NOTE

The need for standardization of normalized multi-element diagrams in geochemistry: a comment

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A potpourri of mutually inconsistent normalized multi-element diagrams ('spider-diagrams') has been used in geochemistry, on the basis of different choices of: (i) *element order*; (ii) *normalizing materials* (chondrite, 'primitive' mantle, MORB, composite shale, etc.); (iii) *normalizing values* (many incompatible sets are used for conventional chondrite-normalized rare-earth element (REE) plots, which generate 'enrichments' varying by as much as 65 % from a single rock, and Eu anomalies of quite divergent strengths). Standardization is urgently required, not least because (1) many published diagrams are unnecessarily difficult to compare; (2) different element orders can drastically affect patterns, or lead to artificial 'pseudo-anomalies' lacking petrogenetic significance. One type of chondrite- and MORB-normalized spider-diagram (each based on *one* set of normalizing values) should suffice to represent most igneous rocks. Arguments favouring the chondrite-normalizing REE values of Nakamura (1974), the chondrite-normalized 19-element plot of Thompson (1982), and the MORB-normalized 15-element plot of Pearce (1982, 1983) are preferred, hopefully as an impetus to wider discussion. Consistently ordered sub-sets can be chosen from either multi-element plot if fewer elements are in fact analysed. A FORTRAN77 program has been written to realize these suggestions.

THE PROFUSION AND INCONSISTENCY OF PUBLISHED NORMALIZED DIAGRAMS

Normalized log-linear multi-element diagrams (Figs. 1–3) are becoming increasingly widespread, abundant and useful in the petrological and geochemical literature. The terms **spidergram**, for a normalized plot of one rock or mineral sample, and **spider-diagram**, for a series of such plots on one figure (Thompson, 1982), will be employed here for brevity. Thompson *et al.* (in Hawkesworth and Norry, 1983) summarised the pre-eminence of spider-diagrams in the literature with the aphorism 'arachnids rule OK', but the present author wonders whether an alternative anagram—'anarchids rule OK'—might not be a closer approximation to the truth, in view of the plethora of mutually inconsistent diagrams now being promulgated.

One need look no further than invaluable recent books by Hawkesworth and Norry (1983) and Menzies and Hawkesworth (1987), to

appreciate the current position: included therein are over 300 spidergrams arranged in no fewer than 130 spider-diagrams of 19 different types! A necessarily cursory examination of other recent literature suggests this is merely the tip of the iceberg, and that a veritable galaxy of spider-diagram varieties is now actively published by different authors.

The parameters causing these perplexing variations are as follows:

(1) *Choice of normalizing material*: In igneous petrology and geochemistry, 3 normalizing materials are most popular: (i) chondrites; (ii) 'primitive' or 'primordial' mantle; and (iii) MORB. Sedimentary and metamorphic geochemists also use N.American composite shale, seawater, average crust, and other normalizing materials.

(2) *Choice of normalizing values*: Even diagrams normalized to purportedly the same material use a bewildering range of normalizing values. Table 1 compiles some commonly used sets of values

Fig. 1. Illustrating the influence of normalizing values on enrichments and Eu anomalies for REE spidergrams. The same rock, a type monchiquite from Serra de Monchique (Portugal), is plotted versus five of the seven different sets of chondrite-normalizing values from Table 1. At this scale, the patterns resulting from the sets of Haskin et al. (1968) and Nakamura (1974) are indistinguishable. The patterns derived from the sets of Schmetzler & Bottino (1971) and Taylor and Gorton (1977) are omitted for clarity, both lying within the range shown; moreover, the former is necessarily exactly parallel to that derived from the Masuda et al. (1973) set. Raw data-values (in ppm) for the monchiquite are as follows: La 103; Ce 253; Pr 27.0; Nd 110; Sm 14.2; Eu 2.0; Gd 7.7; Tb 1.1; Dy 5.9; Ho 0.91; Er 1.5; Tm 0.22; Yb 0.9; Lu 0.15. Produced using SPIDER (Rock, 1987c).

