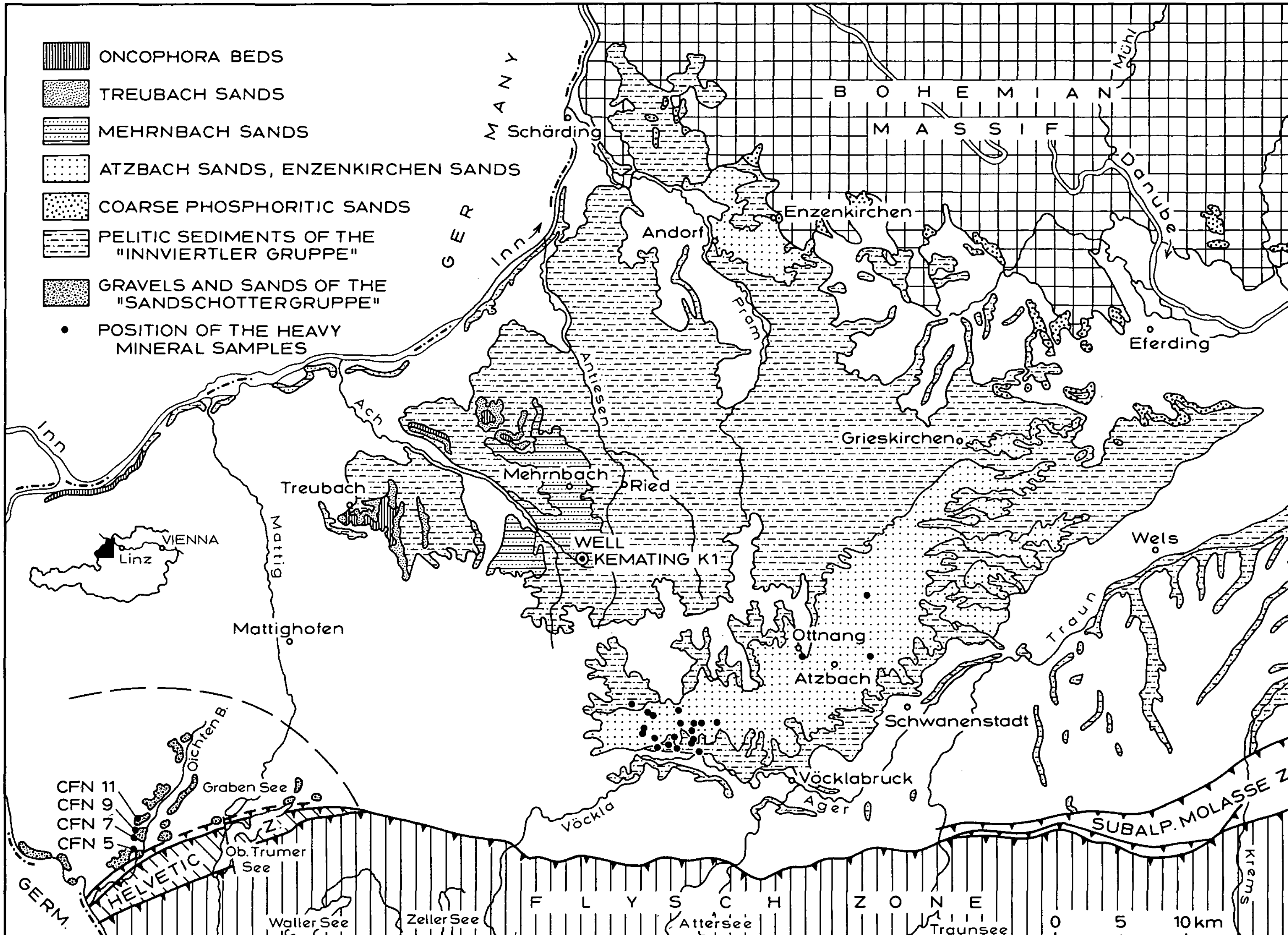


Fig. 1.
The Ottnangian sediments in Upper Austria and Salzburg with the location of the samples.

The Atzbach Sands (ABERER, 1958), belonging to the Upper Austrian Molasse of Ottnangian age (Early Miocene), show sedimentary structures pointing to the "Sandschottergruppe" fan-delta the source of their sediments (FAUPL & ROETZEL, 1987). Both sands contain the same heavy minerals, the differences between the heavy mineral spectra being only quantitative (HERBST, 1985; WOLETZ, 1951, 1955). Could a detailed statistical analysis, using multivariate techniques add new venues and corroborate the conclusion drawn from the sedimentological analysis? Are the sands of the "Sandschottergruppe" really the provenance of the shallow marine Atzbach Sands? What caused the quantitative difference between the heavy minerals? We tried to answer those questions by statistically analyzing the heavy mineral data by all permissible techniques.

2. The Data

Results of heavy mineral determination from 118 samples (see Tab. 3–5) were used. 65 samples – 31 from a well (Kemating K1) and 34 from outcrops – belong to the Robulus Schlier s.l. Most of those samples are from the shallow marine tidal influenced Atzbach Sands (FAUPL & ROETZEL, 1987). 53 samples from four wells of the "Sandschottergruppe" (WOLETZ, 1949) are fan-delta sands. The distribution of the samples is given in Fig. 1. Thirteen minerals were determined. They are in order of abundance: Garnet, Epidote, Staurolite, Hornblende, Apatite, Rutile, Kyanite, Tourmaline, Zircon, Chloritoid, Andalusite, Sillimanite and Varia (mainly Titanite, Brookite and Anatase).

