GAINS AND LOSSES OF ELEMENTS RESULTING FROM WALLROCK ALTERATION A QUANTITATIVE BASIS FOR EVALUATING LITHOGEOCHEMICAL SAMPLES*

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INTRODUCTION

Multi-element lithogeochemical analyses are increasingly widely used in the exploration for many types of gold deposits. To maximize the information gain from such data it is imperative to appreciate the chemical nature of unaltered country rock and altered wallrock of various origins, and to quantify the gains and losses of elements during the alteration process. An understanding of alteration history is important because many alteration zones are closely associated, spatially and genetically, with precious metal deposits.

A number of methods has been proposed to quantify the procedure for major and minor elements, including an assumption of constant volume, Barth's standard cell, and constant silica tetrahedra (Poldervaart, 1953).

The general assumption of constant volume is clearly incorrect. Barth's standard cell assumes that the number of oxygen atoms remains unchanged during metasomatism, whereas Poldervaart assumed that the number of silica tetrahedra is unchanged during the alteration process. Whatever the validity of these approaches to quantifying gains and losses, it is apparent that none of the preceding methods can be applied usefully in the case of carbonate-rich alteration haloes developed around gold-quartz veins enclosed in basic volcanic rocks. Such loss-gain situations can be dealt with by the use of a procedure presented initially by Gresens (1967) and later by Babcock (1973).

GRESENS METASOMATIC EQUATION

Gresens derived an ideal equation for calculating losses and gains of elements during metasomatism in terms of:

(1) Parent and product rock compositions,
(2) Specific gravities of the parent and product rocks,
(3) Volume change during metasomatism.

Gresens' equation will not be developed here but is reproduced with an explanation of terms.

$$X_n = a[f_V X_B (G_B/G_A) - X_A]$$

where X_n = loss or gain (grams of component n).
a = initial weight of rock A, commonly taken as 100 grams so that X_n will be weight per cent change of a component oxide.
f_V = volume ratio of product rock to parent rock.
X_A, X_B = weight fraction of component X in parent rock (A) and product rock (B).
G_A, G_B = specific gravities of parent rock (A) and product rock (B).

PROCEDURE

(1) Whole rock chemical analyses are required for both parent and product rocks to provide values for X_A and X_B.
(2) Specific gravities are measured for both parent and product rocks to provide values for G_A and G_B.
(3) Volume change during metasomatism is estimated as a proportion of the volume of product rock to a unit volume of parent rock. An estimate of f_V is obtained by examining the ratios of immobile elements such as TiO_2 and Al_2O_3. For example:

$$f_V \approx (TiO_2)_A / (TiO_2)_B \approx (Al_2O_3)_A / (Al_2O_3)_B$$

TABLE 6-7-1.
ABUNDANCE OF MAJOR ELEMENTS (WEIGHT PER CENT) FOR DDH 80-88, ERICKSON GOLD MINES LTD.

Element	80-88 –JH–1	80-88 –JH–2	80-88 –JH–3	80-88 –JH–4	80-88 –JH–5	80-88 –JH–6	80-88 –JH–7
SiO_2	38.84	39.55	41.82	48.19	52.60	46.81	47.90
Al_2O_3	11.40	12.07	10.02	15.15	13.43	13.52	14.14
TiO_2	1.00	1.02	0.86	1.40	1.27	1.24	1.32
Fe_2O_3	8.69	8.93	8.97	10.61	10.38	10.87	11.33
MnO	0.15	0.15	0.18	0.16	0.19	0.17	0.16
MgO	5.87	5.60	5.98	5.58	5.83	7.14	7.31
CaO	11.21	10.40	10.43	6.23	4.36	11.19	10.40
Na_2O	0.30	0.28	0.10	0.01	0.01	1.40	2.11
K_2O	2.78	3.12	2.25	0.17	0.58	0.13	0.11
P_2O_5	0.12	0.07	0.07	0.10	0.10	0.10	0.10
LOI*	17.28	15.22	13.70	7.60	7.44	4.14	2.96
Total	97.64	96.41	94.38	95.20	96.19	96.71	97.84

* LOI = Total loss-on-ignition at 550°C and 1000°C.
Analyses done at the Department of Oceanography, The University of British Columbia.

