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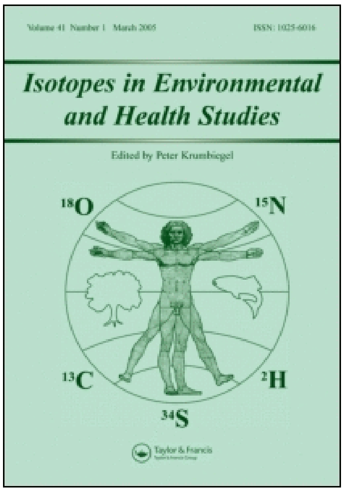

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Fractional Crystallization Models for Calculating Distribution Coefficients of Chemical Elements between Magmas and their Crystallization Products

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Igneous rock suites can be investigated with respect to their genetic coherence or to the role in fractional crystallization during their generation, respectively, by evaluating element concentration correlations.

It is shown that the existence of a linear relation between element concentrations or their logarithms is only a necessary, but not a sufficient condition for fractional crystallization as the dominating factor of graduating element concentrations. On the other hand comparison of the slope of such correlation lines with the slope calculated on the basis of the distribution coefficients evaluated by using Schuetze's ^{18}O *index reveals whether fractional crystallization is dominant in graduating element concentrations in igneous rock suites. Several applications are given.*

Die genetische Kohärenz einer Abfolge magmatischer Gesteine bzw. die Rolle der fraktionierten Kristallisation im Verlauf ihrer Entstehung wird durch die Berechnung von Elementkonzentrationen untersucht.

Es wird gezeigt, daß die Existenz einer linearen Beziehung zwischen den Elementkonzentrationen oder ihren Logarithmen nur eine notwendige aber nicht hinreichende Bedingung für fraktionierte Kristallisation als dem dominierenden Faktor der Abstufung der Elementkonzentrationen ist. Andererseits zeigt der Vergleich des Anstiegs solcher Korrelationsgeraden mit dem mittels des ^{18}O*-Index von Schütze auf der Basis von Verteilungskoeffizienten berechneten Anstieg, ob die fraktionierte Kristallisation bei der Bildung der Elementkonzentrationen in Abfolgen magmatischer Gesteine eine dominierende Rolle spielt. Eine Reihe von Anwendungen wird gegeben.*

Keywords

crystallization; distribution coefficients; element concentration; gabbros; geochemistry; geology; granites; granodiorites; igneous rocks; isotope effects; linear correlation; melting; oxygen 18; quartz diorites; rhyolites; silicates; thermodynamics; trace elements

Coefficients evaluated by using *Schuetze*'s ^{18}O index reveals whether fractional crystallization is dominant in graduating element concentrations in igneous rock suites.

The application of these criteria gives evidence that the concentrations of many alkaline and alkaline earth elements, elements of the first transition period and rare earth elements in the majority of igneous rocks are ruled by fractional crystallization.

Comparison of the slopes of element concentration correlation lines with those calculated from distribution coefficients reveals the validity of distribution coefficients evaluated by *Schuetze*'s ^{18}O indices. There is also a good agreement between distribution coefficients directly determined from element concentrations in rocks of the Hawaiian volcanic rock suite and those derived from ^{18}O indices.

1. Some theoretical considerations

While partial melting represents the common mechanism of the formation of a magma, its crystallization can be considered as the process accomplishing the generation of an igneous rock. Thus elemental concentration patterns of a certain rock series originating from one and the same magma are discussed in terms of fractional crystallization, while the chemical characteristics of certain magma bodies can often be interpreted in terms of partial melting [1–4].

It is the aim of this communication to examine, whether or to what extend the concept that the concentrations of chemical elements in many, if not in the majority of igneous rocks are ruled by fractional crystallization of their parent magmas, can be used for calculating distribution coefficients of chemical elements between magmas and their crystallization products. Because of their relevance for detecting connections between these distribution coefficients and structural parameters the following considerations will be restricted to those elements which are supposed to occupy cation positions in the alumosilicate lattice, i.e. alkaline and alkaline earth elements, elements of the first transition period of the periodic table, yttrium and the lanthanide elements.

There are three ways to determine distribution coefficients between rocks and their parent magmas by measuring element concentrations: Laboratory experiments with crystallizing silicate melts, investigation of natural or artifically prepared phenocryst/matrix systems (see e.g. [4]) and investigation of rock series which can be assumed to be genetically connected with each other [5]. The first two possibilities are not considered here. The third way is gone in a pioneering kind by *P. W. Gast* [1] and *D. M. Shaw* [2]. A review of quantitative models of trace element behaviour in different magmatic processes is given by *C. J. Allègre* and *J. F. Minster* [4]. In our paper we take into account firstly the isotopic composition of the rocks, secondly we use – similar as in isotopic research [6–10], a method comparing the behaviour of two or more chemical elements and thirdly we restrict ourselves to fractional crystallization processes but include a certain kind of open systems.

Exact knowledge of fractional crystallization conditions, particularly precise knowledge of the amounts of crystallization products, is a necessary condition of exactly calculating distribution coefficients of chemical elements in the third case. Thus, the concentration C_i of a chemical element in a magma of the mass M is connected with the concentration C_i^0 of this element in the initial mass M_0 of this magma, underlying crystallization in a closed system, by the *Rayleigh* equation

$$C_i/C_i^0 = (M/M_0)^{D_i - 1} \tag{1}$$

where D_i are the distribution coefficients of the chemical element i:

$$D_i = \frac{\text{concentration in the solid phase}}{\text{concentration in the liquid phase}}$$

[11].

Equation (1) is valid for equilibrium between every differential amount of solid phase and the homogeneous liquid phase the solid phase has been formed from.

One of the authors of the present paper has used equation (1) for calculating the D_i values of the alkaline and the alkaline earth elements, the elements of the first transition period of the periodic table and the rare earth elements, assuming that all the gabbros, diorites, quartz diorites, granodiorites and granites present in the recent continental crust have been formed by fractional crystallization of a magma of the intermediary composition in a closed system [5, 12]. The lower continental crust is assumed to be of dioritic composition. On the basis of this model distribution coefficients D_i of the mentioned elements between gabbros, diorites, quartz diorites and granodiorites on one hand and the magmas these rocks crystallize from on the other hand can be calculated using the global Clarke values of the single rock types and their global abundances in the continental crust. In accordance with the continuity of the chemical composition and the homogeneity of the structure of igneous rocks these distribution coefficients can be related to *Schuetze*'s ^{18}O index I [13] describing the O^2-lattice surrounding the cations in question [5, 12]

$$\begin{aligned} \lg D_i &= k_i + S_i \cdot (I_l - I_s) \\ &= k_i + S_i \cdot \Delta I \,, \end{aligned} \tag{2}$$

where ΔI is the difference of the ^{18}O indices of the liquid (I_l) and the solid phase (I_s), k and S are coefficients to be determined empirically.

Using an approach of statistical mechanics for ideal gas molecules of type AX_{r_i} one can define the ^{18}O index I [8] generally by

$$I = \frac{1}{r_i} \sum_{j=1}^{r_i} \frac{g_j}{g_i} . \tag{3a}$$

The coefficients g_j, g_i are structure dependent and can be calculated using vibrational frequencies of the molecules AX_{r_i} with substitution of the atom X — bounded at position j — by a heavier isotope $^*X$.

In a high temperature approximation the ^{18}O index for alumosilicata can be evaluated by the formula [13].

$$I = \frac{1}{y} (0.977x + 0{\cdot}645z + 0{\cdot}0155w + 4{\cdot}092) \,, \tag{3b}$$

where x, y and z are averaged stoichiometric coefficients of silicium oxygen and not tetrahedrally coordinates aluminium (Al$^{\text{VI}}$) in the chemical formula $M^{n}_{w/n}\text{Al}^{\text{VI}}_{z}[\text{Si}_x\text{Al}^{\text{VI}}_{4-x}0_y]$ of the alumosilicate. The coefficient w of all the cations M other than aluminium which are not in tetrahedron centres is given by the condition of electroneutrality:

$$w = 2y - x - 12 - 3z \,.$$

(Al$^{\text{VI}}$ denotes aluminium in tetrahedral positions and n the mean electrical charge of the cations M).

At least for all alumosilicates formed by crystallization from intermediary to acid melts ΔI can also be calculated by the empirical relation [5]

$$\Delta I = 0{\cdot}475 - 0{\cdot}534 I \,. \tag{4}$$

Equation (4) yields for gabbro and basalts $\Delta I = 0{\cdot}091$, for diorites and other intermediary rocks $\Delta I = 0{\cdot}074$, for quartz diorites $\Delta I = 0{\cdot}0215$ and for granodiorites $\Delta I = 0{\cdot}019$. Granites and quartz monzonites can be supposed to be characterized by $\Delta I = 0$.

The coefficients k_i and S_i in equation (2) calculated by fitting the distribution coefficients D_i determined in the above described way are listed in Tab. 1 [14].

Tab. 1. The coefficients k and S in $\lg D = k + S \cdot \Delta I$ for a number of chemical elements

Element	k	S	Element	k	S
Li	−0·071	−1·79	Ti	0·047	1·95
Na	0·102	−2·54	V	0·007	3·04
K	−0·239	−3·41	Cr	−1·77	26·5
Rb	−0·189	−3·09	Mn	0·041	1·82
Cs	0·0099	−5·17	Fe	0·112	1·16
Be	0·321	−11·4	Co	−0·95	18·9
Mg	0·235	0·983	Ni	−0·445	11·5
Ca	0·229	0·490	Cu	−0·109	5·57
Sr	0·275	−3·56	Zn	−0·023	2·14
Ba	0·056	−4·59	La	0·178	−7·89
Sc	0·152	0·300	Y	−0·085	0·366

It is a remarkable disadvantage of models based on equation (1) that the knowledge of the quantitative progress of crystallization must be taken for granted. Note that the majority of igneous processes are more or less open system processes and that M in equation (1) usually is unknown. Therefore it would be desirable to eliminate the quantity M by any means thus achieving relations for estimating distribution coefficients only using concentrations under certain conditions. This can indeed be attained by combining two (or more) element concentrations in one and the same magmatic bodies with each other. We write equation (1) in its logarithmic form for the element concentrations C_1 and C_2:

$$\lg \frac{C_1}{C_1^0} = (D_1 - 1) \lg \frac{M}{M_0}$$

$$\lg \frac{C_2}{C_2^0} = (D_2 - 1) \lg \frac{M}{M_0} \,,$$

where C_1^0 and C_2^0 denote the initial concentrations in the melt of the amount M_0. Elimination of $\lg \frac{M}{M_0}$ from these equations yields

$$\lg C_1 = \frac{D_1 - 1}{D_2 - 1} \lg C_2 + \lg C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg C_2^0 \,. \tag{5a}$$

Substituting the concentrations C_i in the liquid phase by the corresponding concentrations $c_i = D_i C_i$

$$\lg c_1 = \frac{D_1 - 1}{D_2 - 1} \lg c_2 + \lg D_1 C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg D_2 C_2^0 \tag{5b}$$

or $\lg c_1 = m \lg c_2 + q$.