As there is a difference in the sampling techniques used by FAUPL & ROETZEL (1987) who analyzed the grain-size interval 0.4–0.063 mm and WOLETZ (1949) who analyzed the fraction 0.1–0.05 mm, the dependence between the grain-size and the abundance of the minerals was investigated in the Kemating well. Most minerals show no correlation. There are correlations of about 0.4–0.5 between the mean grain-size of the sands and the amount of Apatite and Zircon present and a high positive correlation between Garnet and the mean grain-size (Fig. 2). Because of this and the great abundance of Garnet, the percentage of all the other heavy minerals without Garnet was calculated and this quantity used for further calculations.

3. Computer Programs

The computer programs used for calculation and graphics were:

1) SPSS-X statistical package, used on the IBM 3083-JX1 computer of the University of Vienna.

Table 1.
Frequencies of heavy minerals from samples of well Kemating K1 (Atzbach Sands).

Probe	ZIR	TOU	RUT	APA	STA	CHL	KYA	EPI	HOR	AND	SIL	VAR	GAR
1.SED2	1	6	1	29	14	1	4	29	12	1	2	-	52
2.SED4	9	5	2	16	16	2	7	26	17	-	-	2	42
3.SED6	-	4	2	18	25	-	4	29	18	-	2	-	72
4.SED7	2	7	1	22	15	-	4	33	15	-	-	1	54
5.SED8	1	8	1	29	11	3	3	29	13	-	1	-	64
6.SED9	3	9	-	19	15	3	6	25	19	-	2	-	67
7.SED11	-	12	-	8	27	-	-	39	15	-	-	-	74
8.SED13	2	12	1	12	9	-	5	26	33	-	-	-	58
9.SED15	-	5	-	27	13	-	5	24	24	-	1	-	63
10.SED17	3	8	-	16	24	1	3	22	22	-	1	-	64
11.SED20	-	4	-	15	22	-	4	33	22	-	-	-	73
12.SED21	-	2	-	7	24	-	3	28	31	3	2	-	72
13.SED22	-	7	-	15	7	-	7	30	30	4	-	-	87
14.SED23	-	9	-	2	23	-	18	23	23	2	-	-	78
15.SED24	1	6	-	19	13	-	11	21	30	-	-	-	53
16.SED26	4	9	-	18	9	1	2	33	22	-	-	1	55
17.SED28	2	6	1	17	15	1	4	23	31	-	-	-	52
18.SED32	5	3	+	16	16	+	5	26	28	-	-	-	43
19.SED33	2	4	-	25	13	+	6	19	30	-	-	+	48
20.SED37	8	2	2	19	13	+	6	25	25	-	-	+	47
21.SED40	-	6	-	32	29	-	3	18	12	-	-	-	66
22.SED42	1	8	-	19	15	6	1	23	25	-	1	-	53
23.SED43	4	6	1	22	16	4	2	24	22	-	-	-	50
24.SED46	2	2	1	12	17	5	5	26	31	-	-	-	57
25.SED48	1	5	1	20	12	3	3	30	25	-	1	-	61
26.SED49	1	5	-	13	15	5	1	35	25	-	-	-	60
27.SED54	4	11	-	11	18	4	7	22	22	-	2	-	72
28.SED56	-	1	3	28	22	1	-	25	19	-	-	-	64
29.SED57	-	2	-	29	10	5	5	19	29	-	-	1	59
30.SED58	1	3	1	25	17	1	3	25	23	-	-	-	65
31.SED59	2	6	2	29	15	-	3	27	18	-	-	-	66
Mean	1.9	5.9	0.7	18.9	16.4	1.6	4.5	26.2	22.9	0.3	0.5	0.2	61.0
Std.-Dev.	2.2	2.9	0.8	7.3	5.5	1.8	3.4	4.8	6.0	1.0	0.7	0.5	10.5

Table 2.
Frequencies of heavy minerals from outcrop-samples of Robulus Schlier s.l.

Probe	ZIR	TOU	RUT	APA	STA	CHL	KYA	EPI	HOR	AND	SIL	VAR	GAR
32.48/119	-	11	3	11	11	6	6	31	20	-	-	-	65
33.48/8	3	6	-	6	30	6	6	36	6	-	-	-	84
34.ATZ 4	-	3	4	2	7	-	7	32	41	2	-	2	32
35.ATZ 4A	-	-	5	3	7	-	5	48	31	-	-	+	42
36.ATZ 5	-	2	4	4	8	-	4	49	29	-	-	-	51
37.ATZ 6	-	2	3	3	8	-	8	35	40	-	-	2	37
38.ATZ 7	-	3	5	3	7	-	5	36	39	2	-	2	38
39.ATZ 8	-	4	3	-	-	-	6	32	52	1	-	1	29
40.ATZ 9	-	4	4	5	4	-	4	36	42	-	-	2	17
41.ATZ 10	-	5	4	7	4	-	7	42	30	-	-	3	23
42.ATZ 11	1	1	4	3	7	-	4	39	38	-	-	3	29
43.ATZ 12	3	-	1	3	4	+	3	60	26	-	-	-	30
44.ATZ 13	+	1	3	3	5	-	1	60	26	-	-	-	26
45.ATZ 14	-	2	4	2	6	1	6	42	36	-	-	2	50
46.47/1/	-	+	3	7	4	-	1	57	25	-	-	1	29
47.47/13/	-	-	4	4	10	1	4	57	20	-	-	1	49
48.47/4/	-	2	3	+	5	-	2	56	30	-	-	+	13
49.47/25/	-	2	3	2	5	-	5	45	35	2	-	3	35
50.47/27-1/	-	4	2	6	4	-	4	53	23	-	-	2	53
51.47/27-2/	-	1	6	8	15	-	6	53	4	4	-	4	48
52.47/42-1/	-	2	7	2	2	1	7	38	33	5	-	2	57
53.47/42-2/	-	1	2	2	4	-	4	42	36	2	-	8	48
54.47/54H/	-	3	3	2	6	-	3	62	14	3	-	3	6
55.47/64/	+	+	4	5	6	-	1	76	4	1	-	2	18
56.47/73/	-	2	2	2	7	-	9	46	26	2	-	4	54
57.47/86/	-	2	11	2	4	-	11	64	7	-	-	-	72
58.47/94/	1	+	4	4	5	1	3	75	3	+	-	3	25
59.47/95/	1	1	4	-	4	-	2	81	6	-	-	1	50
60.47/99/	-	5	3	-	8	5	8	44	26	3	-	-	61
61.47/101/	-	4	-	-	12	-	12	60	4	-	-	8	75
62.47/106/	-	2	4	2	14	4	7	64	2	-	-	2	72
63.47/107/	-	3	5	1	15	-	5	68	-	-	-	3	60
64.47/112/	-	-	5	3	10	-	13	58	13	-	-	-	60
Mean	0.3	2.5	3.7	3.2	7.5	0.8	5.4	50.8	23.1	0.8		1.9	43.6
Std.-Dev.	0.8	2.3	1.9	2.5	5.4	1.7	2.9	13.7	14.4	1.3		1.9	19.4

