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CIPWFULL: A Software Program for Calculation of Comprehensive CIPW Norms of Igneous Rocks

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Abstract CIPWFULL is a user-friendly, stand-alone FORTRAN program designed to calculate comprehensive CIPW normative compositions of igneous rocks and adheres strictly to the original formulation of the CIPW protocol. This adherence alleviates inaccuracies in norms generated by current programs. Additionally, several important petrological and mineralogical parameters are calculated by the program. Along with major element oxides, all significant minor elements affecting CIPW norms are considered. CIPWFULL also calculates oxidation ratios for rocks reporting only one oxidation state of iron. It also provides an option for normalization of analyses to unity facilitating comparison of norms among rock suites. Other capabilities of the program cater to rare situations, like presence of cancrinite and exclusion of rare rocks from norm calculations. CIPWFULL is very efficient and flexible and allows for a user-defined free-format input of elements, and it permits feeding of minor elements in different notations. Results of calculations are printed in a formatted ASCII text file and may be casted into a space-delimited text file ready for export to general spreadsheet programs. CIPWFULL is implemented on the WINDOWS platform. The program source code resides on the journal web site.

Keywords CIPW · Normative · Igneous · Petrology

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1 Introduction

Ever since creation of the normative calculation procedure for CIPW norms in the early part of the twentieth century by Cross, Iddings, Pirsson and Washington (Cross et al. 1902, 1903)—hence the CIPW acronym—and the subsequent refinement by Johannsen (1931) many petrologists used the scheme to convert chemical analyses to theoretical minerals. These founders realized the need for a standardized approach for comparing modal and normative mineralogy of igneous rocks and anticipated future large databases of chemical data. With the advent of computers in the 1960s, attempts ensued to migrate from manual to machine computations, by designing computer codes for norm calculations; an example of early attempts is found in Kelsey (1965). Irvine and Baragar (1971) devised a classification plan for volcanic rocks that requires availability of CIPW norms.

This paper constitutes a description of an efficient CIPW norm program (CIPWFULL). It is written in FORTRAN and implemented on the WINDOWS platform. CIPWFULL computes norms of igneous rocks according to the rules of CIPW norms, while treating shortfalls found in many CIPW programs. Source code of the program is accessed through the journal web site.

2 CIPW Norms

The CIPW is widely used by igneous petrologists as an aid in mineralogical classification and naming of igneous rocks (Rollinson 1993). An alternative approach was devised by Ghiorso and Sack (1995) in the MELT program which applies thermodynamic principles to determine likely minerals crystallizing from melts.

Igneous rocks are composed essentially of silicate minerals. To convert analyses of rocks to theoretical minerals, a procedure is necessary which is compatible with chemical formulae of participating minerals and with magma saturation with silica, alumina, alkalis, iron and magnesium. Assignment of chemical constituents to minerals follows a strict set of rules creating major and accessory minerals (Cross et al. 1902; Johannsen 1931). Such an approach to generate norm minerals requires continuous tracking of element abundance, especially those in large quantities like SiO_2. Every step for formation of a mineral consumes a specified quantity of chemical components. Once the quantity of a chemical entity is exhausted, this entity is no longer available for mineral generation. The process of mineral creation continues until the entire composition is consumed. After consumption of silica in silica-deficient compositions, some minerals previously formed are destroyed to release some of their components to construct remaining minerals.

Computation of norms allows several advantages, most notably ability to deal with fine-grained volcanic rocks whose mineralogy is difficult to decipher. Facility to compare norms with modes of igneous rocks is another advantage. In addition, conclusions are readily extracted during investigations of large petrological databases of diverse compositions. This highly regimented protocol for CIPW norm calculation is explained in original sources (Cross et al. 1902, 1903) and refined by Johannsen (1931). It is described in many textbooks (Barker 1983; Best 1982; Blatt and Tracy

1999; Brownlow 1979; Cox et al. 1979; Morse 1980; Philpotts 1990; Philpotts and Ague 2009; Raymond 1995; Winter 2001). Furthermore, several norm programs have appeared on the Internet in recent years, like the spreadsheet program by Lowenstern (2002) and KWare Magma by Wohletz (1999). A plethora of CIPW norm calculations in university courses is also found on the Internet (e.g., Mattiolin and Zachry 2008).