Equation (5b) is a linear relation between the logarithms of the solid phase concentrations c_1 and c_2 with the slope

$$m = \frac{D_1 - 1}{D_2 - 1} . \tag{6}$$

The corresponding straight line intersects the ordinate at

$$q = \lg D_1 C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg D_2 C_2^0 \,. \tag{7}$$

Equation (5) can be used for revealing fractional crystallization series, if the distribution coefficients D_1 and D_2 and the concentration C_1^0 and C_2^0 in the parent magma can be assumed to be known. If the slope m in equation (5) is solely used, fractional crystallization series can be investigated without any knowledge of C_1^0 and C_2^0, i.e. without any information about the parent magma. Inversely equation (5) can be used for comparison of m and q derived from element concentration correlations with m and q calculated from D_1 and D_2 (and C_1^0 and C_2^0) determined in any other way, particularly in the way described above. This is possible provided that the rocks on which equation (5) is applied can really be assumed to be members of a rock series formed by fractional crystallization of a magma in a closed system.

Because of this important restriction we will now treat the fractional crystallization of a system which is a priori not assumed to be closed, but looses matter invading rocks surrounding the magma chamber.

As *Cann* [34] has shown, fractional crystallization in a magma chamber continuously losing liquid during solidification can be described by a modified *Rayleigh* formula (1) in which D has to be substituted by

$$D^x = \frac{D \cdot q + 1}{q + 1} \,,$$

where q is the ratio of solid precipitated to liquid lost by leakage of the magma chamber under consideration. For a close magma chamber is $q = \infty$ and becomes $D^x = D$, while a chamber losing all its magma by leakage ($q = 0$) is distinguished by $D^x = 1$ corresponding to the absence of any differentiation.

As this equation and equation (1) show, this type of crystallization gives rise to a gradation of element concentrations which at high liquid leakage can be distinguished from the gradation caused by closed system fractionation, particularly in the case of incompatible elements. (For compatible elements D^x approaches D for less than 20 % liquid leakage.) The slope m of a $\lg c_1 - \lg c_2$ correlation line for a magma chamber with continuous removal of liquid is given by

$$\frac{D_1^x - 1}{D_2^x - 1} = \frac{\dfrac{D_1 q + 1}{q + 1} - 1}{\dfrac{D_2 q + 1}{q + 1} - 1} = \frac{D_1 - 1}{D_2 - 2}$$

in analogy to equations (5) and (6). This particular type of system is evidently distinguished by an exact agreement with closed systems with respect to the $\lg c_1 - \lg c_2$ correlation of element pairs.

We now turn a more common type of open systems and consider n subsequent crystallization steps, the first starting with the concentration C^0 in the initial melt and resulting in a solid fraction of the amount $\eta^{(1)}$ and a residual liquid of the amount $1 - \eta^{(1)}$:

$$\eta^{(1)} c^{(1)} + (1 - \eta^{(1)})\, C^{(1)} = C^{(0)} \,, \tag{8}$$

where $c^{(1)}$ and $C^{(1)}$ are the concentrations of any chemical element in the solid or the liquid fraction, respectively. Considering equilibrium conditions between the two phases $c/C = D$ for the first crystallization step equation (8) gets the form

$$\frac{c^{(1)}}{D^{(1)}} = \frac{1}{1 + \eta^{(1)}(D^{(1)} - 1)}\, C^{(0)} \tag{9a}$$

and for the n^{th} step one yields

$$\frac{c^{(n)}}{D^{(n)}} = \frac{1}{1 + \eta^{(n)}(D^{(n)} - 1)}\, C^{(n-1)} \,. \tag{9b}$$

Equations (9a) and (9b) can be rearranged to give the concentration $c^{(n)}$ after n subsequent differential crystallization steps by

$$\frac{c^{(n)}}{D^{(n)}} = \frac{1}{\prod\limits_{j=1}^{n} (1 + n^{(j)}(D^{(j)} - 1))}\, C^{(0)} \,. \tag{10}$$

Applying equation (10) to the concentrations $c_1 C_1$ and $c_2 C_2$ of two chemical elements we obtain

$$\lg c_1^{(n)} = \lg D_1^{(n)} - \sum_{j=1}^{n} \lg (1 + \eta^{(j)}(D_1^{(j)} - 1)) + \lg C_1^{(0)}$$

$$\lg c_2^{(n)} = \lg D_2^{(n)} - \sum_{j=1}^{n} \lg (1 + \eta^{(j)}(D_2^{(j)} - 1)) + \lg C_2^{(0)} \,. \tag{11}$$

Taking into account

$$\sum_{j=1}^{n} \lg(1 + \eta^{(j)}(D_i^{(j)} - 1)) \sim \lg e \sum_{j=1}^{n} \eta(D_i^{(j)} - 1)$$

for $i = 1, 2$ and $\eta^{(j)}(D_i^{(j)} - 1) \ll 1$ and assuming

$$D^{(1)} = D^{(2)} = \ldots = D^{(j)} = \ldots D$$

we get

$$\lg c_1 = \frac{\Sigma\, \eta^{(j)}(D_1 - 1)}{\Sigma\, \eta^{(j)}(D_2 - 1)} \lg c_2 + \lg C_1^{(0)}$$
$$- \frac{\Sigma\, \eta^{(j)}(D_1 - 1)}{\Sigma\, \eta^{(j)}(D_2 - 1)} \lg C_2^{(0)} + \lg D_1$$
$$- \frac{\Sigma\, \eta^{(j)}(D_1 - 1)}{\Sigma\, \eta^{(j)}(D_2 - 1)} \lg D_2$$

and because of

$$\frac{\Sigma\, \eta^{(j)}(D_1 - 1)}{\Sigma\, \eta^{(j)}(D_2 - 1)} = \frac{D_1 - 1}{D_2 - 1}$$

this yields

$$\lg c_1 = \frac{D_1 - 1}{D_2 - 1} \lg c_2 + \lg D_1 C_1^{(0)} - \frac{D_1 - 1}{D_2 - 1} \lg D_2 C_2^{(0)} \,. \tag{12}$$

Equation (12) is identical with equation (5). The assumption of constancy of distribution coefficients during crystallization is only fulfilled if ΔI is constant.

Thus we can draw the conclusion that equation (5) describes fractional crystallization controlled element concentration correlations independent on any knowledge of the quantitative proportions of the liquid and the solid fraction and (with the limitations just described) on any information about whether the magma forms a closed system or a system loosing liquid phase to the surroundings. The plausible explanation of this result is the following: The concentration of a single element strongly depends on how crystallization proceeds, while the relation of the concentration of two or more elements to each other is in a first approximation only dependent on the initial conditions and the distribution coefficients, the degree of differentiation being cancelled.

Magmas assimilating wallrocks during crystallization are of course also open systems. The elemental concentrations of such magmas can be calculated using *de Paolo*'s [15] combined wallrock assimilation and fractional crystallization model. A simple consideration shows that correlations between concentrations of such magmas do not follow equation (5). This type of correlation is therefore characteristic of fractional crystallization of closed systems and of open systems loosing material to the surroundings [16].

Thus we conclude that equation (5) can be used for distinguishing closed and contracting system fractional crystallization controlled processes from any other (extending system fractional crystallization, partial melting, leaching, migration, diffusion, convection etc.) processes influencing element concentrations in igneous rocks, but not for distinguishing different mechanism of crystallization differentiation from each other, particularly for deciding whether or not the solidification proceeds in a closed or in a contracting system. (The latter would at the most be possible by using concentration patterns of elements with D_i values very strongly deviating from unity.) Equation (5) is valid for element concentration correlations of all elements the concentrations of which are ruled by fractional crystallization except for elements with distribution coefficients strongly deviating from unity in systems loosing material to the surroundings.

The application of equations (5) to particular magmatic bodies as well as to global *Clarke* values of different types of igneous rocks reveals high correlation coefficients r and good agreement of m and q in equation (6) and (7) calculated from the $\lg c_1 - \lg c_2$ correlation line on one hand and from D_1 and D_2 (and C_1^0 and C_2^0) on the other hand with respect to many, but not to all element pairs. As we will show below low correlation coefficients and bad agreement is often found, if at least one of the chemical elements is characterized by a D value only slightly deviating from unity ($0{\cdot}8 < D < 1{\cdot}2$). This is clearly due to the fact that the gradation of the concentrations of those elements in a series of igneous rocks is small and is not or not mainly determined by fractional crystallization, but by any other geochemical process. Therefore the distribution coefficients D_i must deviate from unity to a certain extend in order to guarantee a concentration gradation ruled by fractional crystallization, but should not deviate from unity too much in order to get open systems included. (On the other hand D_i should strongly deviate from unity if open systems are intended to be distinguished from closed ones.)

Under these circumstances concentration correlations between the following chemical elements in Tab. 1 can be recommended for investigating magmatic processes and distinguishing them from other geochemical processes: K, Mg, Ca, Fe in granitic rocks, K, Mg, Ca, Fe, Ti, Mn in intermediary rocks and K, Mg, Ca, Fe, Ti, Mn and Na in gabbro-basaltic rocks. (These recommendations are based on D_i values calculated by equation (2) using k_i and S_i values in Tab. 1.)

In the geochemical literature complex element concentration correlations like $c_1/c_2 - c_2$, $c_1/c_2 - c_3$ and $c_1/c_2 - c_3/c_4$ or their logarithms, respectively, are often used for investigating igneous rocks. We will consider whether or which of such correlations can be expected to give results exceeding those obtained from simple correlations as defined by equation (5), particularly in the case of chemical elements with D values only slightly deviating from unity. In accordance with the models described here these considerations are restricted to correlations between tho logarithms of concentration or concentration quotients. $\lg c_1/c_2 - \lg c_2$ correlations can be derived by subtracting $\lg c_2$ from both sides of equation (5b):

$$\lg c_1/c_2 = \frac{D_1 - D_2}{D_2 - 1} \cdot \lg c_2 + \lg D_1C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg D_2C_2^0 \tag{13a}$$

or

$$\lg c_1/c_2 = (m - 1) \lg c_2 + q\,. \tag{13b}$$

Equation (13) will evidently yield the same m and q values as equation (5b), but as we will show later considerably higher correlation coefficients r, if c_1 is the concentration of an element with a D value considerably deviating from unity and c_2 the concentration of an element with $D \approx 1$. This can easily be understood, if one faces the utmost case that c_2 is constant in a certain rock series. Equation (13) then becomes a correlation between $\lg 1/c_2$ and $\lg c_2$:

$$\lg c_2 = -(m - 1) \lg c_2 - q'$$

with a constant $q' = q - \lg c_1$. This of course is a trivial correlation with a correlation coefficient $r = 1{\cdot}00$ without any geochemical meaning. In a similar way a $\lg c_1/c_2 - \lg c_3$ correlation can be derived by substituting $\lg c_2$ in equation (13a) by the simple correlation

$$\lg c_2 = \frac{D_2 - 1}{D_3 - 1} \lg c_3 + \lg D_2C_2^0 - \frac{D_2 - 1}{D_3 - 1} \lg D_3C_3^0$$

or

$$\lg c_1/c_2 = \frac{D_1 - D_2}{D_3 - 1} \lg c_3 + \lg D_1C_1^0 - \lg D_2C_2^0 - \frac{D_1 - D_2}{D_3 - 1} \lg D_3C_3^0 \tag{14}$$

If 1 is an element with $D \approx 1$ and 2 and are elements with D values strongly deviating from unity, we get a similar situation as in the case of equation (13): Equation (14) becomes more or less identical with a $\lg c_2 - \lg c_3$ correlation with respect to its geochemical relevance. But as contrasted with equation (13) equation (14) can be used for correlating two elements 1 and 2 being distinguished by $D_1, D_2 \approx 1$ with an element 3 distinguished by a D value strongly deviating from unity. (In certain cases the quotient c_1/c_2 will be distinguished by a more evident correlation with progress in fraction crystallization than the single concentrations c_1 or c_2, respectively.)