2) Correspondence factor analysis, version Tabet, from the Department of Statistics, University Pierre and Marie Curie, Paris.
3) SMTAB, a program in BASIC for heavy mineral calculations and graphics written by E. POBER (University of Vienna).

4. Results

4.1. Elementary Statistical Analysis

Normality

When all the data are analyzed as one population, only Garnet and Staurolite show a normal distribution. When, however, the data are separated into three groups (A: Atzbach Sands (well Kemating K1); B: Robulus Schlier s.l. with Atzbach Sands (surface samples), and C: the "Sandschottergruppe" samples) most of the minerals in the first two groups show normal distribution. In group C, there is no improvement, only Garnet and Staurolite are normally distributed. In consequence no statistical procedure demanding normality can be used in order to test the similarity or dissimilarity of the heavy mineral spectra. Therefore, non-parametric statistic was used for correlation and variance analysis.

Rank-Variance Analysis

Kruskal-Wallis H test and the Kolmogorov-Smirnov test were used to see if the three groups belong to the same population. The results show that no mineral belongs to one and the same population in all the three groups. Only Tourmaline, Rutile and Apatite of the groups B and C belong to a population with identical distribution parameters.

Mean and Standard Deviation

These are given in Tab. 4. For the minerals with a non-normal distribution only the median should be calculated. The median in our case is, however, practically identical with the mean. The Group C ("Sandschottergruppe") is represented by its 4 wells and their average.

Correlation between Minerals

Non-parametric correlation (Spearman and Kendall rank correlation) of all the samples analyzed as one population shows negative correlation between: Garnet and Epidote; Garnet and Apatite; Rutile and Apatite; and positive correlation between: Garnet and Staurolite; Epidote and Hornblende.

Table 3.
Frequencies of heavy minerals from samples of the wells CFN5, CFN7, CFN9 and CFN11 ("Sandschottergruppe").

Probe	ZIR	TOU	RUT	APA	STA	CHL	KYA	EPI	HOR	AND	SIL	VAR	GAR
1.CFN5-10	3	2	6	31	25	-	2	25	3	-	-	3	68
2.CFN5-15	2	10	2	42	15	-	4	23	-	-	-	2	48
3.CFN5-20	4	4	2	22	19	-	2	45	+	-	-	2	47
4.CFN5-30	2	4	4	18	31	-	7	29	2	-	-	2	55
5.CFN5-35	40	-	8	-	8	-	-	44	-	-	-	-	75
6.CFN5-40	4	-	4	12	20	-	-	56	-	-	-	4	75
7.CFN5-45	13	-	-	32	7	-	-	45	3	-	-	-	68
8.CFN5-50	5	2	5	20	2	-	-	64	2	-	-	-	44
9.CFN5-55	4	2	15	13	8	-	-	45	13	-	-	-	47
10.CFN5-60	2	4	4	24	4	-	-	38	18	-	-	4	55
11.CFN5-65	11	3	3	18	24	-	-	40	2	-	-	-	37
12.CFN5-69	10	3	3	42	13	-	-	19	10	-	-	-	38
13.CFN5-70	6	-	-	40	33	-	-	19	-	-	-	2	52
14.CFN5-71	24	-	-	14	-	-	-	59	-	-	-	3	71
15.CFN5-73	-	8	4	8	39	-	4	35	-	-	-	4	74
16.CFN5-76	7	3	14	-	31	-	-	41	3	-	-	-	71
17.CFN5-80	8	4	8	8	35	-	8	31	-	-	-	-	74
18.CFN5-85	2	8	8	11	42	-	11	19	-	-	-	-	74
19.CFN5-90	4	4	8	4	50	-	4	25	-	-	-	-	76
20.CFN5-95	2	5	9	2	61	-	2	19	-	-	-	-	79
21.CFN5-100	2	2	15	2	49	-	2	20	5	-	-	2	79
22.CFN5-108	4	11	18	4	40	-	7	15	-	-	-	2	73
26.CFN7-30	9	9	4	17	44	-	-	13	4	-	-	-	77
27.CFN7-40	19	-	13	6	44	-	6	13	-	-	-	-	84
28.CFN7-50	-	6	12	12	47	-	6	18	-	-	-	-	83
29.CFN7-60	6	6	6	18	35	-	-	24	6	-	-	-	83
30.CFN7-69	10	3	10	10	36	-	5	26	-	-	-	-	82
35.CFN9-31	-	-	13	8	59	-	5	15	-	-	-	-	61
36.CFN9-33	4	4	11	25	50	-	-	7	-	-	-	-	72
37.CFN9-40	1	8	5	11	43	-	1	30	-	-	-	-	63
38.CFN9-56	6	3	8	8	44	-	11	19	-	-	-	-	64
39.CFN9-64	6	6	14	3	42	-	6	22	-	-	-	3	64
40.CFN9-66	2	4	12	2	64	-	2	12	2	-	-	-	75
41.CFN9-69	1	5	5	13	55	-	1	18	-	-	-	3	60
42.CFN9-75	3	3	10	3	55	-	7	19	-	-	-	-	69
43.CFN9-85	-	2	15	10	44	-	5	20	5	-	-	-	80
44.CFN9-93	4	-	4	12	56	4	8	12	-	-	-	-	75
45.CFN9-96	-	-	17	4	58	-	4	17	-	-	-	-	88
46.CFN9-99	5	5	11	5	58	-	5	11	-	-	-	-	81
47.CFN9-106	12	18	6	-	29	-	6	24	6	-	-	-	83
48.CFN9-116	11	11	3	3	40	-	3	17	11	-	-	-	83
49.CFN9-124	7	7	3	26	45	-	3	7	3	-	-	-	85
50.CFN9-134	7	7	3	17	38	-	3	10	14	-	-	-	71
51.CFN9-143	8	4	8	8	69	-	4	-	-	-	-	-	87
52.CFN9-150	-	-	7	7	71	-	3	13	-	-	-	-	85
53.CFN9-159	10	5	10	5	45	-	5	15	5	-	-	-	80
55.CFN11-35	6	3	6	17	37	-	3	26	3	-	-	-	65
56.CFN11-45	4	4	4	9	39	-	4	35	-	-	-	-	77
57.CFN11-55	2	2	10	13	40	-	2	30	-	-	-	2	77
58.CFN11-65	3	3	6	6	53	-	12	18	-	-	-	-	84
59.CFN11-75	13	2	17	4	52	-	2	9	-	-	-	-	77
60.CFN11-86	11	-	19	4	37	-	4	26	-	-	-	-	73
61.CFN11-89	3	-	-	28	44	-	3	22	-	-	-	-	72
Mean	6.2	3.9	7.8	12.8	38.3	0.1	3.4	24.5	2.3			0.7	70.6
Std.-Dev.	6.7	3.5	4.9	10.7	17.3	0.5	3.1	13.7	4.0			1.3	12.8