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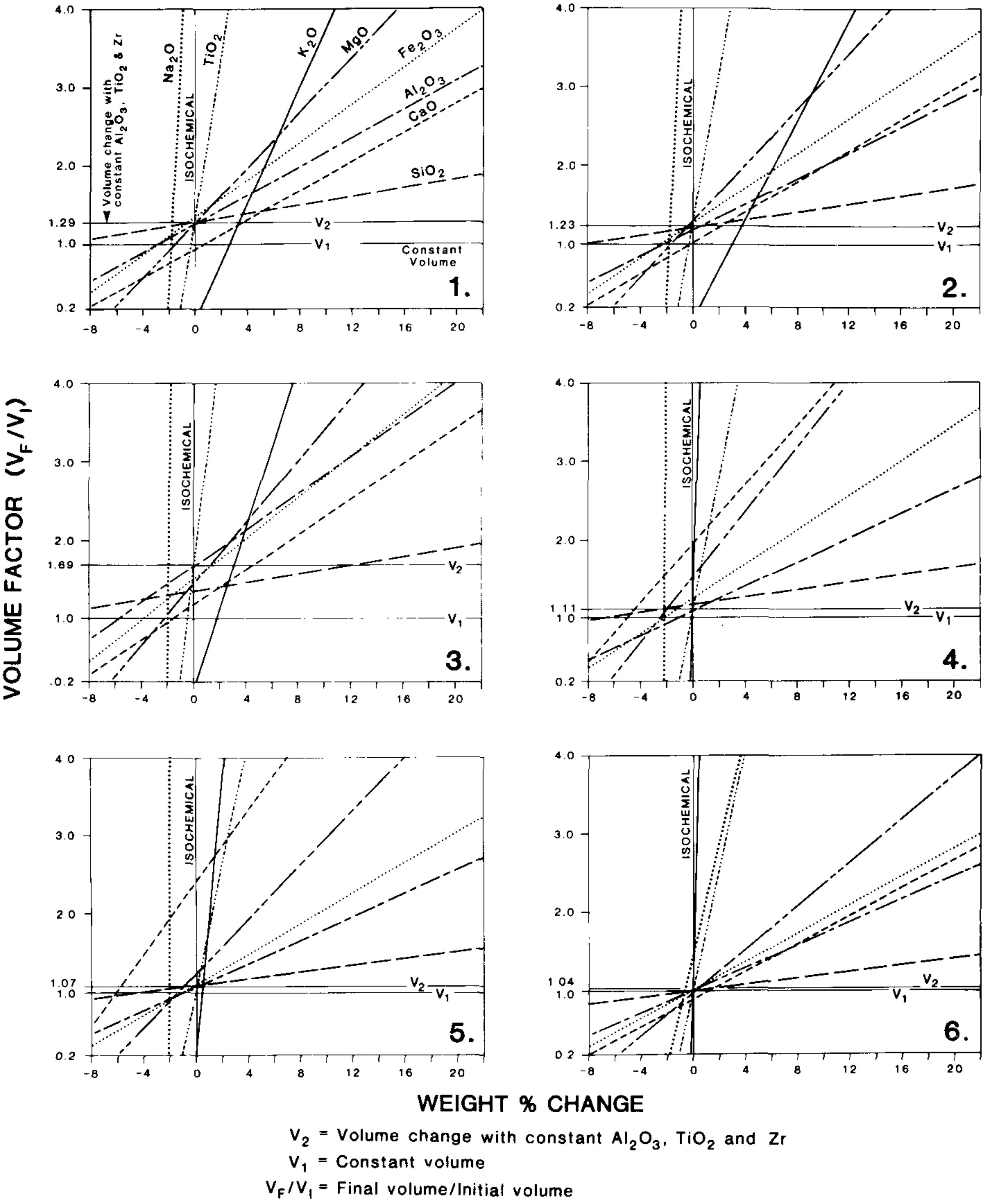