Equation (14) can be extended to a $\lg c_1/c_2 - \lg c_3/c_4$ correlation in the following way: If both sides of equation (13a) are multiplied by -1, using c_3, D_3, C_3^0 instead of c_2, D_2, C_2^0 and c_4, D_4, C_4^0 instead of c_1, D_1, C_1^0, the following relation results:

$$\lg c_3/c_4 = \frac{D_3 - D_4}{D_3 - 1} \lg c_3 - \lg D_4C_4^0 + \frac{D_4 - 1}{D_3 - 1} \lg D_3C_3^0\,. \tag{15}$$

Combination of equations (14) and (15) yields:

$$\lg c_1/c_2 = \frac{D_1 - D_2}{D_3 - D_4} \lg c_3/c_4 + \lg D_1C_1^0 - \lg D_2C_2^0 - \frac{D_1 - D_2}{D_3 - D_4} (\lg D_3C_3^0 - \lg D_4C_4^0)\,. \tag{16}$$

Equation (16) is a $\lg c_1/c_2 - \lg c_3/c_4$ correlation which in addition to the equations (5), (13) and (14) can be used for investigating igneous rock suites with respect to their genetic coherence or to the role of fractional crystallization during their generation, respectively.

Among these correlations equation (16) is the most comprehensive one. Equations (5), (13) and (14) can be derived from equation (16) by substituting definite c_i and D_i values by corresponding values or by unity, respectively. Because of this tight connection we are allowed to face the simplest correlation (5), if we now turn to the question, whether or not distribution coefficients D_i can be calculated solely from element concentration correlations. From a formal point of view this should be possible, if the initial concentrations C_1^0 and C_2^0 are known or can be determined independently, because in equation (5b) m contains an information about $\frac{D_1 - 1}{D_2 - 1}$ and q contains besides $\frac{D_1 - 1}{D_2 - 1}$ also D_1 and D_2 themselves. But in fact this would not work, as the following consideration shows: If we write equation (7) in the form

$$q = \lg C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg C_2^0 + \lg D_1 - \frac{D_1 - 1}{D_2 - 1} \lg D_2\,,$$

we recognize that $\lg D_1 - \frac{D_1 - 1}{D_2 - 1} \lg D_2$ does not considerable contribute to q $\left(\lg D_1 - \frac{D_1 - 1}{D_2 - 1} \lg D_2 \approx \lg e(D_1 - 1) - \lg e \frac{D_1 - 1}{D_2 - 1} (D_2 - 1) = 0, \text{ if } D_1, D_2 \approx 1\right)$. Therefore element concentration correlations can scarcely be used for determining D_i values independently. Either one distribution coefficient can be assumed to be known and the other is calculated with the aid of equation (6) or the slope m of the correlation line is used for controlling D values determined on any other way. The intersection q of the correlation line with the ordinate can be used for gaining information on the initial concentrations C_1^0 and C_2^0 nearly independently on exact knowledge of D_1 and D_2. On the other hand q is, as we have just seen, in no way an adequate means of getting information about D values.

These conclusions are valid not only for equation (5), but also for equations (13), (14) and (16).

2. Applications to definite magmatic bodies

2.1. *Magmatic bodies with known quantitative proportions of crystallization products*

There are a few series of igneous rocks formed by fractional crystallization the quantities of solidification products

IAEA: INTERNATIONAL CO-OPERATION: "ABSOLUTE NECESSITY"

Calling co-operation among nations an "absolute necessity" in today's world, IAEA Director General Hans Blix has urged the international community to "redouble its efforts" to curb the spread of nuclear weapons and to reduce risks from modern technologies. "International rules and regulations must not lag behind the leaps in scientific and technological advancement," he said. Dr. Blix made the remarks on 11 November 1986 in New York during his annual statement to the United Nations General Assembly. In the nuclear field, he said, the past few months have seen international co-operation "at its best", as governments were determined in a spirit of compromise to make full use of the organizations they had set up. The "remarkable international solidarity and co-operation" since Chernobyl, he said, is "an example of how the world can draw together to try to ensure that technology will be used safely for the benefit of humankind". He called the work "especially encouraging" at a time when United Nations organizations are being criticized and multilateral diplomacy in general is "in crisis". (IAEA Newsbriefs 1(1986)4

IAEA:
PLANT BREEDING
FOOD CROPS FROM WILD PLANTS

From the earth's rich variety of more than 200000 species of flowering plants, only a small fraction have been domesticated and grown for food and industrial uses. Today, scientists are looking at ways to domesticate more wild plants, and to change existing crops, to help meet the worlds growing needs. Advances in this branch of plant breeding were reviewed from 17-21 November 1986 by an advisory group of scientists to the IAEA and the Food and Agriculture Organization (FAO) of the United Nations. Since 1964, the two agencies have worked together in plant breeding and other fields through a joint division of isotope and radiation applications of atomic energy for food and agricultural development. The advisory group discussed research and advanced methods being used in plant breeding and addressed important related to breeding procedures, technological developments, co-ordination of future activities, and training programmes. Scientists from the Federal Republic of Germany, Israel, Italy, the Netherlands, Sri Lanka, Sweden, the UK, and the USA attended the meeting. (IAEA Newsbriefs 1(1986)4)

IAEA UNESCO
SCIENTISTS HONOURED AT ICTP IN TRIESTE

Distinguished scientists from several countries have been honoured in award ceremonies at ehthe International Centre for Theoretical Physics (ICTP) in Trieste, Italy. ICTP is a joint research institution of the IAEA and the United Nations Educational, Scientific, and Cultural Organization (UNESCO).
On 15 November, two scientists from the USSR were officially given the Dirac Medal of the ICTP for 1985 and 1986: Prof. Yakov Zeldovich of the Space Research Institute in Moscow, and Prof. Alexander Polyakov of the Landau Institute of Theoretical Physics in Moscow. The two other recipients of the medal in 1985 and 1986 were US scientists Prof. Edward Witten of Princeton University and Prof. Yoichiro Nambu of the Enrico Fermi Institute for Nuclear Studies at Chicago University. The Dirac Medal is issued in honour of Prof. Paul Adrien Dirac, who shared the Nobel Prize for Physics with E. Schroedinger in 1933. The awards were pressented by Prof. Abdus Salam, Nobel Laureate in 1979 and Director of the ICTP, and Prof. Stig Lundquist, Chairman of the ICTP Scientific Council. On 19 November, Prof. Chike Obi, Professor Emeritus of the University of Lagos in Nigeria, received the 1985 ICTP Prize for outstanding contributions in the field of mathematics. The award is in honour of Dr. Sigvard Eklund, who was Director General of the IAEA from 1961-81. Dr. Eklund personally presented the prize of US S1000 and a certificate. The 1986 ICTP Prize will be awarded in March 1987 to Prof. Li Jiaming of China for his contributions in the field of atomic and molecular physics. (IAEA Newsbriefs 1(1986)4)

IAEA: GOVERNMENT SUPPORT FOR NUCLEAR DEVELOPMENT

From several venues and vantage points, governments recently have expressed their interest in the peaceful international development of nuclear energy and the IAEA's expanding programmes and role:
In Tokyo on 29 October, Japan's Prime Minister Yasuhiro Nakasone personally assured IAEA Director General Hans Blix of his country's support for the work of the IAEA. Mr. Nakasone met with Dr. Blix in connection with the 30th anniversary of Japan's peaceful development of nuclear power.
During the talks, Mr. Nakasone underlined Japan's full support for the Agency's expanded nuclear safety programme, and his satisfaction with the IAEA's work, especially since the nuclear plant accident at Chernobyl. Also discussed were Japan's co-operation in safeguards measures and technical assistance programmes.
In Vienna on 3 November, USSR Foreign Minister E.A. Chevardnadze met with Dr. Blix and confirmed his country's support of the IAEA in relatio to the non-proliferation of nuclear weapons and the development of international co-operation in the peaceful uses of nuclear energy. He also expressed satisfaction with the effective measures being taken within the framework of the IAEA for the implementation of the USSR's proposal for the creation of an international regime for the safe development of nuclear power.
In Vienna on 6 November, Foreign Minister Sten Anderson of Sweden and Marian Orzechowski of Poland separately visited Dr. Blix. Discussions related to the present status of nuclear power and and safety, the IAEA's safeguards activities, and international cooperation. Mr. Andersson expressed particular interest in the future development of the safeguards inspections system in the light of nuclear disarmament. Mr. Orzechowski extended his Government's appreciation of the IAEA's work during what he termed a "dramatic period" after the Chernobyl accident. He said Poland intends to continue its nuclear power programme and places high value on IAEA assistance and co-operation. (IAEA-Newsbrief 1(1986)3)

IAEA/WHO: ASSESSMENT OF CHERNOBYL'S LONG'TERM HEALTH EFFECTS

Jointly with the World Health Organization (WHO), the IAEA is continuing to collect the environmental measurement results from those countries affected by the release of radioactive materials from the Chernobyl accident. This information will provide a database for an assesment of the accident's long-term health consequences, which will be done by the United Nations Commitee on the Effects of Atomic Radiation (UNSCEAR). It is expected to be published as part of a comprehensive UNSCEAR report in 1988. Since the Chernobyl accident of 26 April, more t than 20 Member States have voluntarily sent to the IAEA data from their environmental measurements. (A report on this exchange of information appears in the latest edition of the IAEA Bulletin, Vol. 28, No. 3). Data on measurements also have been submitted separately to the WHO. Since the Chernobyl accident, the WHO Regional Office for Europe, based in Copenhagen, has carried out two preliminary overviews. The first, in May, estimated the immediate problems in various European countries, and the second, in June, made tentative predictions of population doses associated with the various exposure pathways. The joint IAEA/WHO programme for the collection of environmental monitoring data was initiated in August 1986 following a joint meeting of the IAEA, the WHO, the World Meteorological Organization (WMO), and UNSCEAR. The IAEA currently is looking at ways to develop a long-term co-operative programme with these and other international organizations. This is part of efforts to improve post-accident of environmental consequences, environmental monitoring capabilities and planning of countermeasures and information exchange. (IAEA-Newsbriefs 1(1986)3)