The correlation calculated between minerals in each group are given in Tab. 5 and Fig. 2. The positive correlation between Garnet and Staurolite remains whereas the negative correlation between Epidote and Hornblende is visible only in group B. Staurolite and Hornblende, Garnet and Apatite are negatively correlated in all three groups.

4.2. Correspondence Factor Analysis

Correspondence analysis is a distribution-free technique of factor analysis (BENZECRI et al., 1973) and therefore suited to our data. This technique takes advantage of the duality between R- and Q-mode analysis. The weighting procedures used reduce the closure effect of percentage data and scaling problems. The final product are diagrams with R-mode (minerals) and Q-mode (samples) plotted together.

Fig. 3 shows the result of our analysis in which 9 minerals participate in the factor axes calculation, whereas Garnet, Chloritoid, Andalusite and Varia are considered as supplementary variables. A three dimensional coordinate system resulted from the reduction of the original 13 dimensional space where each variable-

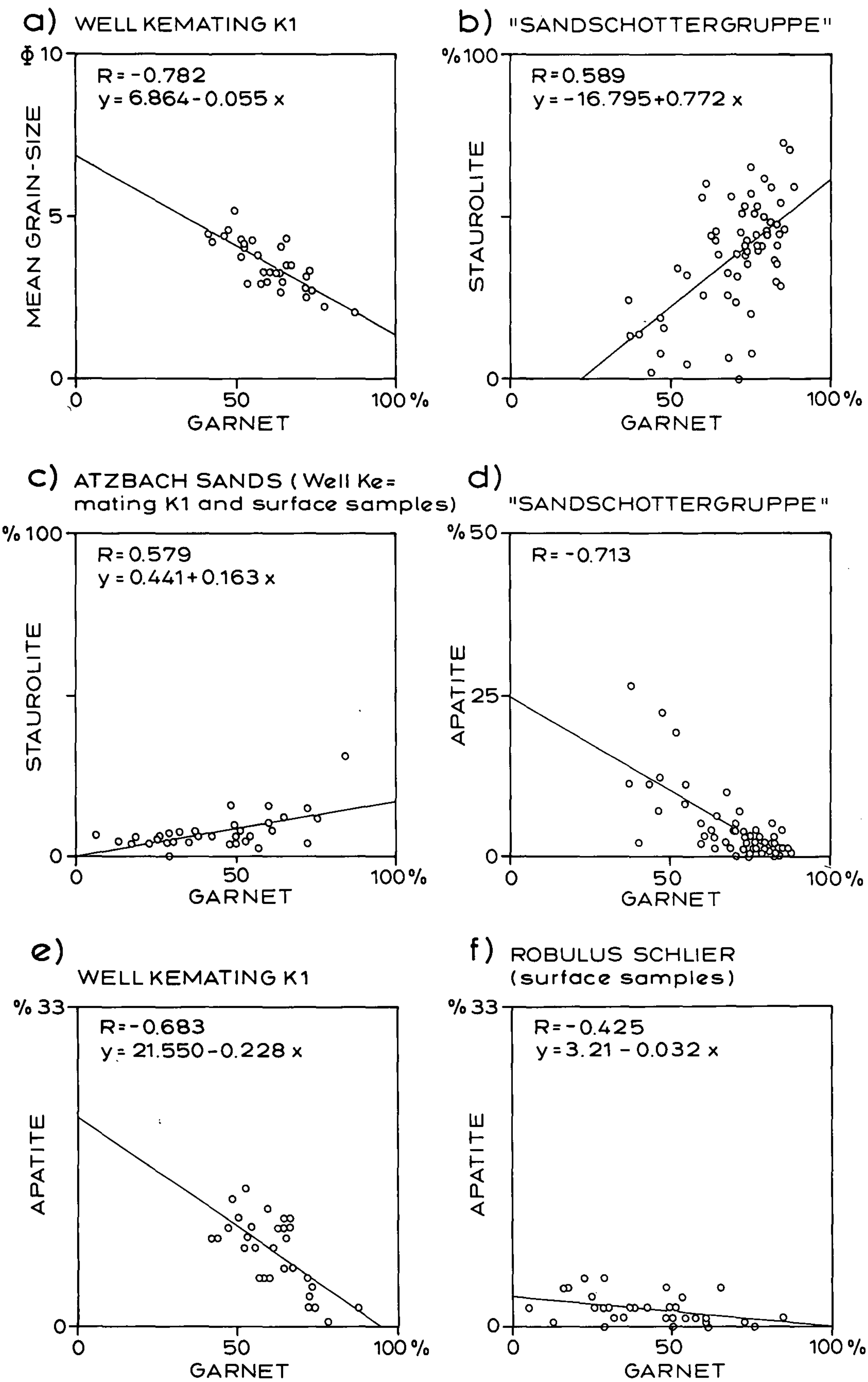


Fig. 2.
Presentation of correlation between some heavy minerals.
a) Correlation between the amount of Garnet and the mean grain-size of the sediments in the well Kemating K1 (Atzbach sands).
b) Correlation between Garnet and Staurolite in the "Sandschottergruppe" samples.
c) Correlation between Garnet and Staurolite in the Atzbach sands (well Kemating K1 and surface samples).
d) Correlation between Apatite and Garnet in the "Sandschottergruppe" samples.
e) Correlation between Apatite and Garnet in the well Kemating K1 (Atzbach sands).
f) Correlation between Apatite and Garnet in the Robulus Schlier s.l. (surface samples, mainly Atzbach sands).

mineral was an axis and each sample a vector in this space. The three dimensional system is shown in 2 planes: axes 1 and 2 and axes 1 and 3. The samples and the minerals are projections into those planes and should be visualized as points in a three dimensional coordinate system consisting of axes 1, 2 and 3. Each axis represents a factor, the positions of the samples correspond to their factor scores. The supplementary minerals, although not contributing to the calculation of the axes, are also represented and their correlations with the existing factors are calculated.