Figure 6-7-1. Composition-volume diagrams for six contiguous carbonatized basalt samples extending from the vein contact (1) outward to weakly altered wallrocks (6). Sample 3 is abnormal in containing a quartz veinlet. Legend for lines representing weight per cent element variations as a function of volume changes is shown for sample 1. Lines labelled V_I are constant volume; lines labelled V_2 are the interpreted volume changes based on Figure 6-7-2. Element gains and losses are thus the intersections of line V_2 with individual element lines.

A value of 1 indicates no volume change whereas >1 indicates volume increase and <1 indicates volume decrease during metasomatism.

AN EXAMPLE — JENNIE VEIN, ERICKSON MINE

Carbonate alteration haloes developed at Erickson mine are described by Sketchley and Sinclair, 1987, Sketchley *et al.*, 1984, and Sketchley, 1986. Seven contiguous samples extending from the Jennie vein, through a carbonatized zone and into adjacent unaltered country rock, were analysed for whole rock chemistry by X-ray fluorescence. Results are listed in Table 6-7-1. Using the analytical data for a single alteration sample and the data for unaltered wallrock, it is simple to construct a composition-volume diagram (Babcock, 1973) as follows: for each element Gresens' metasomatic equation is solved for any two very different values of f_V, say 0.05 and 3.0. Thus, two points are known on the composition-volume metasomatic diagram and can be joined by a straight line as in Figure 6-7-1. Comparable straight lines can be constructed for each element. An estimate of the volume change, f_V, can be made from immobile elements and this can be drawn on the graph parallel to the composition axis. Intersections of the elemental straight lines with the volume factor line provide graphical quantitative estimates of the loss or gain of all elements with volume change taken into account. The losses and gains can be calculated more precisely by use of Gresens' formula. Similar diagrams can be constructed for each analysis of an unaltered rock. Six such diagrams, representing the six altered rock analyses (Table 6-7-1) from the Jennie vein alteration halo, are shown in Figure 6-7-1. They illustrate the variable manner in which individual rocks have reacted to metasomatism. The diagrams become somewhat complicated where substantial and variable losses and gains have occurred as in Figure 6-7-1(1) representing altered rock immediately adjacent to the vein. This pattern is in sharp contrast with the simplicity of Figure 6-7-1(6) which reflects only very minor metasomatic changes.

Volume changes vary from one sample to another. For the Jennie data reported here, we attempted to estimate the volume factor independently for each sample using three separate immobile variables, Al_2O_3, TiO_2 and Zr. Results shown in Figure 6-7-2A indicate that the assumption of immobility of these three components, although not perfect, is reasonably well satisfied. The approximate variation in volume change outward from the vein wall is shown in Figure 6-7-2B. In general, the amount of volume change decreases outwards from the vein toward unaltered country rock. The exception is a single sharp peak representing sample 3 which includes a quartz vein explaining this anomaly.

It is useful to examine individual elements as profiles of loss-gain versus position in an alteration halo (distance outward from vein wall). Results for eight elements are shown in Figure 6-7-3 where dramatic gains of K_2O and SiO_2 and losses of MgO, total Fe (as Fe_2O_3) and Na_2O are apparent from the alteration haloes. Interestingly, our calculations suggest a major rearrangement of CaO in the alteration halo, perhaps with a slight net loss.