IAEA:UPDATE ON THREE INTERNATIONAL CONVENTIONS

The Convention on Early Notification of a Nuclear Accident - which was opened for signature at the Special Session of the IAEA General Conference in Vienna on 26 September - entered into force on 27 October. This came 30 days after Czechoslovakia, Denmark, and Norway - three of the 58 signatory States - expressed their consent to be bound by the convention upon signing it on 26 September. Other States have also declared their willingness to apply the convention provisionally, pending its entry into force them after the deposits of instruments of ratification, acceptance, approval, or accession have been received expressing consent to be bound. The convention will remain open for signature until 26 September 1987 at Vienna and 6 October 1987 at New York. Fifty-seven States have also signed the Convention on Assistance in the case of a Nuclear Accident or Radiological Emergency. It was also opened for signature on 26 September this year. As in the case of the other convention, this will enter into force 30 days after three States have expressed their consent to be bound by its provision. So far, inly Norway has done so. Another international convention - the Convention on the Physical Protection of Nuclear Material - now has been ratified by 19 of the 45 signatory States. Only two more ratifications are needed for it to enter into force. Adopted in Vienna in 1979, the convention provides for a concerted international approach in security measures to physically protect nuclear materials. It commits State Parties to take security measures that will deter or defeat deliberate acts, such as theft, sabotage, or unlawful removal and use of nuclear materials. They also agree not to export or import nuclear material, or allow its transit through their territories, without assurances of its physical protection to specified levels of security. Although several of the convention's provisions deal with nuclear material in domestic use, storage, and transport, its primary focus is on the physical protection of nuclear material during international transport. (IAEA-Newsbrief 1(1986)3)

IAEA: STAND DER KONVENTIONEN

Bis zum 8.10.1986 haben insgesamt 58 Staaten die Konvention ueber Fruehwarnung bei einem Nuklearunfall, die am 26 September 1986 im Kongresszentrum Hofburg in Wien zur Unterschrift aufgelegt wurde, unterzeichnet. Da drei Staaten diese Konvention mit sofort bindender Wirkung unterzeichnet haben, wird sie am 27. Oktober 1986 in Kraft treten. 57 Staaten haben die Konvention ueber Hilfeleistung im Falle eines Nuklearunfalls oder einer Strahlennotstandssituation, die zum gleichen Zeitpunkt zur Unterschrift aufgelegt wurde, unterzeichnet. Wie die andere Konvention wird sie 30 Tage nachdem 3 Staaten sie als bindend anerkannt haben in Kraft treten. Der Generaldirektor der IAEA wurde zum Depositar fuer beide Konventionen bestimmt. und er wird in Kuerze allen Staaten eine Mitteilung bezueglich der, anlaesslich der Unterzeichnung der Konventionen abgegebenen Erklaerungen oder Vorbehalte der Staaten zukommen lassen. (IAEA-Pressekommunique (1986) 36)

IAEA: SYMPOSIUM UEBER SICHERUNGSKONTROLLE BEI KERNMATERIAL EROEFFNET

Die juengst erzielten Fortschritte in der Sicherungskontrolle von Kernmaterial sind das Thema eines internationalen Symposiums, das am 10.11.1986 in Wien eroeffnet wurde. Zu dem eine Woche dauernden Symposium sind ueber 300 Experten aus 30 Mitgliedsstaaten der IAEA und von vier internationalen Organisationen zusammengekommen. Es werden etwa 150 Fachberichte aus 15 Themenkreisen vorgetragen werden. Die Sicherungskontrolle ist das technische Verfahren, das von der IAEA angewandt wird, um zu ueberpruefen, ob kerntechnische Einrichtungen oder Kernmaterial ausschliesslich fuer friedliche Zwecke verwendet werden. Zur Zeit wird die Sicherungskontrolle auf mehr als 95% der zivilen Nukleareinrichtungen ausserhalb der fuenf Kernwaffenstaaten (China, Frankreich, Grossbritannien, UdSSR, USA) angewendet. Vier der fuenf Kernwaffenstaaten haben alle (Grossbritannien, USA) bzw. einige (Frankreich,UdSSR) zivile Kernanlagen der IAEA-Sicherungskontrolle unterstellt. Die IAEA befindet sich derzeit auch in Verhandlung ueber ein Sicherungskontrollabkommen mit der VR China, dem fuenften und letzten Kernwaffenstaat, der dem Kontrollsystem noch nicht untersteht. In den vergangene Jahren wurden bedeutende Fortschritte hinsichtlich der Erreichung der Sicherungskontrollziele der IAEA gemacht. Die Anzahl der schon vorhandenen, der Sicherungskontrolle unterstehenden Anlagen, in denen die Kontrollziele der IAEA fuer das gesamte Kernmaterial zur Gaenze erreicht wurden, hat sich verdreifacht, und die Anzahl der neuen Anlagen, die der IAEA-Sicherungskontrolle unterstellt wurden, ist im gleichen Zeitraum um 60% gestiegen. Auf dem jetzt stattfindenden Symposium, dem sechsten in einer im Vierjahresrhytmus veranstalteten Reihe, wird der gegenwaertige Stand der Sicherungskontrolltechnologie in allen Bereichen ueberprueft. Folgende Themen wird erhoehtes Augenmerk gewidmet: verbesserte zerstoerungsfreie Messverfahren, neuere statistische Verfahren, um aus dem vorhandenen Datenmaterial ein Maximum an Information herauszuholen, und Sicherungskontrollmethoden fuer abgebrannte Brennstoffe, der nicht der Wiederaufbereitung und Wiederverwendung zugefuehrt, sondern langfristig gelagert wird. Ebenfalls ueberprueft wird die aus frueher besprochenen Methoden gewonnene praktische Erfahrung. (IAEA-Pressekommunique (1986) 45)

IAEA:
DIE KERNKRAFT BEDARF DER INTERNATIONALEN SOLIDARITAET UND ZUSAMMENARBEIT

-Ansprache von Dr. Hans Blix, IAEA-Generaldirektor, vor der Generalversammlung der Vereinten Nationen -

Die Kernkraft durch Kernspaltung ist eine Gegebenheit, mit der wir auch in Zukunft leben werden, denn 15% der Elektrizitaet weltweit wird aus Kernenergie erzeugt. Man kann behaupte dass mit der gravierenden Ausnahme von Tschernobyl die Gefahren der Kernenergieerzeugung fuer Gesundheit und Umwelt hypothetisch geblieben sind, waehrend der tagtaegliche Gebrauch von Kohle und Erdoel zur Stromerzeugung die schwerwiegendsten Auswirkungen auf die Umwelt hat, sagte Dr. Hans Blix; er ergaenzte: Die Kernkraft wird uns den Uebergang von der Energiegewinnung aus Erdoel zu einer anderen Energieform erleichtern, vielleicht zur Sonnenenergie oder zur Kernfusion. Aber diese neuartigen Energiequellen sind nicht sofort verfuegbar fue die hohe zusaetzliche Energieerzeugung, die die Menschen benoetigen werden, um den Lebensstanda zu heben und den Fortschrtitt voranzutreiben. Dr. Blix nannte eine Reihe von Massnehmeahmen, von der IAEA seit dem Unfall in Tschernobyl getroffen wurden, und meinte, dass alles getan werden muesse, um die Sicherheit weiter zu erhoehen, und dass das Problem der Kernsicherheit nun eine viel staerkere internationale Dimension habe als vorher. In diesem Zusammenhang sagte er: Verbindliche und einheitliche Kernsicherheitsnormen sind eine komplizierte Angelegenheit, da die Kernreaktoren von Typ zu Typ unterschiedlich sind und es auch bei den Standortbedingungen Unterschiede gibt. Trotzdem sollte ernsthaft in Betracht gezogen werden, ob nicht einige grundlegende allgemeine Sicherheitsprinzipien ausgearbeitet werden koennten und ob nicht ein hoeheres Mass an freiwilliger Annahme und Anwendung der vorhandenen, umfassenden Kernsicherheit der IAEA erreicht werden koennte. Er fuhr fort: Eine Reihe von Einrichtungen, die es in der IAEA gibt, koennten ausgebaut und verstaerkt angewendet werden, um das oeffentliche Vertrauen in die Kernsicherheit zu erhoehen. Eine dieser Einrichtungen, die verstaerkt angewendet werden koennten, sind die Gruppen zur Nachpruefung der Betriebssicherheit von Kernanlagen(OSART). Der Besuch einer solchen Gruppe wird von den Staaten je nach Bedarf angefordert. Immer mehr Behoerden, Regierungen und Eigentuemer von Kernkraftanlagen erachten es als nuetzlich, die Meinung einer hochqualifizierten, internationalen Expertengruppe ueber die Betriebssicherheit ihrer Kernanlagen einzuholen. Das IAEA-Sicherungskontrollsystem beschrieb Dr. Blix zusammenfassend als einzigartige Erfahrung in der internationalen Pruefung an Ort und Stelle, die als Modell fuer die Gestaltung von Ueberpreufungsmethoden in kuenftigen Ruestungskontrollabkommen dienen koennte. 1985 wurden ungefaehr 2.000 Kontrollen in ueber 500 Kernanlagen durchgefuehrt. Wie in den vergangenen Jahren wurde keine Anomalie entdeckt, die auf die Abzweigung von der Sicherungskontrolle unterstehendem Kernmaterial fuer militaerische Zwecke hindeuten koennte, berichtete er. Abschliessend stellte der IAEA-Generaldirektor fest, dass internationale Organisationen auch weiterhin eine unerlaessliche Rolle in unserer turbulenten Welt innehaben, trotz der Kritik, die sich gegen die Vereinten Nationen und ihr System von Organisationen richtet. Er fuegte hinzu: Im Zeitalter der EDV, der Weltraum- und Kerntechnologie ist die Zusammenarbeit der Staaten eine unbedingte Notwendigkeit, um die Gefahren der modernen Technik zu verringern. Insbesondere ist diese Zusammenarbeit notwendig, um die Bedrohung eines Einsatzes von Kernwaffen abzuwenden. Die internationale Gemeinschaft muss ihre Anstrengungen zur Durchsetzung der Nichtweiterverbreitung von Kernwaffen, zur Beendigung des nuklearen Wettruestens und zur Erreichung der Abruestung verstaerken. Die bemerkenswerte internationale Solidaritaet und Zusammenarbeit, die sich nach dem Unfall in Tschernobyl gezeigt hat, ist ein Beispiel dafuer, wie eng die Welt zusammenruecken kann, in dem Bestreben, die Technik zum Wohle der Menschheit sicher einzusetzen. (IAEA-Kommunique (1986) 46)

IAEA:

TSCHERNOBYL - DAS SYMBOL EINER NEUEN OFFENHEIT

- Ansprache von Dr. Hans Blix, Generaldirektor der IAEA vor einer Gemeinsamen AIF/ANS Vollversammlung in Washington, am 18. November 1986-