for chondrite-normalized REE plots. No less than six of these sets appear in different papers within Menzies and Hawkesworth (1987)! Some individual authors use inconsistent normalizing values even within their own opera (cf. plots 4 and 5, Table 2), while others do not state the source of their normalizing values at all (e.g., plots 7–8, Table 2). What might euphemistically be termed 'numerical adjustments' introduce even more confusion—for example, Erlank *et al.* (in Menzies and Hawkesworth, 1987, p.283) state they have used Taylor and Gorton's (1977) REE chondrite values divided by 1.2, but Taylor and Gorton (1977) already use the Leedey chondrite values of Masuda *et al.* (1973) divided by 1.2 (see Table 1). It thus seems that Erlank *et al.* are using Masuda's values divided by 1.44— but

whence this peculiar 'golden ratio' derives is not explained!

(3) *Choice of element order*: Only in the case of REE plots is the element order pre-determined (by atomic number). For other spider-diagrams, element order is necessarily more arbitrary, since elements of adjacent atomic number (e.g., Rb, Sr, Y, Zr) are now chemically too dissimilar to plot contiguously. As with so many other arbitrary orders in geochemistry (e.g., that for SiO_2 , Al_2O_3 etc. in analyses), a plethora of mutually inconsistent personal choices has arisen. Indeed, few authors cited in Table 2 justify their chosen order at all, and some authors even state they have adopted the order of others, but in fact change it in arcane and unexplained ways (cf. plots 1 and 2, Table 2).

Table 1. Examples of varying chondrite-normalizing values used for published REE plots

Source	Schmitt et al. (1964)	Haskin et al. (1968) ^{a)}	Schnetzler & Bottino (1971) ^{a)}	Masuda et al. (1973) ^{a)}	Taylor & Gorton (1977) ^{a)}	Nakamura (1974) ^{a)}	Evensen et al. (1978) ^{a)}		Robust estimates ^{d)}	Dominant cluster mode ^{e)}
La	.30	.33	.....	.378	.315	.329	.2446	.2446	.319-.330	.329
Ce	.84	.88	.934	.976	.813	.865	.6379	.7272	.83-.89	.859
Pr	.12	.112	.....	.....	.116	.....	.0964	.1000	.....	.....
Nd	.58	.60	.683	.716	.597	.63	.4738	.4716	.61-.64	.65
Sm	.21	.181	.218	.23	.192	.203	.1540	.1640	.200-.211	.217
Eu	.074	.069	.077	.087	.072	.077	.0580	.0597	.073-.079	.078
Gd	.32	.249	.308	.311	.259	.276	.2043	.2453	.264-.275	.271
Tb	.049	.047	.....	.....	.049	.....	.375 ^{b)}	.0390	.....	.....
Dy	.31	.....	.366	.39	.325	.343	.2541	.2478	.328-.344	.334
Ho	.073	.07	.....	.....	.073	.....	.0567	.0590	.....	.....
Er	.21	.2	.235	.255	.213	.225	.1660	.1736	.218-.228	.216
Tm	.033	.03	.....	.....	.03	.....	.0256	.0267	.....	.....
Yb	.17	.2	.235	.249	.208	.22	.1651	.1487	.216-.226	.214
Lu	.031	.034	.040	.0387	.032	.0339	.0254	.0262	.0349-.0356	.0389
Method ^{c)}	INAA	INAA	ID	ID	(ID)	ID	ID+INAA	ID	ID	ID
Notes	Accuracy low ($\approx 10\%$); av. of 17	Composite of 10	Composite of ?10	Leedey chondrite alone	Previous column/1.2	Average of 10	Statistical CI average of 56+22	Stat. av. of 56 ^{f)}	Range of 18 averages of 56	Single average