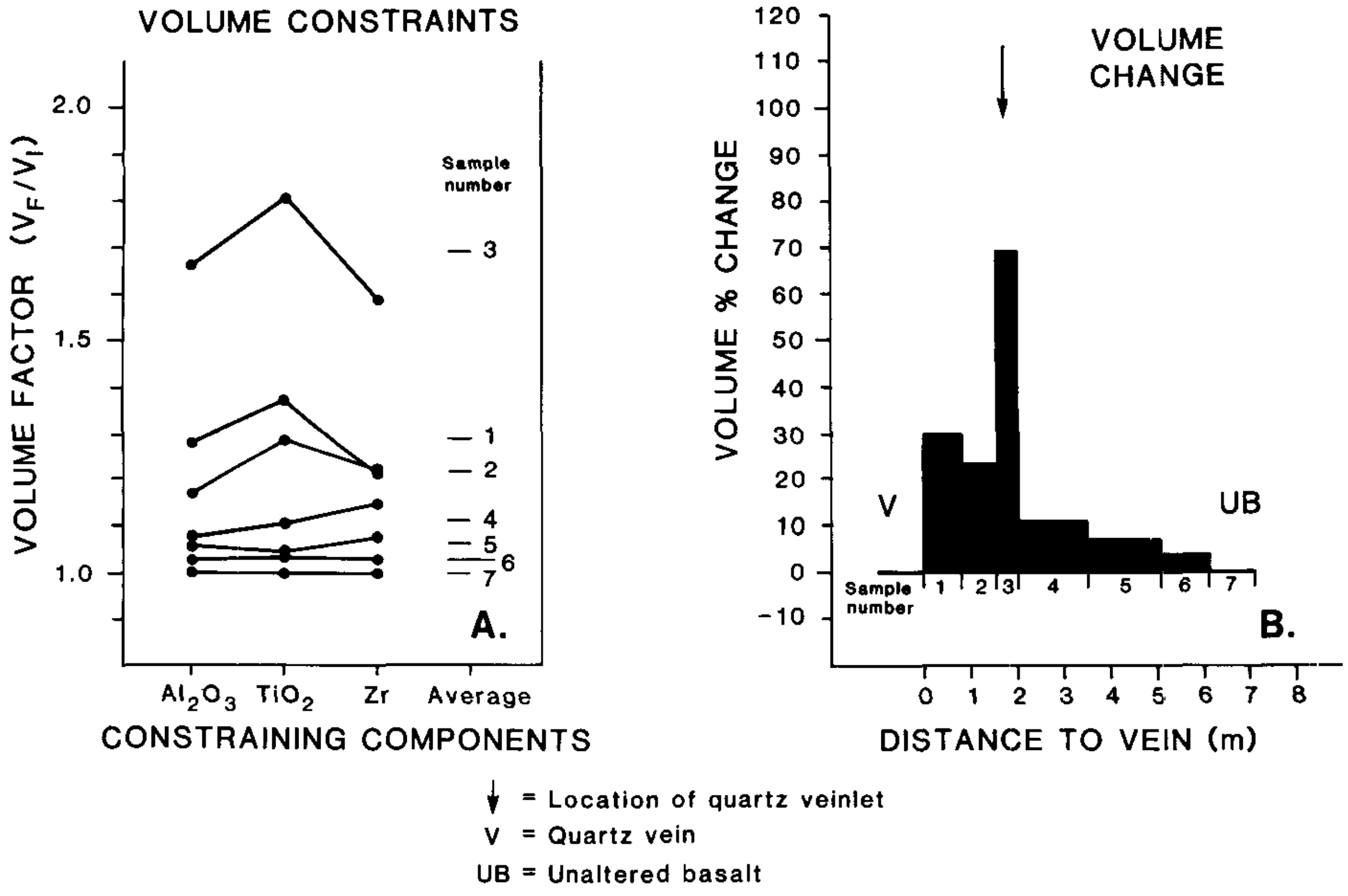

Figure 6-7-2. A — Volume factors (V final/V initial) estimated for each of six carbonatized basalt samples (1-6) and one unaltered sample (7) for each of three relatively immobile components. Volume factors (ratios) are estimated by the ratios of weight percentages for immobile elements in unaltered to altered samples, that is, Wt initial/Wt final. B — Interpreted volume change accompanying alterations for seven contiguous samples extending outwards from adjacent to Jennie vein (1) to unaltered wallrock (7).