3 CIPWFULL Norms

The goal of CIPWFULL is to provide petrologists with a computer program to calculate norms of igneous rocks that is devoid of deficiencies. This contribution describes the program and how it is utilized to calculate norms of igneous rocks.

Deficiencies occur as shortcomings in programs like Igpet (Terra Softa 2007) which deals only with a limited number of elements and excludes many minor elements. Similarly, the scheme of Pruseth (2009a, b) and the norm spreadsheet of Malisetty and Rao (1992) do not follow the CIPW scheme faithfully. Simple and abridged CIPW procedures were described by Glazner (1984) and Bickel (1979). Parslaw (1969) devised a modified CIPW method exclusively for biotite-rich granites. Verma et al. (1986) introduced a software package that contained a CIPW norm calculator, and more recently (Verma et al. 2002a, b) designed SINCLAS, a CIPW program that calculates norms. CHEMPET (Yegorov et al. 1988) is a CIPW program written in Pascal that deviates from the ordinary CIPW sequence by circumventing the simultaneous presence of ilmenite and calcium silicate (wollastonite or larnite).

Primarily, deficiencies in programs are: exclusion of some major and minor elements from calculations, lack of proper iron oxidation correction, consideration of cancrinite in certain igneous rocks and a method for treating variable hydrous contents of igneous rocks. CIPWFULL successfully deals with these limitations. It includes all major and relevant minor elements capable of modifying CIPW compositions of rocks, incorporates a scheme for calculation of a realistic oxidation factor for each sample, and removes effects of variable hydrous- and volatile-bearing minerals. Other shortcomings are circumvented as well. Finally, it computes several mineralogical and petrological indices and parameters.

Written as a stand-alone program in FORTRAN running under the DOS environment on personal computers implementing the WINDOWS platform, CIPWFULL is user-friendly, simple to use and requires no programming by users. The algorithm was designed and its code written and compiled under the environment of the LAHEY FORTRAN 95.5.7 compiler.

3.1 Description of Program Flowchart

Figure 1 is a flow chart showing flow of execution and processing of chemical analyses by CIPWFULL. It displays operation of the various components of the program and the execution path among them.

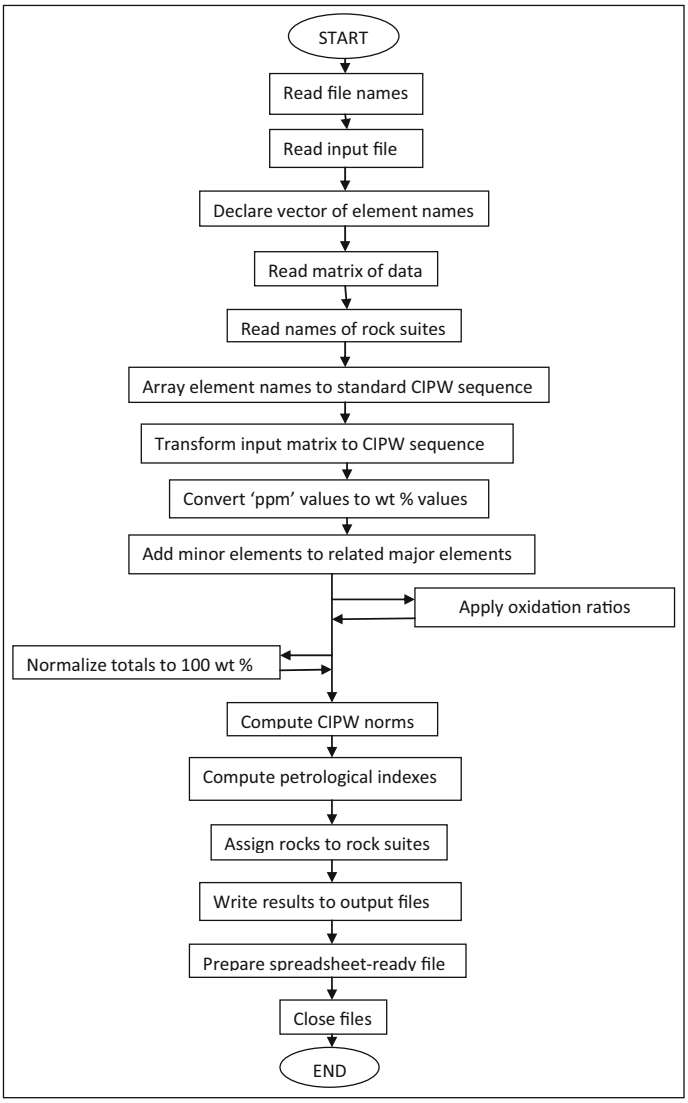

Fig. 1 A flowchart showing steps followed by CIPWFULL during calculations of CIPW norms and petrological indices of igneous rocks