Dr. Hans Blix, Generaldirektor der IAEA, appellierte an die nukleare Gemeinschaft, soviele Daten und Fakten und verantwortungsbewusste Ueberpruefung und auch soviele konstruktive Massnahmen wie moeglich beizutragen, und sicherzustellen, dass die Folgen eines nuklearen Unfalls, sollte es dazu kommen, begrenzt und praktisch ohne radioaktiven Austritt in die Umwelt blieben. Er machte diesen Apell vor der Vollversammlung einer Gemeinsamen Wintertagung des Atomindustrieforums (AIF) der USA und der Amerikanischen Kernenergiegesellschaft (ANS) in Washington. Er sagte: Fortgesetzte Bemuehungen zur Verbesserung der Kernsicherheit bedeuten nicht, dass der gegenwaertige Stand der Sicherheit schlecht sei. Die Sicherheit - in der Kernkraft, in der Luftfahrt oder in welcher Industrie auch immer - ist in staendiger Entwicklung begriffen. Auch wuerde die Behauptung, dass es in den Reaktoren der westlichen Welt zu keinem schwerwiegenden Unfall kommen koenne, nicht viel bringen. Alle Formen der Energieerzeugung - Kernenergie, Wasserkraft, Erdoel, Kohle oder Erdgas - bergen Unfallgefahren in sich. Eine offen gezeigte Bereitschaft, aus allen Unfaellen Lehren zu ziehen, ist bei weitem konstruktiver, und dazu geeignet, Vertrauen in der Oeffentlichkeit zu wecken. Diese Offenheit und Bereitschaft war auf der im vergangenen August in Wien abgehaltenen IAEA-Tagung zur Ueberpruefung des Unfallhergangs in Tschernobyl zu spueren. Dr. Blix sagte: Tschernobyl war eine traumatische Erfahrung, nicht nur fuer die Sowjetunion, sondern auch fuer Europa und die ganze Welt. Es ist ein Merkmal unserer Zeit, dass durch den raschen Informationsaustausch und die Massenkommunikationsmittel auch die traumatischen Ereignisse weltweit uebermittelt werden. Aber Tschernobyl ist auch zu einem Symbol einer neuen Offenheit von seiten der Sowjetunion geworden, einer Bereitschaft von seiten der betroffenen Regierungen sich an internationale Institutionen zu wenden und einer internationalen Solidaritaet, die die Staaten in gemeinsamen Anstrengungen zusammenfuehrt. Bezugnehmend auf den Ruf nach der Errichtung eines "internationalen Kernsicherheitssystems" um einen hoechstmoeglichen Sicherheitsstandard weltweit zu garantieren, sagte Dr. Blix, dass eine Reihe von Einrichtungen und Mechanismen, die den Regierungen in der IAEA zur Verfuegung stehen, ausgebaut und verstaerkt angewendet werden koennten. Dazu zaehlen das Kernsicherheitsnormenprogramm (NUSS), das Meldesystem fuer Betriebsstoerungen (IRS) und die Gruppen zur Nachpruefung der Betriebssicherheit (OSART). Er stellte fest, dass ein sprunghafter Anstieg in der Nachfrage nach den Diensten dieser Gruppe zu verzeichnen sei. Es sind dies internationale Expertenteams bestehend aus 12-15 Kernsicherheitsexperten zur Pruefung der Betriebssicherheit von Kernanlagen auf Ansuchen einer staatlichen Behoerde. Der IAEA Generaldirektor kam dann auf die Bedeutung der nuklearen Abfallbeseitigung zu sprechen und erinnerte daran, dass vor Tschernobyl die Besorgnis der Oeffentlichkeit diesbezueglich staerker war als in Fragen der Kernsicherheit. Diese Besorgnis, so sagte er, steht in seltsamem Widerspruch zu der festen und wachsenden Uebereinstimmung zwischen Wissenschaftlern und Technikern, dass wir bereits ueber Technologien zur Sicheren Endlagerung des nuklearen Abfalls verfuegen, und dass kein grosser Durchbruch in der Technik mehr noetig ist. Um die Oeffentlichkeit davon zu ueberzeugen ist es unerlaesslich, mit verbranntem Brennstoff und Abfall immer und ueberall aeusserst sorgfaeltig umzugehen und geeignete Installationen zu planen und bauen. Das ist die Aufgabe von Industrieeinrichtungen und staatlichen Behoerden. Daran muss verstaerkt gearbeitet werden. (IAEA-Pressekommunique (1986) 48)

IAEA: KONVENTION UEBER FRUEHWARNUNG TRAT IN KRAFT

Die Konvention ueber Fruehwarnung bei einem Nuklearunfall, die am 26. September im Kongresszentrum der Hofburg in Wien zur Unterzeichnung aufgelegt wurde, trat am 27.10.1986 in Kraft. Die Konvention wurde bisher von insgesamt 58 Staaten unterzeichnet. Am 27.10.1986 waren es genau 30 Tage, dass drei Staaten- Daenemark, Norwegen und die Tschechoslowakei, gleichzeitig mit der Unterzeichnung am 26.9. ihre Zustimmung zur Anwendung der Konvention zum Ausdruck brachten. Andere Staaten haben sich ebenfalls bereit erklaert, die Konvention anzuwenden, und zwar auf vorlaeufiger Basis, bis die fuer diese Staaten nach Hinterlegung der Ratifikationsinstrumente, Annahme, Genehmigung oder Beitritt mit Bindungserklaerung in Kraft tritt. Fuer jeden Staat, der auf diese Weise seine Zustimmung zur Bindung kundtut, tritt die Konvention 30 Tage nach dem Zeitpunkt seiner Zustimmungserklaerung in Kraft.

Die Konvention liegt bis zum 6. Oktober 1987 in New York zur Unterzeichnung aus. 57 Staaten haben eine zweite Konvention, ueber Hilfeleistung bei Nuklearunfaellen oder in Strahlennotstandssituationen, unterzeichnet, die ebenfalls am 26.9.1986 zur Unterzeichnung aufgelegt wurde. (IAEA-Pressekommunique (1986)38)

IAEA/UdSSR: GESPRAECHE IN DER IAEA

E.A. Schewardnadse, der sowjetische Aussenminister, stattete am 3.11.1986 Dr. Hans Blix, dem Generaldirektor der IAEA am Amtssitz in Wien einen Besuch ab. Waehrend ihres Gespraeches bestaetigte Schewardnadse die Unterstuetzung der Sowjetunion fuer die IAEA in ihrer statutenmaessig verankerten Aufgabe bezueglich der Nichtweiterverbreitung von Kernwaffen und der Entwicklung der internationalen Zusammenarbeit fuer die friedliche Nutzung der Kernenergie. Er brachte auch seine Zufriedenheit mit den sehr wirkungsvollen Massnahmen zum Ausdruck, die im Rahmen der IAEA zur Verwirklichung des sowjetischen Vorschlages eines internationalen Systems fuer die sichere Entwicklung der Kernenergie getroffen werden. Dr. Blix erwaehnte mit dankender Anerkennung das Vertrauen, das die UdSSR der IAEA in den vergangenen Monaten entgegengebracht hat, indem sie durch die IAEA die aus dem Unfall in Tschernobyl gewonnenen Erfahrungen mit der Welt teilte, um so zur Erhoehung der Kernsicherheit beizutragen. Er schaetzte die Initiativen der UdSSR auf dem Gebiet der Kernsicherheit als wichtigen Beitrag zu dem erweiterten Sicherheitsprogramm der IAEA aeusserst hoch ein. (IAEA-Pressekommunique (1986)42)

IAEA: DIE ZUKUNFT DER KERNENERGIE

Die Kernenergie erhaelt auch weiterhin starke Unterstuetzung als bewaehrte Technologie und Energiequelle, sagte Dr. Hans Blix, Generaldirektor der IAEA am 31.10.1986 in Tokio auf einer Sondertagung zur Feier des 30. Jahrestags der Entwicklung der Atomenergie in Japan. Er stellte fest, dass bei der Diskussion ueber die Zukunft der Kernkraft der Unfall Tschernobyl, die Reaktionen darauf, und die Moeglichkeiten zur Erhoehung der Sicherheit der Kernkraft in der Zukunft miteinbezogen werden muessten. Von der Regierungen aller Staaten, die die Kernkraft nutzen, sei anzunehmen, dass sie ihre Vorschriften und Kontrollen der Kernkraftanlagen ueberpruefen werden, um sicher zu gehen, dass ein hoher Sicherheitsstandard gewaehrleistet ist. Darueberhinaus wuerden Regierungen auf internationaler Basis zusammenarbeiten wollen, um einander gegenseitig dabei zu helfen, aus den gemachten Erfahrungen zu lernen. Ein erweitertes Kernsicherheitsprogramm der IAEA koennte ein wichtiges Hilfsmittel zur Verwirklichung dieses Vorhabens sein. Dr. Blix nannte als einen Bereich, in dem sich die internationale Zusammenarbeit hoechstwahrscheinlich verstaerken werde, die vom Betriebspersonal der Kernkraftwerke geforderten Qualifikationen. "Der Vorschlag wurde gemacht, dass wir die Zweckmaessigkeit der Erstellung internationaler Normen fuer Ausbildungsprogramme der Reaktorfahrer pruefen sollten", sagte er. "Dieser Vorschlag ist darauf zurueckzufuehren, dass sowohl der Three-Mile-Island-Unfall als auch der Unfall in Tschernobyl durch Fehlverhalten des Betriebspersonals verursacht wurden". Er hielt fest, dass die IAEA die Abhaltung einer Konferenz ueber Erfahrungen in der Beziehung Mensch-Maschine, im Jahre 1988 in Japan plane. Das, so sagte er, sei "voellig berechtigt" im Hinblick auf Japans staendige Verbesserungen in der Leistung von Kernkraftwerken seit 1980. Man muesse Japan zu den jetzt erzielten ausgezeichneten Ergebnissen begluecKwuenschen. (IARA-Pressekommunique (1986)40)

Nuclear Energy:

JAPAN MARKS 30 YEARS OF PEACEFUL NUCLEAR DEVELOPMENT

Japan has passed the 30-year mark in its peaceful development of nuclear energy. In a speech in Tokyo on 31 October to help mark the occasion, IAEA Director General Hans Blix commended Japan for its achievements and long-standing support of international co-operation in the field. Dr. Blix was the guest of the Japanese Atomic Energy Commission (AEC). He specifically cited Japan's "excellent results" in improving the operating performance of its nuclear power plants since 1980 and the importance the Gouvernment places on safety. The country has 32 nuclear power plants in commercial operation that together supply about 26% of the electricity, and about 8% of the total energy. (A full report on nuclear power development in Japan will appear in the next edition of the IAEA Bulletin, Vol. 28, No 4). (IAEA-Newsbriefs 1(1986)3)

Detektoren:

URANBLECH FUER DAS CERN-KALORIMETER

Die franzoesische Unternehmung Compagnie pour l'Etude de la Realisation de Combustibles Atomiques (CERCA) begann in October 1986 mit der Produktion von gewalztem Blech aus 100 t abgereicherten Uran. Das Blech wird im Kalorimeter Verwendung finden, das gegenwaertig fuer das UA 1 Experiment im Europaeischen Nuklearforschungscentrum CERN gebaut wird. Das Uranblech soll schichtweise zu einem runden Schild in Form eines mehrere Meter langen Zylinders zusammengebaut werden. Das Kalorimeter dient der Detektion von Partikelemissionen, die beim Aufprall von Elektronen und Protonen hoher Energie entstehen. Die Wechselwirkung dieser Partikel mit den Strukturmaterialien erzeugt unter anderem typische elektrische Signale, die dann aufgezeichnet und analysiert werden. Da der Raum fuer die zu messenden Wechselwirkungen beschraenkt ist, waehlte das CERN als Material mit hoher Dichte Uran. CERCA verfuegt ueber lange Erfahrung in der Bearbeitung von abgereichertem Uran und propagiert dessen Einsatz in unterschiedlichsten Bereichen wie Segelschiff-Kiele oder Container fuer radioaktive Abfaelle. (SVA-Bulletin (1986) 20)