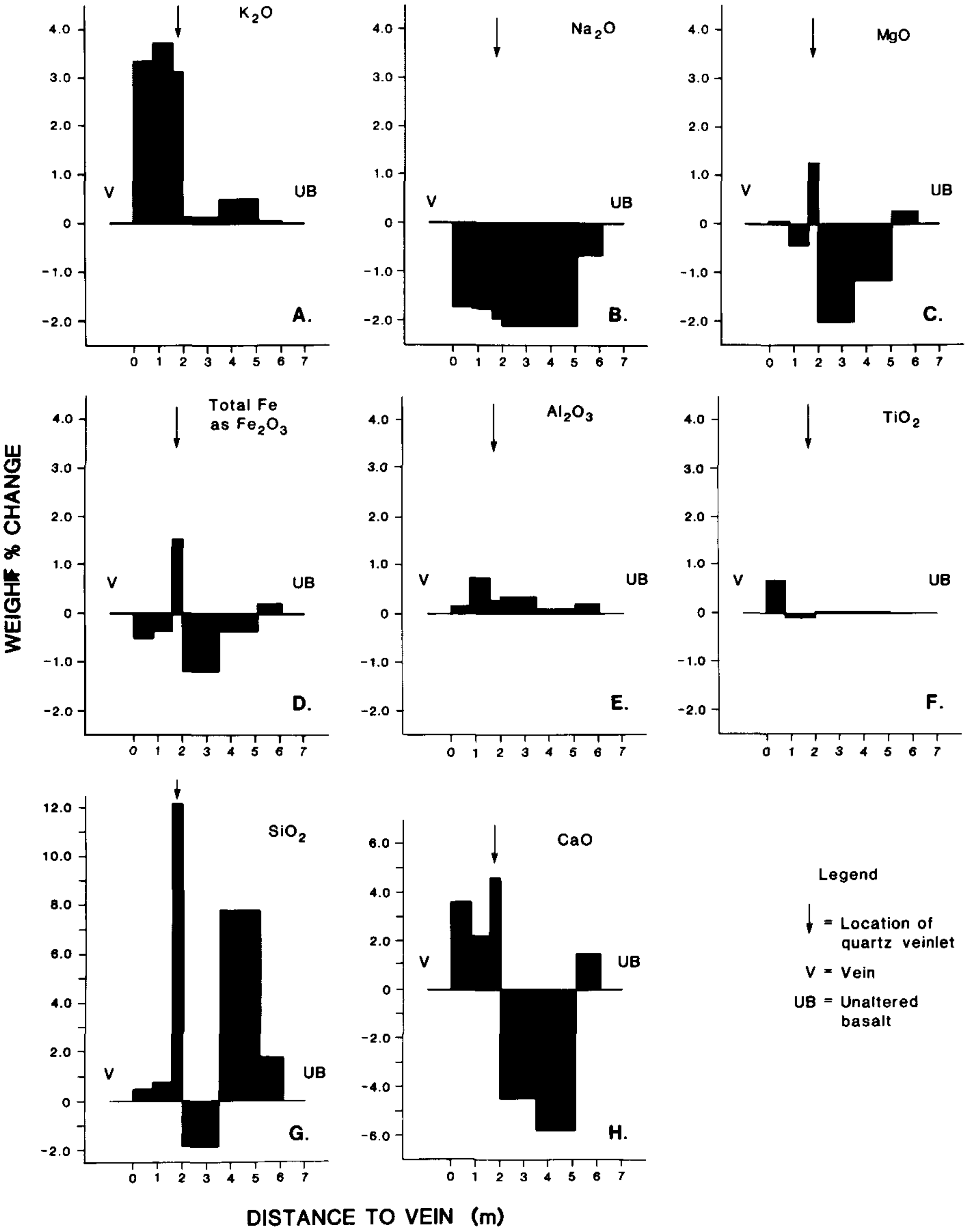

Figure 6-7-3. Losses and gains of major oxides in six carbonatized basalt samples extending outwards from Jennie vein and expressed as weight per cent of "unaltered" basalt. Results shown are based on average volume changes of Figure 6-7-2.