3.2 General CIPWFULL

3.2.1 Minor Elements

The twelve most abundant major element oxides constitute nearly 99 % of most rocks. Other elements are minor and trace. Some of these elements, reported as parts per million (ppm), attain in certain rocks high concentrations and influence CIPW norms.

Table 1 CIPWFULL chemical notations

Element	Symbol	Element	Symbol
SiO_2	wt%	F	wt%
Al_2O_3	wt%	FP	ppm
TiO_2	wt%	CL	wt%
FeO	wt%	CP	ppm
Fe_2O_3	wt%	BaO	wt%
MgO	wt%	Ba	ppm
MnO	wt%	SrO	wt%
CaO	wt%	Sr	ppm
Na_2O	wt%	Rb_2O	wt%
K_2O	wt%	Rb	ppm
P_2O_5	wt%	Zr_2O	wt%
CO_2	wt%	Zr	ppm
SO_3	wt%	Cr_2O_3	wt%
S	wt%	Cr	ppm
SP	ppm	NiO	wt%
		Ni	ppm
		Li_2O	wt%
		Li	ppm

Examples are Cr and Ni in ultramafic rocks and Ba and Sr in felsic ones. Some minor elements are stipulated in the CIPW method (Cross et al. 1902), but a few more are included in CIPWFULL. CIPWFULL minor elements include F, Cl, Zr, Sr, Ba, Rb, Cr, Ni, S and Li. These are the only significant minor elements whose elevated abundances may alter norms. Some minor elements are reported as either wt% or as ppm; examples are S, Cl and F. Elements also may be reported in more than one form; for example, sulphur is reported as SO_3 or S and chromium as Cr_2O_3 or Cr. CIPWFULL distinguishes between the different notations and accepts minor elements in any representation. Table 1 lists notations used by CIPWFULL.

Any combination of minor elements is handled by CIPWFULL. They are assigned to different minerals according to generally accepted chemical substitutions of minor elements into major elements (e.g., Rb for K_2O and Sr for CaO). Minor elements are added to major elements before creation of theoretical minerals. Inclusion of minor elements yields accurate norms that nearly resemble modes.

3.2.2 Oxidation

Oxidation of iron in igneous rocks is a significant factor influencing dramatically their normative character and silica mineral saturation. For example, certain rocks of quartz-normative or hypersthene-normative character may become nepheline-normative, depending on oxidation. Presence of Fe_2O_3 and FeO in analyses is mandatory for correct calculations of realistic norms. Presence of only Fe_2O_3 results in Fe^{+3} minerals like hematite (Fe_2O_3) and enhances their abundance erroneously. It will also

suppress the formation of Fe^{+2}-bearing minerals like olivine, diopside and orthopyroxene. An analysis presenting iron only as FeO will favor Fe^{+2}-bearing minerals. Minerals like hematite and magnetite will not be formed. In both cases, resulting norms will be markedly dissimilar to modal mineralogy.

Instrumental analytical techniques like XRF and ICP almost invariably show only one form of iron in chemical analyses (commonly Fe_2O_3). To produce accurate norms, an approximate Fe_2O_3/FeO ratio is assumed a priori, and the total iron partitioned accordingly. For example, Hughes and Hussey (1976) pleaded for a standardized ratio of Fe_2O_3/ (Fe_2O_3+FeO) of 0.2 for basic rocks, and Middlemost (1989) recommended a standard oxidation for each major group of volcanic rocks. Sack et al. (1980) described how ferric–ferrous partitioning is achieved through knowledge of T and fO_2 of natural magmas. Even though normative calculations produce both Fe^{+2}- and Fe^{+3}-bearing minerals, results are nonetheless arbitrary and artificial.