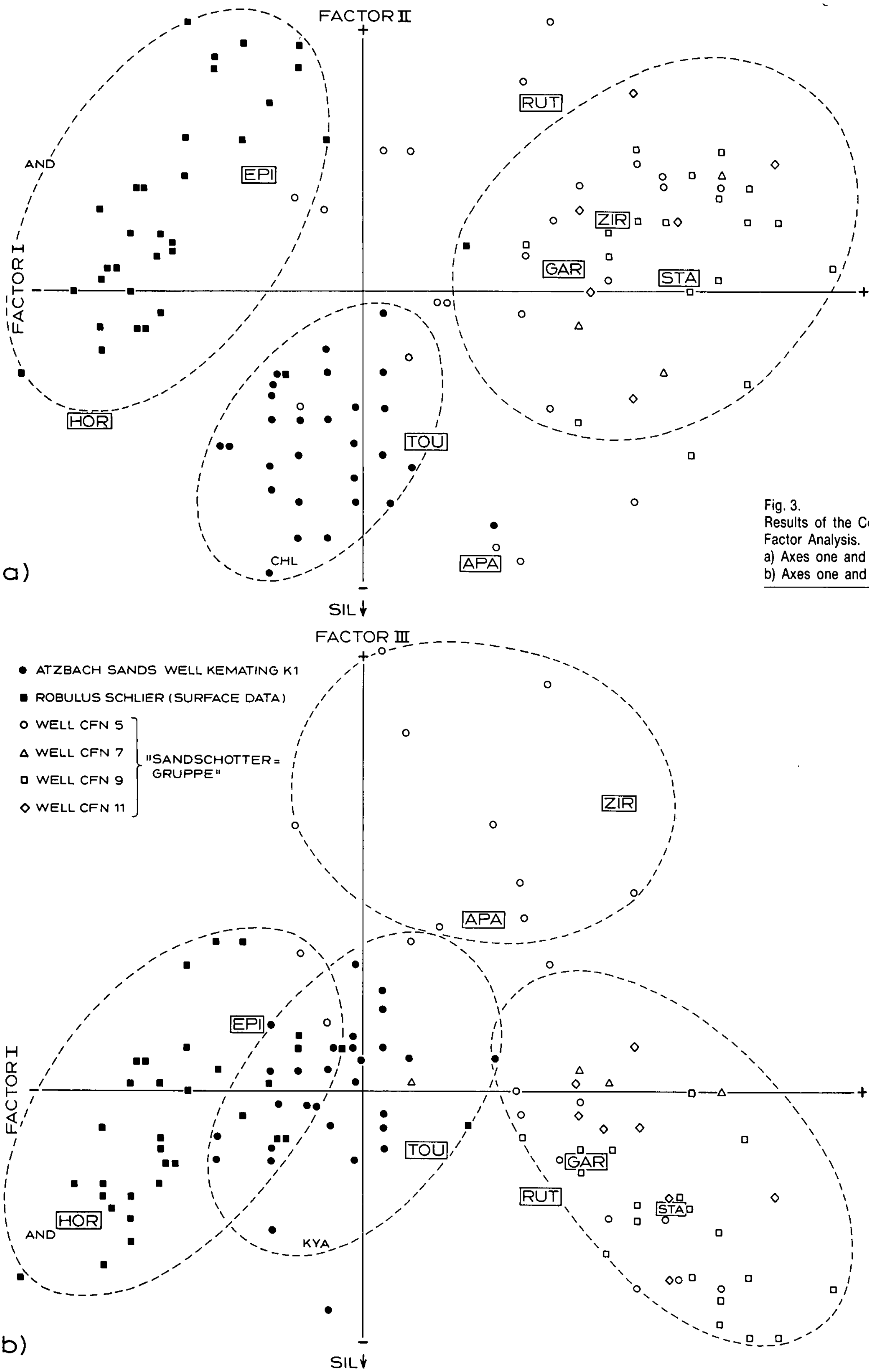


Fig. 3.
Results of the Correspondence Factor Analysis.
a) Axes one and two.
b) Axes one and three.

Table 4.
Mean (○) and standard deviation (●) of the heavy mineral frequencies.
ZIR = Zircon; TOU = Tourmaline; RUT = Rutile; APA = Apatite; STA = Staurolite; CHL = Chloritoid; KYA = Kyanite; EPI = Epidote; HOR = Hornblende; AND = Andalusite; SIL = Sillimanite; VAR = Varia; GAR = Garnet.

		ZIR	TOU	RUT	APA	STA	CHL	KYA	EPI	HOR	AND	SIL	VAR	GAR
Atzbach Sands (well Kemating K1)	○	2	6	1	19	16	2	5	26	23	+	1	+	61
	●	2	3	1	7	6	2	3	5	6	1	1	1	11
Robulus Schlier s.l. (surface)	○	+	3	4	3	8	1	5	51	23	1	–	2	43
	●	1	2	2	3	5	2	3	14	14	1	–	2	19
"Sandschottergruppe" (CFN5)	○	7	3	6	16	24	–	2	33	3	–	–	1	62
	●	9	3	5	14	18	–	3	15	5	–	–	2	14
"Sandschottergruppe" (CFN7)	○	9	5	9	13	41	–	4	18	2	–	–	–	82
	●	7	3	4	5	5	–	3	6	3	–	–	–	3
"Sandschottergruppe" (CFN9)	○	5	5	9	9	51	+	4	15	2	–	–	+	75
	●	4	4	4	7	11	1	3	7	4	–	–	1	9
"Sandschottergruppe" (CFN11)	○	6	2	9	12	43	+	4	24	+	–	–	+	75
	●	4	2	7	9	7	–	4	9	1	–	–	1	6
All Samples of "Sandschottergruppe"	○	5	4	6	12	31	+	4	28	9	+	+	1	66
	●	3	2	3	6	17	1	1	13	11	+	+	1	14

+ denotes a quantity more than zero and less than 0.5.

Table 5.
Correlation between the heavy minerals.
A, B, C denote high correlation in the respective groups.
a, b, c denote significant correlation (but not high).

	Garnet	Staurolite	Epidote	Hornblende
Garnet	–			
Staurolite	a B C			
Epidote	C	–C		
Hornblende	–	–a –B –c	–B	
Apatite	–A –b –C	–c	–a	–

Factor one which causes 42% of the variance consists of Staurolite opposed to Epidote and Hornblende, which means that all samples rich in Staurolite (and Garnet) will have a positive factor-one score, whereas samples rich in Epidote and/or Hornblende will be factor-one negative. The axis is highly correlated with Staurolite (0.8), Hornblende (0.6) and to a lesser degree with Garnet and Epidote.

Factor two (20% of variance) opposes Epidote to Hornblende and Apatite. The correlation with Apatite and Epidote is rather high.