- a) These sets all used in different chapters of Hawkesworth and Norry (1983) or Menzies and Hawkesworth (1987).
- b) This value should read 0.03745.
- c) INAA = instrumental neutron activation analysis; ID = isotope dilution.
- d) Range for 18 different robust estimates of location(averages): 4 of Hampel's 3-part redescending series; 3 of Huber's one-step series; Andrew's sine estimate; one adaptive estimate; the 10%, 20%, 25% and 50% trimmed means; the Shorth mean; John's estimate; the Gastwirth median; the Trimean; and a multiply-skipped estimate (Andrews et al. 1972). Uses the same database of 56 ID chondrite analyses as Evensen et al. (1978).
- e) Ellis et al. (1977); an iterative robust estimate which rejects data at successively fewer standard deviations from the mean until the estimate stabilises. Closely analogous to the statistical procedure used by Evensen et al. (1978).
- f) NAA values in table 3 of Evensen et al. (1978) multiplied by 0.2446, i.e., same factor as used by these authors themselves to derive "CI average" (previous column).

The extraordinarily inconsistent element orders in Table 2 are in no way 'excused' by the 3 different normalizing materials. If all these orders reflected some *objective* physico-chemical parameter measurable on at least an ordinal (i.e. rankable) scale, they should be immutable under varying normalization. In fact, several element pairs appear reversed on different plots (see for example **Ba,Rb** and **K,Nb** in Table 2 where, in each case, two plots differ from all the others); such choices are thus revealed as entirely arbitrary. Although it would be reasonable to plot *subsets* of some omnibus order, so that diagrams for smaller numbers of analysed

elements (e.g., XRF data alone) could be consistent with those for more comprehensive (e.g., XRF+INAA) data, no plot in Table 2 in fact appears to be an exact sub-set of any other. On the contrary, many orders are totally irreconcilable.

THE NEED FOR DIAGRAM CONSISTENCY IN PETROGENETIC INTERPRETATION

These variations are unimportant *only* if spider-diagrams are used merely for comparing those rocks or minerals plotted *within the diagram* (or within a fully consistent set of

diagrams). Spider-diagrams of whatever kind can then be a highly effective means of condensing and displaying multivariate chemical data in two dimensions, and this author is by no means averse to spidergrams in principle (e.g., Rock, 1986, 1987a,b). However, variations become not only more confusing and frustrating, but actively hinder genetic interpretation, in circumstances outlined below:

Comparison of different plots. It becomes difficult or impossible to compare different plots if different normalizing materials, values or element orders are used. Fig. 1 shows how different normalizing values from Table 1 affect REE patterns. Although the overall pattern for this rock is not fundamentally altered, normalized enrichments vary by as much as 65% between the different plots; this variation exceeds that for entire igneous rock suites in some published spider-diagrams! Put another way, a rock may appear 'more enriched' on one REE plot than another, even if its raw REE abundances are as much as 65% less, if the two plots use different sets from Table 1.

Significance of element anomalies. Anomaly recognition is an increasingly widely used technique in the nascent 'science' of spidergram interpretation. Probably the most widely recognised are Eu (Fig. 1) and Nb anomalies (e.g., Fig. 2a)—the latter supposedly a hallmark of subduction-derived magmas (Pearce, 1982, 1983). However, 'pseudo-anomalies' can also be generated by purely artificial (graphical) rather than real magmatic effects:

(i) *Effect of excessively high or low normalizing values.* This applies to *all* types of spidergram, including REE plots. For example, the chondrite values of Schmitt *et al.* (1964) are intrinsically less prone to generating negative Eu anomalies, because Sm/Eu (2.84) and Gd/Eu (4.32) are significantly higher than in the other sets in Table 1: in Fig. 1, the Eu anomaly evident in three patterns has all but disappeared in the fourth, Schmitt *et al.* pattern. Clear, graphical differences, of a type normally imbued with petrogenetic significance but in actuality purely

artificial, can therefore easily arise. Yet even if readers are alerted to the possibility of apochryphal differences, recognising them is often impeded by authors' reluctance to state their normalizing values clearly. At best, these vital values will be hidden in the 'small print' of the respective figure captions; more likely, they will be given in neither of the actual captions being compared, but hidden in the captions of earlier REE plots in the same respective papers; at worst, normalizing values will not be given at all in one or other paper (e.g., plot 8 in Table 2), altogether preventing meaningful comparisons. A universal, consistent set of normalizing values on *all* plots is thus needed, which will be understood implicitly, and thus need no longer be explicitly quoted.