Le Maitre (1976) devised a realistic approach for partitioning Fe_2O_3 and FeO. His approach utilizes a statistical method which partitions iron based on regression analysis of a large number of chemical analyses of young volcanic and plutonic rocks. It uses SiO_2, Na_2O and K_2O to estimate an oxidation ratio for each igneous rock. Based on regression, Le Maitre (1976) computed the following equations for specifying oxidation ratios:

$$\text{Oxidation Ratio} = 0.93 - 0.0042 * SiO_2 - 0.022 * (Na_2O + K_2O) - \text{Volcanic rocks}$$
$$\text{Oxidation Ratio} = 0.88 - 0.0016 * SiO_2 - 0.027 * (Na_2O + K_2O) - \text{Plutonic rocks}$$

Application of these equations produces more valid approximations of iron forms than the assumed oxidation ratios. Other workers used different methods for determining oxidation ratios (e.g., Middlemost 1989; Verma et al. 2002a, b). Exact Fe^{+2} and Fe^{+3} contents are only determined by the time-proven wet chemical techniques and methods like Mossbauer.

Validation of oxidation correction. For testing validity of these equations, nine rocks (five volcanic and four plutonic) were selected from the compilation database of Cox et al. (1979). A gabbro sample was selected from Hess and Poldervaart (1967). Each sample contains both forms of iron. Selected samples cover the spectrum of igneous rocks and span the typical range of iron in rocks (felsic, intermediate, mafic, ultramafic and syenitic) (Online Resource 1— upper block). Care was taken to select analyses with different total iron and varying contents of FeO and Fe_2O_3. Each analysis was subjected to norm calculations by application of the two equations of Le Maitre (1976). First, norms were determined by direct application of CIPWFUL to produce 'ordinary' CIPW norms. Second, for each sample the FeO content was converted to Fe_2O_3 and the product was added to the available Fe_2O_3; subsequently the norm of sample was calculated ('Fe_2O_3' norms). Third, a similar calculation was carried out after conversion of Fe_2O_3 to FeO, and addition of this value to the available FeO; norms were similarly calculated subsequently ('FeO' norms). Online Resource 1 (lower block) displays and compares results of the three calculations for each rock. A simple relative comparison index (RCI) was calculated for rows 2 and 3 of each rock. This index reflects the magnitude of correspondence of norms in these rows with the corresponding 'ordinary'

norms in row 1. This measure is calculated by adding the absolute difference between the oxidized-corrected norm and the corresponding 'ordinary' norm for all normative minerals in the rock, summation of these values and division by the norm total in row 1, and finally multiplying by 100, according to the equation

$$\text{RCI} = \sum_1^n (\text{Corrected Sum} - ' \text{Ordinary Sum}') \times 100.0/\text{Norm total in row 1}$$
$$n = \text{number of normative minerals}$$

Inspection of Online Resource 1 shows for each rock type the general close correspondence between all their normative minerals in the two oxidized rows and their corresponding values in the 'ordinary' (i.e., exact) norm in row 1. Smaller RCI values signify closer agreements between oxidized-corrected norms and 'ordinary' ones. Correspondence is remarkably close, especially for low-iron quartz-normative rocks. Understandably, iron-rich rocks will show more divergence between the two oxidized-corrected norms and the 'ordinary' norms than the low-iron rocks. Generally, Fe_2O_3- and FeO-norms have slightly higher and lower norm totals, respectively, than 'ordinary' norms.

Major minerals like orthoclase and minor minerals like fluorite show same norm values and are not affected by oxidation. This is not surprising as these minerals are formed early in the CIPW sequence before oxidation effects creep into calculations.

Felsic rocks Felsic rocks show hardly any difference between oxidation-corrected and 'ordinary' norms. Iron resides in hypersthenes and magnetite in these rocks. These two minerals differ in the corrected norms by an insignificant 0.0–0.2 wt%.

Intermediate rocks Intermediate rocks show similar variations as felsic rocks. They carry diopside in their norms. Hardly any difference shows between the 'ordinary' diopside norm and the oxide-corrected diopside norm. Hypersthene shows slightly higher variation than in felsic rocks, being between 0.7 and 1.2 wt%. Oxidation-corrected magnetite norms are different from 'ordinary' norms by 0.0–0.5 wt%.