Factor three (18% of variance) shows samples rich in Apatite, Zircon and/or Epidote opposed to more Staurolite and Hornblende bearing samples.

Three clusters containing about 90% of all the samples can be seen. *Cluster A* has mainly samples from the well Kemating K1, *cluster B* surface samples of the Robulus Schlier s.l. (Atzbach Sands) and *cluster C* samples of the "Sandschottergruppe". A fourth cluster containing samples from "Sandschottergruppe" well CFN5, rich in Apatite and Zircon can be seen in the axis 1/axis 3 plane.

Fig. 4 shows the clusters A, B, C in the plane axis 1/axis 2 and the composition of actual samples in each cluster. The sample in the middle of the ellipse represents the midpoint samples, whereas the other two represent samples of extreme compositions along a diagonal through the cluster.

5. Discussion

The results of the factor analysis as well as the correlation between the minerals show the heavy mineral assemblages consisting of several components.

a) Garnet and Staurolite are the most abundant minerals, positively correlated between themselves. Their possible source are mica schist and related metamorphic rocks (FÜCHTBAUER, 1964). This component is highest within the fan-delta (group C) and lowest in the samples from the Kemating well (group A).

b) Epidote and Hornblende are positively correlated when all samples are taken together, but negatively correlated in group B (Robulus Schlier s.l., mainly Atzbach Sands – outcrops). This duality is also evident in the factor analysis results. The main factor (one) has the two minerals opposed to Staurolite and Garnet, whereas factors two and three oppose Hornblende to Epidote. Group B samples vary from high Epidote, high Hornblende to even higher Epidote, low Hornblende. The source of Epidote according to FÜCHTBAUER (1964) are greenschists and granites, Hornblende being derived from the erosion of amphibolites and Hornblende-gneisses. The Epidote-Hornblende component is highest in group B and lowest in group C where Hornblende is rather rare.