(ii) *Effect of element order:* Nb anomalies, as on Fig. 2a, are statistically quite different from the often quantitatively interpretable Eu anomalies on REE plots. Whereas the X-axis on REE plots is a *higher-ordered metric* variable (Coxon, 1982)—i.e. $X_1 < X_2 < \dots < X_{15}$ and $\{X_n - X_{n-1}\}$ is constant, with the element symbols effectively proxying for ranked integers (atomic numbers) from 57 to 71—the X-axis on other types of spider-diagrams is only a *nominal* variable—i.e. one can no longer say $X_i < X_j$ but only that that $X_i \neq X_j$, since atomic numbers are no longer in any logical order (Fig. 2). It is thus possible to generate (or suppress) a 'negative Nb anomaly' merely by judicious choice of element order (Fig. 2). Once again, some orders (e.g., 2 and 4 in Table 2) will be more prone to generate negative Nb anomalies than others (e.g., 3 and 12), from an analysis of the type displayed in Fig. 2, because Nb appears much earlier in the sequence, among the elements of higher normalized tenure.

Significance of overall spidergram shapes: Pearce (1983) devised an empirical scheme for 'dissecting' spider-diagrams into their component parts. He inferred for example that rocks yielding spidergrams similar to Fig. 3 contained 3 source components: a mantle component (A), a sublithospheric component (B), and a subduc-

Fig. 2. Illustrating the major influence of element order on the overall shape of a spidergram. (a) and (b) use the same normalized value for every element, but contrasting orders following plots 3 and 4 from Table 2. (The two plots use identical subsets except for Ca, which is here omitted). Note particularly that an Nb anomaly appears only in (a). Atomic numbers are added to show the lack of any logical sequence.

tion zone component (C). This scheme has been widely imitated (e.g., Macdonald *et al.*, 1985). However, the above remarks concerning anomaly interpretation apply with equal force here. For when some elements appear at such disparate positions in different sequences (e.g., Sr, varying from 1st to 8th position in Table 2) consistency of spidergram shapes is inconceivable: it is still possible to move elements between the various inferred components by juggling the sequence.

CRITERIA FOR PREFERRING PARTICULAR NORMALIZED PLOTS

The irrationalities and inconsistencies outlined above seem to ally spider-diagram interpretation more with alchemy than with modern geochemistry. Indeed, the situation strongly resembles the imbroglio in geochronology, prior to Steiger and Jaeger's (1977) highly effective rationalization of decay constants. Similar recommendations are badly needed in geochemis-

try to establish standards which, though not absolutely 'perfect', can nevertheless be accepted and employed consistently by all. The remainder of this note is intended as both impetus and exhortation towards such progress. The present section outlines objective reasons for preferring particular plots or normalizing parameters in Tables 1–2 to others, while the final section proffers a more pragmatic approach, *via* computerization.

It is proposed that *four* basic types of spidergrams should be sufficient for most purposes: (i) chondrite-normalized REE (normalizing values of Haskin *et al.*, 1968 and Nakamura, 1974); (ii) composite shale-normalized REE (normalizing values of Gromet *et al.*, 1984); (iii) MORB-normalized multi-element (plot 12 in Table 2); (iv) chondrite-normalized multi-element (plot 1). There is no need to justify normalized REE plots (i) and (ii) *per se*, as they have been the most widely-used form of spidergram since the pioneering Japanese REE work of the 1960's. However, the rationale behind the

Table 2. Examples of the plethora of multi-element 'spider-diagrams' in two recent textbooks