Isotopentrennung:

Japan - INDUSTRIE WILL CHANCEN DER LASER-ANREICHERUNG UNTERSUCHEN

Trotz einer Erklaerung des japanischen Ministers fuer Wissenschaft und Technologie vom Juni 1985, wonach Japan am Aufbau einer eigenen U-Anreicherungs-Industrie auf der Basis von Gaszentrifugen festhalten werde, hatte die Federation of Electric Power Companies (FEPC) zur gleichen Zeit verlauten lassen, dass die Technik der U-Anreicherung mittels Laserstrahlen fuer eine kommerzielle Anlage in Rokkashomura in Frage kommen koenne. Nunmehr sind dieser Verlautbarung konkrete Schritte gefolgt. Die neun in der FEPC zusammengeschlossenen Elektrizitaetsunternehmen Japans, die Japan Atomic Power Company, das zentrale Forschungsinstitut der Elektrizitaetswirtschaft und die japanische Nuklearbrennstoff-Firma JNFI haben beschlossen, ab 1. Januar 1987 eine Forschungsgemeinschaft fuer U-Anreicherung mit Laserstrahlen einzusetzen. Waehrend einer in drei Phasen unterteilten Untersuchungsperiode sollen bis 1990 alle technischen und wirtschaftlichen Kenntnisse und Daten erarbeitet werden, die erforderlich sind, um die Wettbewerbsfaehigkeit der U-Anreicherung mittels Laserisotopentrennung von U im elementaren, gasfoermigen Zustand (Avlis-Prozess) beurteilen zu koennen. Die kurzen Fristen von jeweils nur einem Jahr sind angesetzt fuer drei aufeinander folgende Phasen, naemlich experimentelle Grundlagenversuche, Entwicklung und Bau einer Trennkammer sowie Betriebe einer integralen Versuchsanlage mit einer Kapazitaet von 1000 bis 5000

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The scattered component of flux in gamma-irradiated heterogeneous media - A.I. Kirdin; V.T. Lazurik of which are rather well known, e.g. the Hawaiian volcanites and the rocks of the Skaergaard intrusion, East Greenland. In these cases equation (1) can be used for determining distribution coefficients D_i.

MacDonald [17] has estimated the amounts of original olivine basalt liquid which must have crystallized to yield the Hawaiian andesine andesite, oligoclase andesite and soda trachyte, as 64, 70 and 86%, respectively. Using these data, *MacDonald*'s major constituent concentrations [17] and trace element concentrations given by *Wager* and *Mitchell* [33], we have estimated the distribution coefficients D_{exp} between basalts, andesine andesite, oligoclase and andesite on one hand and the magmas they have crystallized from the other hand.

Tab. 2 gives the arithmetic mean values $\overline{D}_{\text{exp}}$ for the single chemical elements in the first column. Further $\Delta I = I_l - I_s$ for the solid/liquid systems have been calculated by means of equation (3) as a basis for evaluating D_{calc} using the k and S values in Tab. 1. The corresponding mean values $\overline{D}_{\text{calc}}$ are given in the second column of Tab. 2. Apart from Sr, Ni and Mn there is a rather good, in the case of Mg, Fe, K, Ba, La, Co and Ca even remarkably good agreement between distribution evaluated on the two independent ways and on the basis of completely different experimental data. This endorses the chemical composition of the Hawaiian volcanic rock series to be ruled by fractional crystallization, but also the validity of equation (2) together with the described model for calculating the k and S values given in Tab. 1.

Element concentration correlations would not reveal insights beyond the results given in Tab. 2 with respect to distribution coefficients. On the other hand the initial concentrations C_i^0 can be calculated as weighted arithmetic mean values C_i and used for estimating q in equation (5). Tab. 3 shows the results obtained for three $\lg c_1 - \lg c_2$ correlations with a correlation coefficient $|r| \geqq 0{\cdot}70$ and reveals a good agreement between q_{exp} and q_{calc} as further evidence of the validity of the existing assumptions about the genesis of the Hawaiian volcanic suite.

Tab. 2. Distribution coefficients for Hawaiian volcanic rocks and their parent magmas calculated from equation (1) ($\overline{D}_{\text{exp}}$) in comparison with those calculated on the basis of equation (2) ($\overline{D}_{\text{calc}}$)

element	$\overline{D}_{\text{exp}}$	$\overline{D}_{\text{calc}}$
Li	0·482	0·661
Na	0·676	0·887
K	0·446	0·372
Rb	0·229	0·421
Mg	2·25	1·98
Ca	2·02	1·82
Sr	1·75	1·14
Ba	0·678	0·602
Ti	1·94	1·47
Mn	1·08	1·42
Fe	1·52	1·53
Co	2·37	1·91
Ni	1·25	1·94
Y	0·509	0·866
La	0·662	0·512

Tab. 3. Intersection with the ordinate q of $\lg c_1 - \lg c_2$ correlation lines as determined by linear regression of element concentrations c_1 and c_2 (index "exp") in the ten volcanic rocks of the Hawaiian suite in comparison with those calculated from distribution coefficients as derived from equation (2) and Tab. 1 (index "calc"). ΔI has been calculated by equation (3) to be 0·043. All concentrations of Na, K, Mg, Ca, Fe, Mn and Ti in this paper are given in weight % of their oxides (Fe as FeO), all other concentrations in ppm. $\left(\text{For calculating } q_{\text{calc}} \text{ by equation (7) } m_{\text{exp}} \text{ has been used instead of } \frac{D_1 - 1}{D_2 - 1}.\right)$

element pair 1–2	c_1	c_2	m_{exp}	q_{exp}	r	q_{calc}
Mg–Ca	7·94	7·43	1·28	−0·304	+0·85	−0·259
Ca–Ti	7·43	2·48	0·924	+0·505	+0·92	+0·637
Na–K	3·56	1·50	−0·453	+0·499	−0·90	+0·450

2.2. *Magmatic bodies with unknown quantitative proportions of crystallization products*

A number of further magmatic bodies has been investigated in terms of element concentration correlations according to equations (5), (13), (14) and (16), where informations about the quantitative proportions of solidification products and other genetic characteristics are lacking. As far as granitic rocks are concerned, experimental data of *Eidam* and *Seim* [18] on the granites of the Ramberg massif in the Harz mountains, G.D.R., of *Seim* and *Eidam* [18] on the granites of the Brocken massif in the Harz mountains, of *Tischendorf* et al. [19] on the intrusive granites of the Western Ore mountains, G.D.R., of *Johanning* [20] on the Bärhalde granite in the Southern Schwarzwald, F.R.G., of *Richter* and *Stettner* [21] on the granites of the Fichtelgebirge, F.R.G. and of *Madel* [22] on the Leuchtenburg granite of the Oberpfalz, F.R.G., were used. All correlation with $|r| \geqq 0{\cdot}70$ that we have found within the framework of these investigations are listed in Tab. 4.

For lack of better knowledge about the initial concentrations C_1^0 and C_2^0 the simple arithmetic mean values are applied for calculating q_{calc} by equation (7).

Tab. 4 reveals a rather good agreement between m_{exp} and m_{calc} on one hand and between q_{exp} and q_{calc} on the other hand with the exception of the granites of the Western Ore Mountains. This indicates that the gradation of the concentrations of the investigated elements in these rocks is not mainly ruled by fractional crystallization. This is in agreement with the hypothesis of *Gerstenberger* et al. [23] that the differences in the chemical compositions of the younger and the older granites of the Western Ore Mountains are due to a different degree of assimilation of adjacent rocks. The large discrepancy between m_{exp} and m_{calc} in the case of Be-Ca in the granites of Brocken massif is probably due to the high fraction of the $S \cdot \Delta I$-term in the sum $k + S \cdot \Delta I$ ($k = 0{\cdot}321$, $S = -11{\cdot}4$) which gives rise to large changes of the distribution coefficient even at small variations in the chemical composition of the magma.

As far as basaltic and intermediary rocks are concerned geochemical data of *Taylor* et al. [24] in low Si of andesites of Mt. Bagana and on andesites of the closeby Billy Mitchell volcano, Central Bougainville, New Guinea, of *Rea* [25] in andesitic and basaltic rocks of Montserrat, Lesser Antilles, of *Baker* [26] in intermediary and basaltic volcanic rocks of Saint Helena Island, South Atlantic, of *Nockolds* and *Allen* [27] in 15 British Tertiary tholeiitic rocks and of *MacDonald* [17] on the principal rock types of the Hawaiian petrographic province were used. All correlations with $|r| \geqq 0{\cdot}70$ in these rocks are listed in Tab. 5 which reveals a good agreement between m_{exp} and m_{calc}. This is evidence of fractional crystallization without considerable wallrock assimilation as the process ruling concentrations patterns in these rocks on one hand and of the validity of equation (5) for calculating whole rock distribution coefficients for basaltic and intermediary rocks and their parental magmas.

Tab. 4. Comparison of m_{exp} and q_{exp} as derived from element concentration correlations according to equations (5) or (16) with m_{calc} and q_{calc} as calculated using equation (2), the k and S values of Tab. 1, the ΔI values given in the first column and the simple arithmetic mean values $\bar{c}_1$ and $\bar{c}_2$ of n samples given in the third and the fourth column for a number of granites. Other symbols are the same as in Tab. 3.

rock or rock series	1 – 2	$\bar{c}_1$	$\bar{c}_2$	m_{exp}	q_{exp}	r	m_{calc}	q_{calc}
granites of the Ramberg massif ($n = 52$; $\Delta I = 0$)	Mg – Ca	0·145	0·471	1·14	–0·514	0·79	1·04	–0·491
granites of the Brocken massif ($n = 12$; $\Delta I = 0$)	Ca – Ti	0·57	0·15	2·11	1·52	0·82	6·07	1·63
	K – Ca	4·30	0·57	–0·0534	0·629	–0·82	–0·610	0·394
	Ca – Fe	0·57	1·39	2·95	–0·700	0·70	2·36	–0·767
	Be – Ca	4·2	0·57	–0·976	0·609	0·97	1·58	0·929
granites of Bärhalde ($n = 89$; $\Delta I = 0$)	K – Ca	5·01	0·322	–0·727	0·323	–0·80	–0·610	0·270
granites of the Western Ore Mountains ($n = 89$; $\Delta I = 0$)	Mg – Ca	0·299	0·652	1·43	–0·291	0·98	1·04	–0·351
	Ti – Mn	0·183	0·026	1·59	1·74	0·74	1·14	1·76
	Mg – Ti	0·299	0·183	0.933	0·149	0·93	6·30	0·355
	Ti – Fe	0·183	1·165	1·32	–0·861	0·82	0·393	–0·924
	Ca – Ti	0·652	0·183	0·617	0·278	0·89	5·69	0·458
	Mn – Fe	0·026	1·165	0·578	–1·62	0·77	0·345	–1·64
	Mg – Mn	0·299	0·026	1·62	1·98	0·75	7·18	2·21
	Mn – Ca	0·026	0·652	0·517	–1·48	0·76	0·154	–1·55
granites of the Fichtelgebirge ($n > 100$; $\Delta I = 0$)	Cs – Ba	27	402	–0·390	2·20	–0·83	+0·167	2·48
	Ba – Rb	402	394	–3·12	10·3	–0·91	–0·397	10·2
	K/Rb – Ca/Sr	– *)	– *)	–0·590	3·26	–0·86	+0·368	– *)
Leuchtenberg granites of Oberpfalz ($n = 45$; $\Delta I = 0$)	Rb – Ca	242	1·26	–0·367	–1·19	–0·79	–0·508	–1·25
	Sr – Ca	173	1·26	1·30	–7·95	0·80	1·270	–8·03
	Rb – Sr	242	173	–0·234	2·86	–0·84	–0·600	2·77

*) $\bar{c}_i$ and q_{calc} cannot be calculated, because only quotients of concentrations are specified. (Sources of experimental data see text.)