c) Apatite which is sometimes accompanied by Zircon is seen in the factor three positive samples (mostly in the "Sandschottergruppe" but also in some other samples). FÜCHTBAUER (1964) gives granite rocks as a source of Apatite and Zircon. Apatite is also a common mineral in Biotite-Plagioclase-gneisses. It is a resistant mineral in alkaline pH, whereas Zircon is one of the most stable heavy minerals known. Both minerals are fine-grained. The samples containing this component could therefore represent an occasional influx of material from source rocks of granitic composition, but the grain

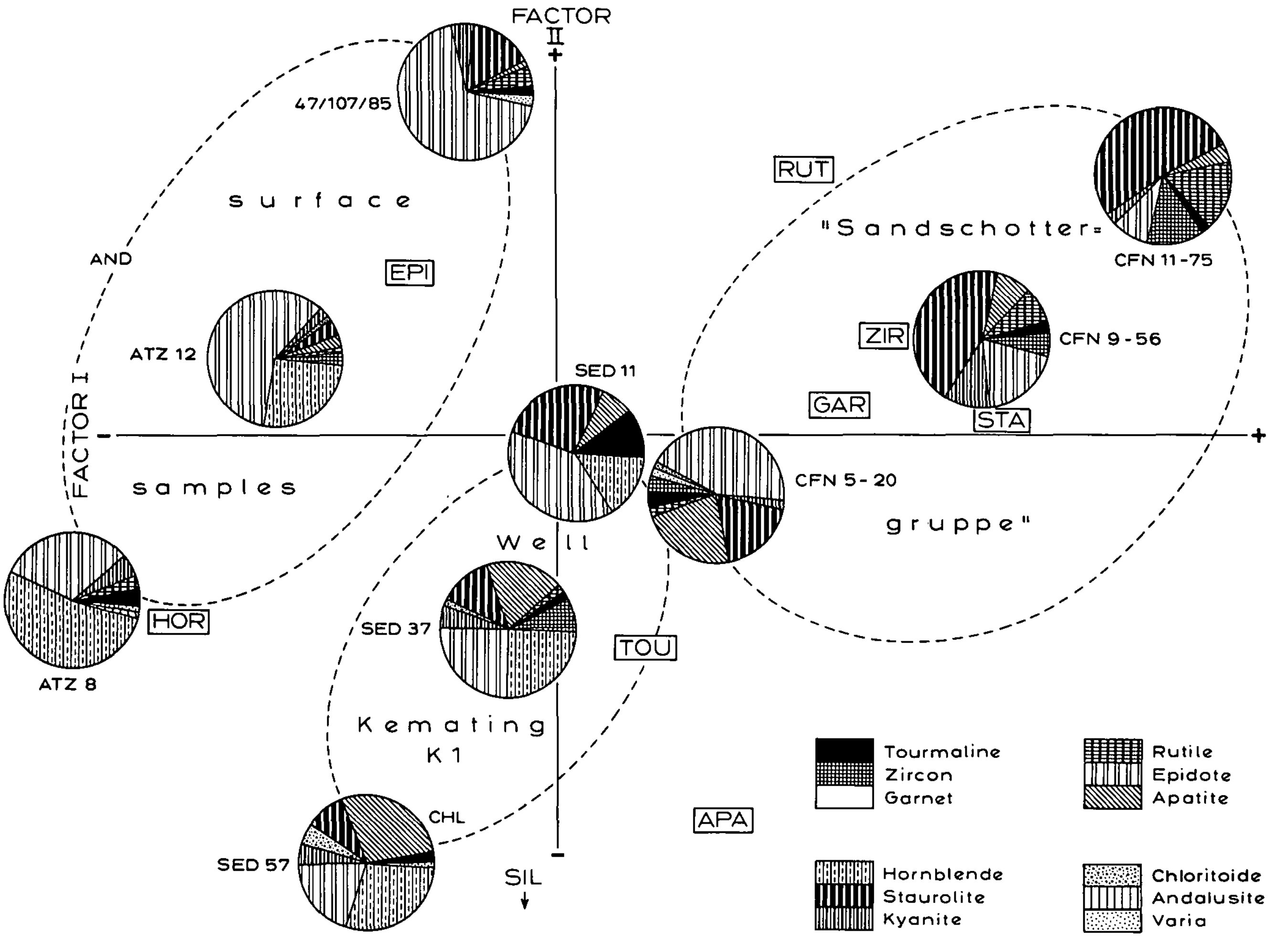


Fig. 4.
Correspondence Factor Analysis with characterization of the clusters.

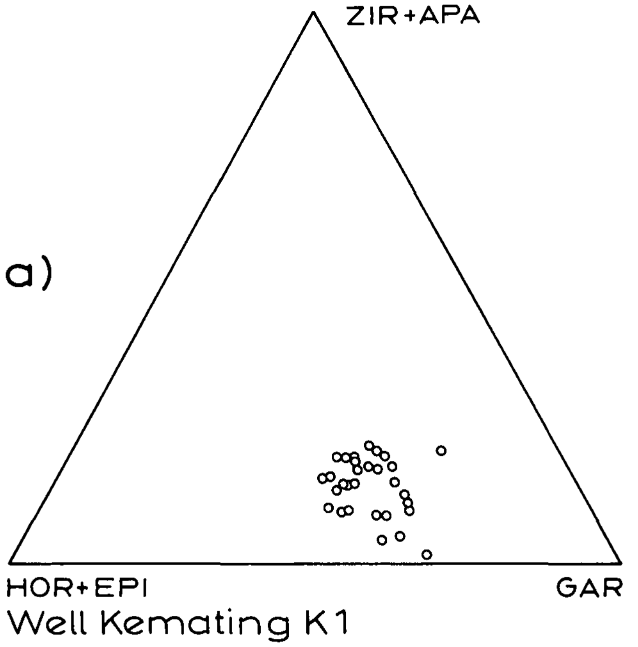
size of the sediments could also contribute to this abundance.