Source of diagram ^{a)}	Element order	Normalizing values from
Chondrite-normalized spider-diagrams		
1) Thompson et al., in H & N, p.168	Ba,Rb ,Th,K,Nb,Ta,La,Ce,Sr,Nd,P,Sm,Zr,Hf,Ti,Tb,Y,Tm,Yb	Thompson (1982)
2) Lloyd in M & H, p.115	Rb,Ba ,Nb,La,Sr,Zr,Y,Cr,Ni	Thompson (1982)
Mantle-normalized spider-diagrams		
3) Dawson in M & H, p.134	Ca,Sr,K, Rb,Ba ,Nb,P,Zr,Ti,Y	Jagoutz et al. (1979), Wood et al. (1979)
4) Erlank et al., in M & H, p.281	Rb,Ba ,Nb,K,Sr,P,Zr,Ti,Y	Rogers (unpubl.thesis)
5) Harte et al., in M & H, p.183	Sr, Rb,Ba ,Ta+REE	Jagoutz et al. (1979), Nakamura (1974)
6) Harte in H & N, p.60	Cs, Rb,Ba ,K,Sr+REE	Wood et al. (1979)
7) Menzies et al. in M & H, p.330	Rb,Ba ,Th,Ta,K,La,Ce,Sr,Nd,P,Sm,Eu,Hf,Ti,Tb,Y,Yb,Lu	Values quoted but source not given
8) Hawkesworth et al. in M & H, p.375	Rb,Ba ,Th,K,Nb,La,Ce,Sr,Nd,P,Zr,Ti,Y	Not stated ^{c)}
9) Le Roex in M & H, p.398	Ba,Rb ,K,Nb,La,Sr,Zr,P,Ti,Y,Yb,Sc,V,Fe,Cr,Co,Ni	Sun and Nesbitt (1977)
10) Weaver and Tarney in H & N, p.211	Rb,Ba ,Th,K,Nb,La,Ce,Sr,Nd,P,Hf,Zr,Sm,Ti,Tb,Yb	Wood et al. (1981)
11) Thirlwall and Jones in H & N, p.188	Rb,Ba ,Th,Nb,K,La,Ce,Sr,Nd/P,Zr/Sm,Ti/Eu,Gd,Dy,Y,Er,Yb	Sun (1980)
MORB-normalized spider-diagrams		
12) Pearce in H & N, p.232	Sr,K, Rb,Ba ,Th,Ta,Nb,Ce,P,Zr,Hf,Sm,Ti,Y,Yb	Pearce (1982) ^{b)}

a) M & H = Menzies and Hawkesworth (1987); H & N = Hawkesworth and Norry (1983).

b) A subset of this diagram is also used by Cox in Hawkesworth and Norry (1983, p.144).

c) Also used by Norry and Fitton in Hawkesworth and Norry (1983, p.7); source of normalizing values again not stated.

Italics and bold type merely emphasise inconsistencies between element orders.

other recommendations now follows.

Complementary use of MORB-, chondrite- and shale-normalized spidergrams

Use of all 3 types is justifiable because they respectively serve to compare geological materials with 'the most abundant volcanic rock', 'mantle source' and 'representative crustal material', and are therefore complementary. Furthermore, as only one set of shale-normalizing values has been widely used, it requires no further justification.

Choice of chondrite-normalizing values

The 'best' set of chondrite-normalizing REE values (from the medley in Table 1) does however require careful consideration. These sets are based on varied and largely irreconcilable criteria: some represent analyses of single chondrites, some averages of several chondrites, and others mixtures of chondrites. Those of

Schmitt *et al.* (1964) constitute pioneering analytical work, but are now largely of historical interest (Evensen *et al.*, 1978) as their accuracy ($\approx 10\%$) can now be bettered; Fig. 1 has already shown how these values tend to generate different patterns from the other sets in Table 1. Those of Schnetzler and Bottino (1971) can also be excluded as the least complete, the lack of a value for La being particularly deleterious; furthermore, they are partly based on the more complete set of Haskin *et al.* (1968). Those of Masuda *et al.* (1973, p.240) were based on "every consideration", claimed as suggesting the Leedey chondrite to be the "safest" normalizing material, but these 'considerations' were not explained. In view of the notorious variability and inhomogeneity of chondrites, it is difficult to choose a single example as 'typical', and both this set of values and that of Taylor and Gorton (1977—derived simply from them) are surely therefore less reproducible than the remaining 3

sets, which represent averages of *several* or *many* chondrites.