Mafic rocks These rocks show diopside norms that change only as high as 0.2 wt%, hypersthene as high as 1.9 wt% and olivine as high as 3.0 wt%. Magnetite deviates from the 'ordinary' values by 0.2–1.5 wt%. These values are relatively small and the oxidation corrections do not alter norms appreciably.

Ultramafic rocks Peridotite and pyroxenite are devoid of quartz and contain olivine. They contain elevated levels of diopside. Oxidation-corrected diopside norms differ by a value of 0.0–0.4 wt% from 'ordinary' norms, and hypersthene by 2.8–4.0 wt%. Oxidized-corrected olivine norms are different by a value of 4.4–6.4 wt% from 'ordinary' values. Olivine norms are influenced more than norms of other minerals.

Alkali undersaturated rocks These rocks carry variable amounts of nepheline and leucite. More minerals are affected by oxidation in these rocks due to their undersaturation. Oxidation corrections produce leucite differences ranging from 0.9–1.7 wt% and nepheline differences between 0.0 and 0.1 wt% between 'ordinary ' and oxidation-corrected norms. These minerals lead to less albite and orthoclase. Oxidation corrections for the two minerals range from 0.0–2.1 wt% in the former and 0.1–0.3

wt% in the latter. Diopside differences vary from 0.2–0.5 wt% and wollastonite from 0.1–0.2 wt%. Olivine and magnetite norms show slightly more differences, being from 0.7–1.2 and 0.2–1.2 wt%, respectively

The oxidation test attests to validity of iron partitioning utilizing regression equations of Le Maitre (1976). The equations are most likely the best available method to partition iron in igneous rocks which exhibit only one form of iron, and results obtained testify to the soundness of the approach.

3.2.3 Normalization

Chemical analyses of igneous rocks are considered good if the sum of major elements falls between 99 and 101 %. Frequently, this sum may be slightly below 99 % in rocks containing large amounts of hydrous minerals or special rocks with exceptionally high content of minor and trace elements. Some petrologists resort to normalization of analyses to 100 % to remove effects of comparing rocks whose total contents deviate from the 100 % summation; this ensures that all rocks are treated on anhydrous basis.

CIPWFULL can normalize an analysis to 100 % weight total, after addition of minor elements to major elements. This renders comparisons within a suite of rocks or between rock suites meaningful and devoid of inconsistencies. Normalization introduces complications posed by the closer problem and constant sum variables dilemma (Chayes 1960; Miesch 1969), which impart uncertainties to mathematical and statistical manipulation of data. However, the closer problem is not likely to cause severe uncertainties in the calculation of CIPW norms, because the difference from unity in igneous rocks is minimal.

Another effect produced by normalization is the disproportionate change in the amount of abundant elements. For example, high-silica rocks will incur a larger change in SiO_2 amount than an element which has low content in the rock, such as MgO. A consequence of this effect is an increase in normative quartz, whereas a magnesium-bearing mineral like diopside will decrease in the calculated norm. For rocks that are neither oversaturated nor undersaturated in SiO_2 (like tholeiitic and alkalic basalts, respectively) normalization may change their saturation from Si-oversaturated to Si-saturated or even Si-undersaturated, due to artificial creation in the norm of quartz or olivine and nepheline. Thus, normalization may favor appearance of olivine to the exclusion of quartz or vice versa.

Users normalizing chemical analyses must be aware of the effects of normalization and should be careful during selection of this procedure. Resultant norm compositions will influence positions of samples in discrimination diagrams and possibly lead to samples crossing field boundaries. Interpretations based on these diagrams must be viewed with caution.

3.2.4 Special Situations

Cancrinite Presence of cancrinite—a hydrous Na–Ca–Al–Si carbonate idealized by the formula Na_2CO_3—as a unique mineral in highly undersaturated alkali-rich basaltic rocks requires a special calculation. This is a consequence of the possibility of rep-

resenting cancrinite components (Na_2O and CO_2) either as calcite or cancrinite. In alkalic rocks lacking cancrinite in the mode CO_2 is allocated to calcite, but if cancrinite is present in the mode, this presence must be declared during input for cancrinite to be formed to the exclusion of calcite.