Tab. 5. Comparison of m_{exp} as derived from element concentration correlations according in equation (5) with m_{calc} as calculated using equation (2), the k and S values of Tab. 1 and the ΔI values given in the first column for a number of basaltic and intermediary rocks. (Sources experimental data see text.)

	1 – 2	r	m_{exp}	m_{calc}
andesites of Mt. Bagana and Billy Mitchell, Central Bougainville, New Guinea ($\Delta I = 0·065$)	Mg – Ca	0·75	1·28	1·21
	K – Ca	–0·94	–0·529	–0·796
	K – Rb	0·91	0·517	1·10
	Mn – Fe	0·75	0·427	0·815
	Mn – Cu	0·76	0·201	0·557
	Rb – Ca	–0·92	–1·08	–0·719
andesitic and basaltic rocks of Montserrat, Lesser Antilles ($\Delta I = 0·0324$)	Mg – Ca	0·84	1·65	1·20
	Mg – Fe	0·88	1·68	1·83
	Ti – Fe	0·83	1·58	0·911
	Ca – Fe	0·81	0·775	1·52
	K – Ca	–0·79	–1·23	–0·798
	Rb – Ba	0·78	1·15	1·38
	Rb – Cu	–0·89	–1·03	–0·748
	Rb – Co	–0·70	–0·885	–0·659
	Rb – V	–0·87	–0·925	–0·983
	Rb – Li	0·95	1·92	1·69
	Ba – Cu	–0·75	–0·571	–0·541
	Ba – V	–0·85	–0·622	–0·711
	Ba – Li	0·95	1·32	1·22
	Sr – Cu	0·70	0·164	0·134
	Sr – Co	0·73	0·154	0·118
	Cu – Co	0·77	0·651	0·880
	Cu – V	0·85	0·822	1·31
	Cu – Li	–0·89	–1·55	–2·26
	Co – V	0·77	0·827	1·49
	Co – Li	–0·81	–1·27	–2·57
	V – Li	–0·92	–1·63	–1·72
intermediary and basaltic rocks of Saint Helena Island, South Atlantic ($\Delta I = 0·065$)	Mg – Ca	0·97	1·99	1·20
	Na – K	0·97	0·663	0·206
	Ti – Fe	0·97	3·28	0·911
	Ca – Ti	0·96	1·75	1·67
	K – Rb	0·92	0·613	1·10
	Mg – Fe	0·92	3·52	1·83
	Ca – Fe	0·94	1·75	1·52
	Na – Fe	–0·72	–0·695	–0·250
	K – Fe	–0·81	–1·14	–1·21
	Rb – Mg	–0·98	–0·448	–0·599
	Rb – Ca	–0·96	–0·952	–0·719
	Na – Rb	0·93	0·367	0·228
	Mg – Ti	0·95	1·08	2·02
	Ti – Rb	–0·97	–2·07	–0·826
	Na – Ti	–0·78	–0·221	–0·276
	Rb – Fe	–0·92	–1·66	–1·10
	K – Ti	–0·85	–0·353	–2·18
	Mg – K	–0·92	–2·50	–1·53
	K – Ca	–0·93	–1·23	–0·798
	Mg – Na	–0·87	–3·47	–1·33
	Ca – Na	–0·88	–1·71	–6·07
British tertiary tholeiitic rocks ($\Delta I = 0·091$)	Mg – Ca	0·85	0·930	1·27
	K – Fe	–0·76	–1·19	–1·10
	Ca – Ti	0·78	1·11	1·30
	Mg – Fe	0·79	1·45	1·71
	Mg – K	–0·76	–0·909	0·534
	Ca – Fe	0·91	1·54	1·35
	Ti – Fe	0·87	1·02	1·01
	K – Ca	–0·90	–0·827	–0·817
	Ca – Na	–0·73	–2·62	–3·41
	Na – K	0·76	0·229	0·358
rocks of the Hawaiian petrographic province ($\Delta I = 0·091$)	Na – K	0·90	0·577	0·518
	Mg – Ca	0·89	1·36	1·27
	Ca – Ti	0·92	1·12	0·501
	Mg – Fe	0·92	2·65	1·71
	Mg – K	–0·80	–1·10	–1·55
	Ca – Fe	0·98	1·84	1·35
	Ti – Fe	0·92	1·42	1·04
	Mg – Na	–0·74	–1·57	–4·32
	Mg – Ti	0·74	1·38	1·64

3. Application to global Clarke values of different types of igneous rocks

3.1. Granitic rocks

The global *Clarke* values of Na, K, Mg, Ca, Fe, Ti and Mn in 10 different granitic rocks (alkali granite, alkali rhyolite, granite, rhyolite, quartz monzonite, quartz latite, granodiorite, rhyodazite, quartz diorite and dacite) as specified in *Wedepohl*'s Handbook of Geochemistry [28] are used to reveal $\lg c_1 - \lg c_2$ *correlation with correlation coefficients* $|r| \geqq 0{\cdot}70$. Among $\frac{1}{2}(7 \cdot 7 - 7) = 17$ such element pairs there are only 7 with $|r| < 0{\cdot}70$: Na–Ti, Ca–Na, K–Ti, Na–K, Na–Fe, Na–Mn and Mg–Na. All the other pairs are specified in Tab. 6. Beside mean concentrations $\overline{C}_1$ and $\overline{C}_2$ initial concentrations C_1^0 and C_2^0 are given, as derived from the model described above [29]. Intersections with the ordinate calculated from C_i are denoted with $\overline{q}_{\text{calc}}$, those derived from C_i^0 with q_{calc}:

$$\overline{q}_{\text{calc}} = \lg D_1\overline{C}_1 - m_{\text{exp}} \lg D_2\overline{C}_2$$

$$q^0_{\text{calc}} = \lg D_1 C_1^0 - \frac{D_1 - 1}{D_2 - 1} \lg D_2 C_2^0 \, .$$

As for the other symbols see Tab. 3. The distribution coefficients are calculated by equation (2) using $\Delta I = 0{\cdot}0097$ which is the weighted mean of 19·6% granites and quartz monzonites (2:1), 15·6% granodiorite and 3·8% quartz *diorite, the fractions of these granitic rocks in the continental crust* [29]: ΔI granotoids

$$= \frac{1}{19{\cdot}6 + 15{\cdot}6 + 3{\cdot}8} [19{\cdot}6 \Delta I_{\text{granites}} + 15{\cdot}6 \Delta I_{\text{granodiorites}} + 3{\cdot}8 \Delta I_{\text{quartz diorites}}]$$

$$= \frac{1}{19{\cdot}6 + 15{\cdot}6 + 3{\cdot}8} [19{\cdot}6 \cdot 0 + 15{\cdot}6 \cdot 0{\cdot}019 + 3{\cdot}8 \times 0{\cdot}0215] = 0{\cdot}0097 \, .$$

As Tab. 6 shows, there is commonly good agreement between m_{exp} and m_{calc} on one hand and between q_{exp} and q_{calc} on the other hand except in the case of Ca–Ti, Ti–Fe, K–Mn, Mg–Mn and Mg–Ti. The reason becomes clear, if we face the concerning chemical elements. All pairs with $|r| < 0{\cdot}70$ or with large discrepancies between m_{exp} and m_{calc} are pairs with either Na, Ti or Mn or with two of them. As equation (2) shows, just these elements show distribution coefficients only slightly deviating from unity in granitic rocks ($D_{\text{Mn}} = 1{\cdot}15$, $D_{\text{Ti}} = 1{\cdot}16$ and $D_{\text{Na}} = 1{\cdot}20$), thus being distinguished by only a small gradation of their concentrations in the single granitic rock types. (Therefore these elements have not been included into our recommendations for the use of element concentration correlations for investigating fractional crystallization of granitic magmas.)

In order to include these elements into the evaluation *of fractional crystallization in the genesis of granitic rocks* some $\lg c_1/c_2 - \lg c_3/c_4$ correlations have been investigated. Tab. 7 shows a rather good agreement between m_{exp} and q_{exp} on one hand and m_{calc} calculated one the basis of equations (2) and (16).

Thus we can conclude that the global concentrations of such elements like K, Fe, Ca and Mg, but which some restriction also Na, Ti and Mn in granitic rocks, are mainly ruled by fractional crystallization.

3.2. Intermediary rocks

The global Clarke values of Na, K, Mg, Ca, Fe, Ti and Mn in 10 different intermediary rocks (alkali syenite, alkali trachyte, syenite, trachyte, monzonite, latite, monzodiorite, latite andesite, diorite, andesite), as specified in *Wedepohl*'s Handbook of Geochemistry [28] are used to reveal $\lg c_1 - \lg c_2$ correlations with correlation coefficients $|r| \geqq 0{\cdot}70$. The results are summarized in Tab. 8. Beside mean concentrations $\overline{C}_1$ and $\overline{C}_2$ initial concentrations C_1^0 and C_2^0 are given in terms of the above described model

Tab. 6. Comparison of m_{exp} and q_{exp} as derived from global *Clarke* values of granitic rocks with m_{calc} and q_{calc} calculated by equations (6) and (7)

$M_1 - M_2$	$\overline{c}_1$	$\overline{c}_2$	c_1^0	c_2^0	q_{exp}	$\overline{q}_{\text{calc}}$	q^0_{calc}	m_{exp}	m_{calc}	r
Ti–Mn	0·443	0·064	0·506	0·066	1·045	1·063	1·039	1·19	1·13	0·77
Ca–Fe	2·581	3·237	2·73	3·35	−0·667	−0·629	−0·737	2·01	2·17	0·96
Mn–Fe	0·064	3·237	0·066	3·35	−1·58	−1·60	−1·41	0·729	0·442	0·87
Ca–Ti	2·581	0·443	2·73	0·506	0·878	1·05	1·67	1·42	4·35	0·96
Mg–Ca	1·003	2·581	1·158	2·73	−0·535	−0·562	−0·402	1·25	1·06	0·98
Ti–Fe	0·443	3·237	0·506	3·35	−1·01	−1·10	−0·554	1·29	0·500	0·93
Mg–K	1·003	3·87	1·158	3·965	0·625	0·697	0·836	−1·43	−1·62	−0·75
K–Ca	3·87	2·581	3·965	2·73	0·710	0·660	0·764	−0·549	−0·654	−0·81
K–Fe	3·87	3·237	3·965	3·35	1·11	1·10	1·27	−1·20	−1·42	−0·85
Mg–Fe	1·003	3·237	1·158	3·35	−1·30	−1·31	−1·18	2·44	2·30	0·91
K–Mn	3·87	0·064	3·965	0·066	−0·970	−1·08	−3·27	−1·23	−3·27	0·81
Mg–Mn	1·003	0·064	1·158	0·066	2·53	2·72	6·17	2·18	5·21	0·75
Mn–Ca	0·064	2·581	0·066	2·73	−1·33	−1·35	−1·26	0·338	0·203	0·77
Mn–Ti	1·003	0·443	1·158	0·506	0·577	0·769	1·37	1·82	4·61	0·97