At first sight, the set of Evensen *et al.* (1978) would seem the optimum choice, since these authors compile a large database of 22 INAA and 56 ID chondrite analyses; clearly justify their choice of compiled analyses; amply allow for the different analytical methods in Table 1; and make the only serious attempt so far at a rigorous statistical estimation, by censoring erroneous and atypical analyses in order to generate *robust* averages. Unfortunately, three other factors undermine the value of their recommendations:

(i) The Tb value is given as 0.3745 instead of 0.03745; even if this is merely a typographic error, it is most unfortunate in a set of standard values, and begs the question of whether other errors have been overlooked.

(ii) Their calculations involve several 'numerical adjustments', such as 1.0412 to 'reconcile' the ID and INAA data, and 0.2446 to produce a least-squares best fit to CI chondrites. As the final figures are significantly lower than all others in Table 1, these factors may well need reassessing. Furthermore, least-squares is an inappropriate statistical technique here because it assumes data normality, whereas these data-distributions are not only very strongly skewed and leptokurtic ($\sqrt{b_1}$ skew and b_2 kurtosis up to +4.9 and +29.6 respectively), but also include gross statistical outliers (Rock, 1987d).

(iii) They chose an iterative robust statistical technique, similar to the Dominant Cluster Mode (DCM) of Ellis *et al.* (1977): after calculation of an initial arithmetic mean, results k standard deviations from the mean were eliminated and the process repeated with decreasing k at each iteration, until the estimate stabilised. This is an equally unfortunate choice, for DCM-type estimates are known from detailed Monte Carlo studies to be much less efficient than, for example, Hampel's robust location estimates (Andrews *et al.*, 1972; Hampel *et al.*, 1986). Furthermore, DCMs in practice produce demonstrably unreliable estimates of

location with a wide range of real *geological* data-sets (Lister, 1985, 1986; Rock, 1987d). Like hierarchical cluster analysis, they are prone to unstable solutions, which may just as easily home in on *atypical* as typical results, early on in the iteration. The present, highly skewed and outlier-ridden, REE data appear to have produced just such a result, for computer recalculation (Rock, 1987e), using the original database of Evensen *et al.* (1978), confirms that the DCM is discordant with 18 other robust estimates of location for Nd, Sm, Er, Yb and Lu (Table 1). With Lu, for example, the DCM lies not only well outside the narrow range for the 18 robust estimates, but even outside 95 % confidence limits for *both* the arithmetic mean *and* median. The consistency of the other 18 estimates for all REE (Table 1), which arises despite their use of a wide diversity of censoring procedures, is evidence in itself of their greater reliability.

A more detailed description of these robust procedures is presented by Rock (1987d) and Rock *et al.* (1987), being out of place here, but Table 1 suggests that Nakamura's (1974) normalizing values are the most reasonable, from a purely statistical viewpoint. Since Nakamura's values are also favoured by the geological and analytical elimination process above, there are good overall grounds for preferring them. Although Nakamura's set does lack values for 4 REE, these can be interpolated from the set of Haskin *et al.* (1968), these two sets again being almost identical for the remaining 11 (Fig. 1; Table 1). Nakamura's set also has the compensating major advantage that it is used in Thompson's (1982) multi-element plot; vital consistency between these two recommended plots is therefore achieved.

Choice of chondrite- rather than mantle-normalization for multi-element spidergrams

Chondrite-normalization and mantle-normalization serve effectively the same purpose (i.e. to compare with 'mantle source material'); they are competitive, not complementary. Chondrite-normalization is prefer-

red for 4 reasons: (a) chondrite-normalized plots have precedence and are probably more numerous in existing literature; (b) REE plots are almost universally chondrite-normalized, and consistency is thereby maintained between these two types of plot—vital when nearly all multi-element plots also include REE (Table 2); (c) the plethora of mantle-normalized plots is a symptom of their imprecise, subjective rationale; (d) agreement on the one widely-used type of chondrite-normalized plot (Thompson, 1982) is more feasible than on one of the mutually inconsistent mantle-normalized plots.