CIPWFULL recognizes cancrinite-bearing rocks by a flag '1' in the data input line specific for each rock (Online Resource 2). Thus, rocks with cancrinite in their mode produce norms that resemble their modes.

Incomplete analyses Proper computation of CIPW norms inherently assumes that main chemical elements (i.e., the 12 major oxides) are present in chemical analyses. In some analyses some of these major oxides are lacking, rendering the analyses incomplete; thus, resultant norms are meaningless. CIPWFULL detects presence of partial analyses and excludes them from calculations. A chemical analysis must at least contain the oxides SiO_2, Al_2O_3, MgO and CaO to enter calculation of CIPW norms. Absence of these four oxides will automatically remove a rock from norm computations.

Special igneous rocks The CIPW scheme is designed specifically for magmatic silicate rocks. Rare igneous rocks like carbonatite are logically excluded from application of the CIPW analysis. In a large database that includes such rocks interspersed with silicate rocks, CIPWFULL is sufficiently intelligent to detect these rocks and to exclude them from norm calculations.

3.2.5 Petrologic Parameters

CIPWFULL computes petrological parameters and casts them in spreadsheets. Parameters include commonly utilized petrological ratios and indices. Rollinson (1993) and Shand (1951) discuss many of these parameters. Examples are the differentiation index (DI of Thornton and Tuttle 1960), magnesium number (MN), agpaitic coefficient (AC) and the plagioclase ratio. CIPWFULL also calculates chemical affinity indicators like alkalinity–aluminosity (Shand 1951). Table 2 lists these parameters.

3.3 CIPWFULL Testing

CIPWFULL was tested on data from Brownlow (1979), Cox et al. (1979), Morse (1980), Best (1982) and Barker (1983). Analyses were fed into an input data file and subjected to program execution. Online Resource 2 shows test data from these sources. Data are intentionally deviated from the tabular format to illustrate the flexibility of program input. Results are displayed in Online Resource 3. Output returned excellent norms that agree favorably with norms reported. Online Resource 4 contains error-inconsistency results and Online Resource 5 shows results in Online Resource 3 after streamlining in a spreadsheet format. Data in Online Resource 5 are ready for manipulation.

Table 2 CIPWFULL petrological and mineralogical parameters and ratios

Parameter ratio	Definition
Plagioclase ratio	Molecular An/(Ab + An)
Differentiation index (DI)	Normative $100 \times (Qz + Or + Ab + Ne + Lc + Ks)$
Mg number (MN)	Atomic $100 \times Mg/(Mg + Fe_2 + Fe_3 + Mn)$
Agpaitic coefficient (AC)	Atomic (Na + K)/Al
Peralkaline	Molecular $Al_2O_3 < (Na_2O + K_2O)$
Subaluminous	Molecular difference between alumina and alkalis $< 0.01\,\%$
Metaluminous	Molecular $Al_2O_3 < Na_2O + K_2O + CaO$
	But $Al_2O_3 > Na_2O + K_2O$
Peraluminous	Molecular $Al_2O_3 > Na_2O + K_2O + CaO$
Quartz–Albite–Orthoclase	Molecular Q–Ab–Or
Anorthite–Albite–Orthoclase	Molecular An–Ab–Or
Silica–Aluminum–Alkalis	Molecular SiO_2–Al_2O_3–Alkalis
Aluminum–Iron–Magnesium	Molecular Al_2O_3–FeO–MgO

4 Discussion

4.1 Description

CIPWFULL is a powerful program for calculation of norms. It adheres to the rules set originally by the CIPW scheme (Cross et al. 1902, 1903). CIPWFULL also calculates many petrological parameters and geochemical indices (Table 2).

4.2 Advantages

Advantages of CIPWFULL are dual: advantages of capability and advantages related to ease of use. The first category includes inclusion of minor elements likely to contribute to norms, determination of oxidation ratios for each rock, catering for rocks containing cancrinite and normalization to unity. Calculations of indices and parameters also fall within this category. The second category resides in the simplicity of utilization and transparency. Substitution of minor into major elements enhances contribution of minor elements towards total major element compositions. It increases normative abundance of certain minerals and may alter the chemical character of rocks, leading to correct classification and discrimination. Lack of Fe_2O_3 or FeO in analyses and assumption of arbitrary oxidation ratios lead to norms that are artificial. CIPWFULL follows a realistic method to partition iron. It calculates iron ratios from relationships established by Le Maitre (1976) using SiO_2, K_2O and Na_2O.