Tab. 7. Some $\lg c_1/c_2 - \lg c_3/c_4$ correlations including global *Clarke* values of Mn, Ti and Na in granitic rocks

$c_1/c_2 - c_3/c_4$	$\overline{c}_1$	$\overline{c}_2$	$\overline{c}_3$	$\overline{c}_4$	q_{exp}	$\overline{q}_{\text{calc}}$	m_{exp}	m_{calc}	r
Mn/K–Na/Mg	0·064	3·87	3·66	1·003	−1·31	−1·02	−0·626	−1·14	−0·74
Ti/Ca–Na/K	0·443	2·581	3·66	3·87	−0·700	−0·787	−0·447	−0·849	−0·86
Ti/K–Fe/K	0·443	3·87	3·237	3·87	−0·872	−0·943	1·07	0·748	0·97
Na/Mg–Fe/K	3·66	1·003	3·237	3·87	0·652	0·678	−0·890	−0·645	−0·80
Mn/Ca–Fe/K	0·064	2·581	3·237	3·87	−1·55	−1·63	−0·470	−0·833	−0·73
Mn/Mg–Ti/K	0·064	1·003	0·443	3·87	−1·69	−1·78	−0·669	−1·16	−0·83

Tab. 8. Comparison of m_{exp} and q_{exp} as derived from global *Clarke* values of intermediary rocks with m_{calc} and q_{calc} calculated by equations (6) and (7)

$M_1 - M_2$	$\bar{c}_1$	$\bar{c}_2$	c_1^0	c_2^0	q_{exp}	$\bar{q}_{\text{calc}}$	q_{calc}^0	m_{exp}	m_{calc}	r
Ca – Ti	5·64	1·03	5·82	0·699	0·718	0·736	0·977	1·38	1·53	0·88
Mg – Ca	3·10	5·64	4·16	5·82	–0·578	–0·624	–0·336	1·40	1·23	0·99
Ca – Na	5·64	4·10	5·82	2·835	2·00	2·15	2·74	–2·15	–4·67	–0·94
Ca – Fe	5·64	6·59	5·82	6·86	–0·414	–0·469	–0·419	1·41	1·45	0·93
Ti – Fe	1·03	6·59	0·699	6·86	–0·709	–0·691	–0·947	0·879	0·948	0·91
Mg – Na	3·10	4·10	4·16	2·835	2·24	2·40	3·02	–3·04	–5·72	–0·95
K – Ca	4·23	5·64	2·44	5·82	1·19	1·04	0·726	–0·896	–0·807	–0·70
Na – Fe	4·10	6·59	2·835	6·86	1·01	1·05	0·687	–0·512	–0·310	–0·77
K – Fe	4·23	6·59	2·44	6·86	1·85	1·79	1·11	–1·63	–1·17	–0·83
Mg – Fe	3·10	6·59	4·16	6·86	–1·15	–1·19	–0·915	1·95	1·78	0·92
Na – Ti	4·10	1·03	2·835	0·699	0·598	0·629	0·378	–0·503	–0·327	–0·73
K – Ti	4·23	1·03	2·44	0·699	0·542	0·471	–0·062	–1·66	–1·23	–0·81
Mg – Ti	3·10	1·03	4·16	0·699	0·425	0·409	0·904	1·92	0·665	0·87

[29]. The distribution coefficients are calculated by equation (2) using $\Delta I = 0{\cdot}074$ like for diorites.

As Tab. 8 shows there is an excellent agreement between theory and experiment except in the case of element pairs with Na. This is just the only element in the series investigated here the distribution coefficient of which in intermediary rocks deviates only slightly unity ($D = 0{\cdot}820$).

Thus we can conclude that the global concentrations at least of K, Mg, Ca, Fe and Ti in intermediary igneous rocks is mainly ruled by fractional crystallization.

3.3. *Some elements in some other types of igneous rocks*

Rader et al. [30] have investigated the correlation between the concentrations of Zn and Fe in 157 basalts. The $\lg c_{\text{Zn}} - \lg c_{\text{Fe}}$ line has been found to have a slope of $m_{\text{exp}} = 0{\cdot}582$, while m_{calc} from equations (2) and (6) with $\Delta I = 0{\cdot}091$ is equal to $0{\cdot}750$. The correlation coefficient $r = 0{\cdot}71$.

Abramovič and *Klushin* [31] have described a correlation between Na and Ca in volcanic rocks of the pacific ring comprising 544 rock samples. The correlation for a $\lg c_{\text{Ca}} - \lg c_{\text{Na}}$ correlation is 0·64 the slope $m_{\text{exp}} = -0{\cdot}980$ instead of $m_{\text{calc}} = \dfrac{1{\cdot}84 - 1}{0{\cdot}820 - 1} = -4{\cdot}67$. The discrepancy is probably again due to $D_{\text{Na}} \approx 1$.

Gunn [32] has found K–Rb and K–Ba correlations in 41 Antarctic and New Zealand tholeiites and alkali basalts which lead us to slopes $m_{\text{exp}} = 1{\cdot}02$ instead of $m_{\text{calc}} = 1{\cdot}09$ for K–Rb and $m_{\text{exp}} = 0{\cdot}980$ instead of $m_{\text{calc}} = 1{\cdot}27$ for K–Ba. ΔI was supposed to be 0·091.

4. Conclusions

The investigation of element concentrations in rock series which can be assumed to be genetically connected with each other is a good means of determining distribution coefficients between rocks and their parent magmas. Based on the assumption that all the gabbros, diorites, quartz diorites, granodiorites and granites present in the recent continental crust have been formed by fractional crystallization of magmas of intermediary composition in closed systems. The distribution coefficients of the alkaline and the alkaline earth elements, the elements of the first transition period and the rare earth elements can be calculated and related to *Schuetze*'s ^{18}O index describing the O^2-lattice surrounding the cations in questions [29].

These distribution coefficients are in a good agreement with those calculated from element concentrations in the Hawaiian volcanic rock suite.

If the quantitative proportions of the crystallization products are unknown, however, the investigation of element concentration correlations is a good means of evaluating fractional crystallization. But the existence of a linear relation between element concentration or their logarithms, even if distinguished by a high correlation coefficient, is only a necessary, but by far not a sufficient condition for fractional crystallization as the dominating factor of graduating element concentrations. In particular the existence and the particular form of such correlations do not give evidence of the special mechanism of fractional crystallization.

On the other hand comparison of the slope of the $\lg c_1 - \lg c_2$ correlation line with the slope calculated on the basis of the distribution coefficients evaluated by using *Schuetze*'s ^{18}O index whether fractional crystallization is dominant in graduating element concentrations in igneous rock suites. The intersection of this straight line with the ordinate on the other hand contains informations about the initial chemical composition of the magma the rock suite stems from.

The application of these criteria gives evidence that the concentrations of Na, K, Mg, Ca, Fe, Ti and Mn in the majority of intermediary and granitic rocks is ruled by fractional crystallization. (Only in the case of Mn, Ti and Na in granitic rocks and in the case of Na in intermediary rocks this gradation is often concealed by other than magmatic processes.)

The slopes of the correlation lines found for single magmatic bodies as well as for global *Clarke* values of igneous rocks of different types generally show a good agreement with the slopes calculated from distribution coefficients evaluated on the basis of *Schuetze*'s ^{18}O indices. Thus this method for evaluating distribution coefficients has found a convinsing verification by these investigations.

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Decontamination of a Radioactive Process Waste Water by Adsorbing Colloid Flotation

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As a part of a research program on the treatment of a radioactive process waste water by foam separation techniques, adsorbing colloid flotation was tested to remove ^{144}*Ce,* ^{60}*Co,* ^{65}*Zn and* ^{89}*Sr from the waste water. Potassium oleate was used as the collector, and Fe(III) hydroxide, Al(III) hydroxide or Co(II) hydroxide as the coprecipitant. Under the optimal conditions, removals exceeding 99% could be achieved for* ^{65}*Zn with any of the tested coprecipitants, for* ^{144}*Ce with Fe(III) and Co(II) hydroxides and for* ^{60}*Co with only Co(II) hydroxide. For* ^{89}*Sr removals* $>90\%$ *could be achieved with only Fe(III) hydroxide. The adsorbing colloid flotation process was compared with both chemical precipitation and ion exchange, and advantages of adsorbing colloid flotation were enumerated.*

Als Teil eines Untersuchungsprogrammes zur Behandlung von radioaktiven Abwässern durch eine Schaum-Trenntechnik wurde auch die adsorptiv-kolloidale Flotation zur Abtrennung von ^{144}*Ce,* ^{60}*Co,* ^{65}*Zn and* ^{89}*Sr getestet. Als Sammler wurde Natriumoleat verwendet und Fe(III)-hydroxide, Al(III)-hydroxide oder Co(II)-hydroxide als Mitfällungsmittel eingesetzt. Unter optimalen Bedingungen konnten Abtrennungen von mehr als 99% des* ^{65}*Zn mit einem der Mitfällungsmittel erreicht werden, für* ^{144}*Ce konnten nur mit Fe(III)- und Co(II)-hydroxiden und für* ^{60}*Co konnten nur mit Co(II)-hydroxiden solche guten Abtrennungen erzielt werden. Im Falle des* ^{89}*Sr lagen die Abtrennungen von mehr als 90% nur bei Verwendung von Fe(III)-hydroxiden. Der adsorptiv-kolloidale Flotationsprozeß wurde mit den Verfahren der rein chemischen Fällung und des Ionenaustausches verglichen und seine hohe Wirksamkeit erkannt.*

Keywords

adsorbents; colloids; foams; oleic acid; potassium compounds; precipitation; radioactive waste processing; separation processes; surfactants

1. Introduction

Radioactive process waste water is a dilute solution, usually consisting of ordinary drinking water having a very low radioactivity level and containing small amounts of laboratory chemicals. The water is usually produced at high rates (about 5000 gal./day in large plants) and has to be properly treated to remove the hazardous isotopes prior to its release to the environment. Because of very low concentrations, the isotopes cannot be efficiently removed by the currently used drinking water purification techniques (chemical precipitation and flocculation). Also, other separation techniques including ion exchange, adsorption and reverse osmosis are not recommended since they are either time consuming or expensive or both. Therefore, the attention of many investigators has been directed towards foam separation methods. These methods have been quite pertinent for the removal of trace concentrations of metal ions from large volumes of solutions and are based on the fact that a surface-active material tends to concentrate at the gas-liquid interface. If not surface active, the substance to be removed can be made so through union