The nature of our chemical data did not permit identification of specific volatile materials such as H_2O, CO_2 and sulphur. Instead, we obtained a weight measure of "loss-on-ignition" (LOI) as shown in Figure 6-7-4 but recognize the addition of H_2O (sericite), CO_2 (carbonate) and S_2 (pyrite) to the alteration halo.

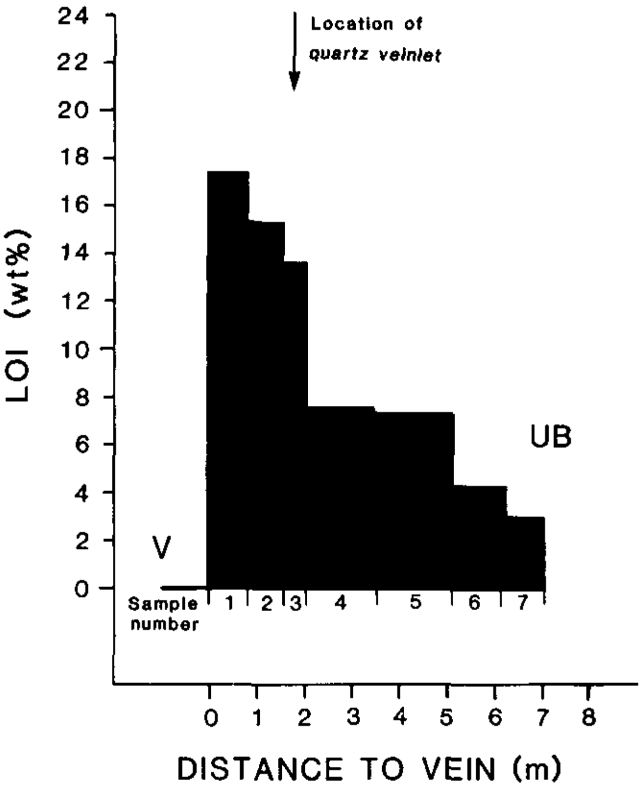

Figure 6-7-4. Loss-on-ignition (LOI) for seven contiguous basalt samples extending outwards from Jennie vein into unaltered basalt. Data from Table 6-7-1.

DISCUSSION

An understanding of element exchange during metasomatic processes involving wallrock alteration is an essential base for the interpretation of multi-element lithogeochemical data in precious metal exploration. For a quantitive study of the kind described here whole rock chemical analyses are required. It is important to realize that most multi-element inductively coupled plasma (ICP) data sets cannot be used for such calculations as they are generally obtained using partial extraction techniques. A small group of well-selected samples analysed both by ICP and an appropriate whole rock method (for example, X-ray fluorescence) will provide data to carry out the calculations recommended here and also will permit an evaluation of the extent of partial extraction inherent in the ICP data. Both types of information are essential to a sound interpretation of ICP data.

CONCLUSION

Gresens' metasomatic equation provides a useful procedure for examining gains and losses of elements in altered rocks. The procedure utilizes whole rock chemical analyses for altered and unaltered rocks and permits a quantitative evaluation of the effects of metasomatism without relying on peculiar constraints such as "constant number of oxygen atoms" or "constant number of silica tetrahedra".

In the case of the Jennie vein the whole rock data provide the following information:

(1) Volume changes during alteration are most pronounced near the vein (approximately 30 per cent) and decrease outwards toward unaltered wallrock.

(2) Addition of volatiles from the vein to altered wallrock decreases outwards from the vein wall.

(3) SiO_2 and K_2O have been added throughout the alteration halo with only rare exception.

(4) Na_2O, MgO and total Fe (as Fe_2O_3) have been lost from throughout the alteration halo.

(5) CaO has been redistributed in the alteration halo such that near the vein CaO is abnormally high whereas further away CaO has been lost.

(6) Al_2O_3 and TiO_2 appear to have increased slightly in the halo although these very minor changes may simply reflect local variations in the original composition.

ACKNOWLEDGMENTS

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