Presence of cancrinite in alkali-rich mafic rocks requires special treatments. Cancrinite receives little consideration from norm programs in use. CIPWFULL deals with

it and assigns it equal status as other minerals. This feature is useful for researchers working with silica-undersaturated alkalic mafic rocks.

Normalization of chemical analyses of igneous rocks is a feature sought after by petrologists when dealing with element totals of different magnitudes. Such normalization creates a 100 % total for rock analyses, rendering chemical and mineral comparisons acceptable, particularly when rocks contain highly disparate quantities H_2O and CO_2. Many chemical totals of igneous rocks are within approximately 1 % of unity, obviating the need for normalization.

4.3 Ease of Use

Simplicity of use of CIPWFULL is an attractive feature. Creation of an input data is accomplished by feeding information in a free-format flat ASCII file (Online Resource 2). Aside from sample name in each record, data are positioned in records freely, separated by spaces. This freedom is augmented by ease by which chemical concentrations are sequenced in record lines; no specific order is imposed. Concentrations may be mixed freely on the declaration line. Online Resource 6 describes this feature of data file organization. CIPWFULL recognizes dual representation of elements (e.g., Rb_2O and Rb) and is able to deal with them transparently; users need not convert manually minor element concentrations (ppm) to (wt%) and vice versa prior to feeding data.

4.4 Spreadsheet Capability

CIPWFULL allows users to cast norms into ASCII text tables compatible with spreadsheets like EXCEL. Creation of space-delimited spreadsheet-ready files to export to spreadsheet programs is of paramount importance, because this facility allows for speedy production of publication-ready illustrations. Online Resource 5 shows an example of these files. Left block of the spreadsheet lists sample compositions and petrological indices and right block lists CIPW norms.

5 CIPWSFULL Implementation

CIPWFULL is easily used by individuals lacking programming, computerization and knowledge of CIPW. CIPWFULL NOTES (Online Resource 6) is a DOCS ‘readme’ document explaining format of data input. CIPWFULL.DOCS (Online Resource 7) contains the CIPWFULL FORTRAN code. The executable version of CIPWFULL is in file CIPWFULL.exe (Online Resource 8). Applying CIPWFULL involves launching the program on the system prompt on computers running under the WINDOWS operating platform, by simply typing ‘CIPWFULL’ and pressing ‘ENTER’. Once invoked, users need only supply names of input file, output file, and spreadsheet file. It is recommended that both CIPWFULL and data files reside in the same folder or subfolder.

6 A Final Remark and a Word of Caution

Individuals are encouraged to test CIPWFULL accuracy on cited trial data sets. Slight differences in CIPW norms may appear. Insignificant discrepancies occur because some sources use approximate elemental values and incomplete analyses, and calculations were not aimed at exactness but rather to illustrate only the sequential approach of the CIPW protocol (e.g., Morse 1980; Barker 1983). Differences also result from rounding off molecular formula weights, oxide weights and mineral molecular weights. Exclusion of some minor elements from analyses and utilization of assumed oxidation ratios also contribute to differences. Robustness of FORTRAN compilers in different installation sites may also contribute to small variations in norms.

Melilite (Chayes and Yoder 1971), lamproites, kimberlites and lamprophyres require a special understanding during norm calculations. Yoder (1979) gives a review of these rocks and their norms.

7 Conclusions

CIPWFULL is an easy FORTRAN program designed to compute exact comprehensive CIPW norms of igneous rocks. It produces norms faithful to the formulation of the classical scheme of Cross, Iddings, Pirrson and Washington. It treats lack of ferric or ferrous iron and presence of significant minor elements in analyses. Presence of cancrinite, identity of volcanic or plutonic rocks, normalization of analysis to unity, and special situations are also handled. CIPWFULL generates many petrological indices and ratios. Ease of use and simplicity of data input and output and interface with common spreadsheet programs make the program extremely beneficial. It is extremely powerful when applied to large geochemical data sets of igneous rocks.

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