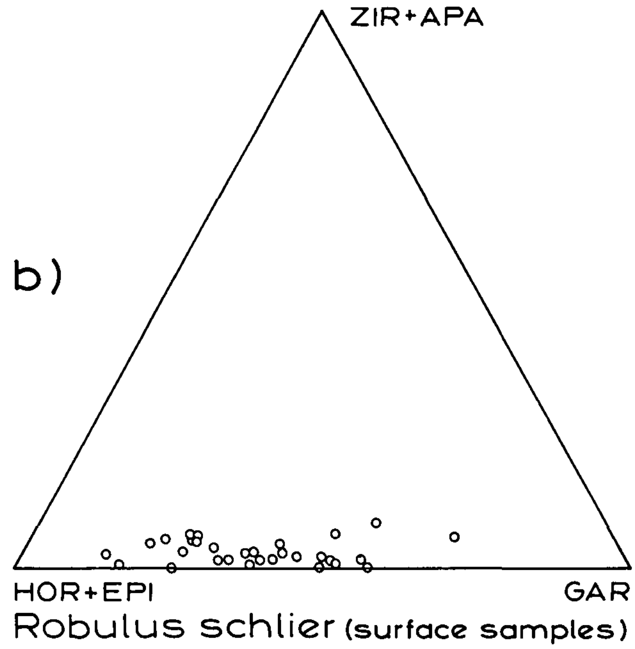
The influence of the three components can be seen in Fig. 5 where triangular diagrams with those three components as apexes are represented. The basis of the diagrams shows the decrease of the Hornblende-Epidote component in the "Sandschottergruppe". This could be a result of postdepositional solution of those two minerals (FAUPL & ROETZEL, 1987) which are the least stable ones in the conditions of diagenetic intrastratal solutions and in alkaline conditions (FÜCHTBAUER, 1964; GRIMM, 1973; NICKEL, 1973). The Apatite (and Zircon) component is lowest in group B (outcrop samples of the Robulus Schlier s.l., mostly Atzbach Sands). Whether this is only an effect of grain-size (there is a slight correlation between size and quantity of those minerals) or a change in provenance is still not clear as there are no grain-size data for the "Sandschottergruppe" material available.

Starting from the model of FAUPL & ROETZEL (1987) where the fan-delta was the source of the sedimentary material from which the Atzbach Sands were deposited as suggested by sedimentary structures a subsequent diagenetic change of the original sediment has to be supposed. This sediment, probably having a composition similar to that of group A samples, underwent post-sedimentary diagenetical changes in the fluvio-marine fan-delta environment. This presumably happened after the supply of the Atzbach Sands was distributed in the marine Molasse basin, predominantly by tidal currents. The relative stability of Garnet and Apatite excludes dissolution in an acid environment, but points to a process similar in chemical environment to the diagenetic intrastratal dissolution (FÜCHTBAUER, 1964; GRIMM, 1973).

6. Conclusions

1) The heavy minerals in three groups of samples from the Ottnangian sediments of the Austrian Molasse of Upper Austria and Salzburg belong to different populations, although consisting of the same spectrum of minerals.
2) Three components, revealed by correspondence factor analysis, can be seen:
   a) Garnet and Staurolite which originated in the erosion of Alpine crystalline complexes (mica schists and related rocks)
   b) Epidote and Hornblende, whose source could be predominantely greenschists, amphibolites and hornblende-gneisses
   c) Apatite (and Zircon) whose provenance is not exactly known, but which are slightly correlated with the grain-size.
3) Originally, the fan-delta sediments of the "Sandschottergruppe" had contained all three components in more different proportions than today. The Atzbach Sands whose material is probably derived from this fan-delta may reflect the original composition. Some differentiation between the two





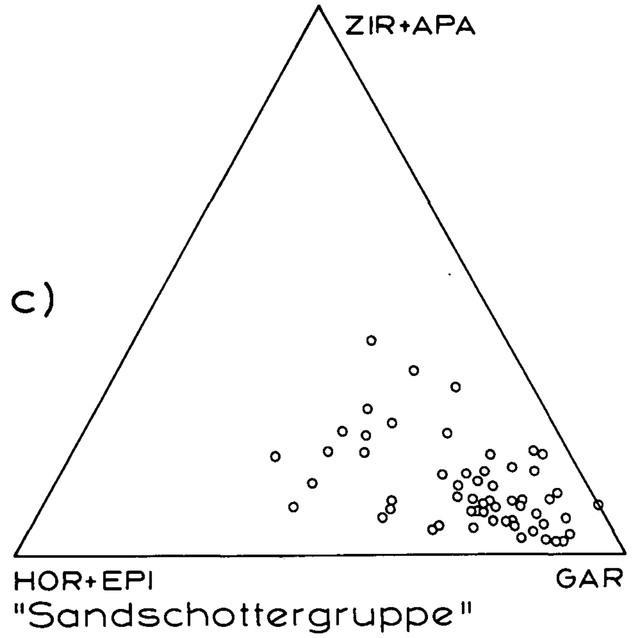


Fig. 5.
Triangular diagrams.

groups of Atzbach Sands (well Kemating K1 and surface samples) did also take place.

4) Post-sedimentary dissolution processes in the fan-delta in post-Atzbach Sands times caused the disappearance of Hornblende and of parts of the Epidote and the passive enrichment of Garnet, Staurolite and Apatite.

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