Fig. 3. Example of Pearce's (1982, 1983) MORB-normalized spidergram, illustrating empirical petrogenetic interpretation from spidergram shape (after Macdonald et al., 1985). Such a shape is considered to comprise 3 components A, B and C derived from different sources. The elemental constitution of A, B and C is clearly dependent on displayed element order.

Choice of element order on multi-element spidergrams

All the above arguments lead to preference for a chondrite-normalized multi-element plot. The two such plots in Table 2 both use Thompson's (1982) normalizing values, and Lloyd's element order is stated to be a sub-set of Thompson's (although for some unstated

reason, Rb/Ba have become inverted and Cr and Ni added). Thompson's plot can thus be recommended without further discussion.

Earlier arguments also support use of a MORB- (rather than mantle-normalized) plot to complement Thompson's. It is therefore fortunate that the only so far widely-used MORB-normalized form (no.12 in Table 2) is also the most objectively based (Pearce, 1982, 1983): it is ordered on the basis of elemental ionic potentials and lherzolite/melt distribution coefficients, such that the incompatibilities of both mobile and immobile elements increase towards the centre of the pattern (Fig. 3). This is surely further justification (if any were needed) for preferring Pearce's plot.

Of course, the compatibilities and mobilities of chemical elements are not as immutable as their atomic numbers: for example, Zr and Nb (the archetypal incompatible, immobile elements) can become compatible, mobile elements in alkaline, halide-rich media (e.g., agpaite syenite magmas) which favour transition-metal complexing and crystallisation of complex Zr or Nb minerals (eudialyte, pyrochlore, etc.). The characteristic Nb 'anomalies' on the spidergrams of destructive plate-margin igneous rocks appear precisely because Nb has a different compatibility and mobility in their precursor magmas relative to the tholeiitic normalizing material (MORB); that is, Nb is in the 'wrong' position for such rocks. However, to change element order with different rock-types would be to annul the entire logic of normalized plots: they only have comparative value when the *same* order is used for all types.

Pearce's order was chosen on a quite different basis to Thompson's in Table 2: the latter gives "the smoothest overall fit to data for Icelandic lavas and North Atlantic ocean-floor basalts" (Thompson, 1982, p.105). Although these two recommended orders consequently bear little relation to one another (Table 2, nos. 1 and 12), they are based on two quite different normalizing materials, and should not therefore be regarded as incompatible but as com-

plementary, illuminating quite different aspects of the rocks they are used to depict.

COMPUTER IMPLEMENTATION

It is one thing to suggest recommendations such as the above, and quite another to achieve standardization in practice. A computer program, which can plot consistent spider-diagrams quickly and easily, is a hitherto little-explored but powerful means to this end. Such a program can effect standardization by itself, since many geologists may be prepared to trade a minor element of personal choice for its far greater work-saving powers. This course has already been taken with amphibole nomenclature: a program to output International Mineralogical Association-recommended names (Rock and Leake, 1984) has already been implemented worldwide, and now appears to be catalyzing rationalization in the literature (e.g., Horak and Gibbons, 1986).

Another program (SPIDER) has therefore been written in standard FORTRAN77, to produce the four basic types of spider-diagram advocated above. SPIDER is documented elsewhere (Rock, 1987c), and is already in use at several UK institutions. It is sufficiently flexible to generate subsets of each spider-diagram type where only a subset of elements have been analysed. It can even generate user-defined spider-diagrams for any whom the present recommendations do not convince. It has been made as machine- and system-independent as possible, although, of course, portability for graphics programs is at present strictly constrained.

Should geochemists ever achieve consensus that another set of normalized plots is preferable to those advocated here, adjustments to SPIDER would be easily made. The author would therefore welcome comments on the subject.

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