WinRock

Reference Guide — IUGS Classification, Norm Calculations and Diagrams

A technical companion to the WinRock user manual

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Contents

1. About This Guide

1.1 Scope

This is a reference volume for the petrological content of WinRock: what each classification schema means, exactly how the two norm calculations proceed, what every diagram plots, and where each scheme comes from in the literature. It is written for the geologist who needs to defend a rock name or a normative mineralogy — in a report, a thesis or a court of law — and therefore needs to know precisely what the program did to the numbers.

Every field boundary, formula and allocation step documented here was read out of the WinRock source rather than transcribed from a textbook, so the guide describes the program as built. Where the implementation departs from the published scheme, that is stated explicitly.

1.2 Relationship to the WinRock manual

The existing WinRock manual covers installation, the spreadsheet, the drawing tools, plot formatting and printing. This guide does not repeat that material. It picks up where the manual's operational instructions end: you know how to get data into the grid and how to open a plot window, and you now want to know what the plot means.

Cross-references to menu commands are given in the form *Calculate ▸ IUGS CIPW Norm* so that you can find the operation without a separate lookup.

1.3 Conventions used here

- Oxide values are weight percent unless stated otherwise; trace elements are ppm.
- Normative mineral abbreviations follow the program's own output: `Q` quartz, `or` orthoclase, `ab` albite, `an` anorthite, `ne` nepheline, `lc` leucite, `di` diopside, `hy` hypersthene, `ol` olivine, and so on. The full list is in §4.4.
- In QAPF work, **P′** always means the plagioclase ratio `100 × P / (A + P)`, which fixes the horizontal position in the triangle. It is not the same as normalised plagioclase.
- Column numbers refer to the fixed spreadsheet layout in §2.1.

2. The Data Model

2.1 The fixed column layout

This is the single most important thing to understand about WinRock. The calculation modules do not look up oxides by column heading — they read them from **fixed column positions**. A spreadsheet whose columns are in the wrong order will still calculate, and will still produce plausible-looking numbers, but they will be wrong.

> **Always start from a supplied template, or from *Edit ▸ Add Headings*.** If you paste data in from elsewhere, check that every oxide sits under the heading the program wrote, not merely that the headings are present.

Col	Heading	Col	Heading	Col	Heading
1	Sample #	12	CaO	23	NiO
2	Rockname	13	Na_2O	24	CoO
3	Symbol	14	K_2O	25	BaO
4	Color	15	P_2O_5	26	SrO
5	SiO_2	16	H_2O+	27	Rb_2O
6	TiO_2	17	$H_2O–$	28	F
7	Al_2O_3	18	CO_2	29	Cl
8	Fe_2O_3	19	Other	30	S
9	FeO	20	ZrO_2	31	Total
10	MnO	21	Cr_2O_3		
11	MgO	22	V_2O_3		

Columns 1–4 are identification and plotting attributes: the sample number, the rock name (written into by the classification routines), the plot symbol and the plot colour. Columns 5–30 are the analysed oxides, and column 31 carries the analytical total.

2.2 Major, minor and trace columns

Columns 5–18 are the classical major-element suite. **Every norm calculation reads all fourteen of them**, so a blank cell is treated as zero rather than as "not determined" — see §4.8.

Columns 19–30 carry the minor oxides and volatiles that the IUGS norm uses for its substituting-oxide corrections and for the halide, sulphide and carbonate minerals. They may be left empty for ordinary silicate rocks with no penalty.

Trace elements begin at column 38 and run in a fixed order through the transition metals, the precious metals, the heavy metals and then the full lanthanide series. The order matters for the same reason the oxide order does. The sequence is:

```
Rb  Cs  Sr  Ba  Y  Zr  Hf  V  Nb  Ta  Cr  Co  Ni  Cu  Zn  Ga  As  Mo  W
Ru  Rh  Pd  Re  Os  Ir  Pt  Ag  Sn  Sb  Au  Hg  Pb  Bi
La  Ce  Pr  Th  Pa  U  Nd  Pm  Sm  Eu  Gd  Tb  Dy  Ho  Er  Tm  Yb  Lu
Trace1 … Trace5   (free columns for anything else)
```

Note that Th, Pa and U are interleaved between Pr and Nd rather than placed after the lanthanides. This is deliberate — it follows the periodic-table row order used by the spider-plot module — but it does mean an REE list pasted in lanthanide-only order will be misaligned.

2.3 Derived columns

Columns 32–37 are written by the program, not by you. They are recomputed whenever a norm or a chemical classification runs.

Col	Heading	Meaning
32	K_2O+Na_2O	Total alkalis, the Y axis of every TAS plot
33	FeOt	Total iron as FeO: `Fe2O3/1.1113 + FeO`
34	MgRatio	Molecular Mg/(Mg+Fe) × 100 — see §8.1
35	Felsic Index	$100\cdot(Na_2O+K_2O)/(Na_2O+K_2O+CaO)$
36	Mafic Index	$100\cdot(Fe_2O_3+FeO)/(Fe_2O_3+FeO+MgO)$
37	SIndex	Solidification index — see §8.2

2.4 Templates and file formats

Six templates ship with the program, each pre-headed for a rock class: `1171Ig` (igneous), `1172Met` (metamorphic), `1173Sed` (sedimentary), `1174Lime` (limestones), `1175Pyro` (pyroclastics) and `1176Ore` (ore). Equivalent `.xls` versions are supplied for people who prefer to prepare data in Excel.

The native data format is `.rok`, a tab-delimited text file with a single header row — readable by any spreadsheet or text editor, which is what makes WinRock data durable. Import and export also support CSV, Excel, HTML and PDF.

2.5 Preparing an analysis

Three preparation commands are worth knowing before any calculation:

- **Recalculate 100% Volatile Free** strips H_2O and CO_2 and rescales the remaining oxides to sum to 100. This is the conventional pre-treatment for TAS and for most discrimination diagrams, and the IUGS norm expects it unless you specifically want the volatiles allocated to normative minerals.
- **Recalc to a New Sum** rescales a nominated column set to any total you choose.
- **Normalize** takes a single column and a target sum. The *Calc* button reads back the column's current total so you can see what you are rescaling from.

> **Order of operations matters.** Recalculate volatile-free *before* classifying on TAS, because the alkali and silica values that place a sample in a TAS field are sensitive to a few percent of undeclared water. Do not recalculate volatile-free before an IUGS norm in which you intend CO_2 to form carbonate minerals — you will have thrown away the CO_2.

2.6 The iron ratio

Most published analyses report total iron, or report an Fe^{3+}/Fe^{2+} split that reflects post-magmatic oxidation rather than the melt. Because normative olivine, hypersthene, magnetite, haematite and acmite all depend on that split, the norm is only as good as the ratio you assume.

WinRock offers a fixed ratio through *Calculate* ▸ *Fe Ratio*. Enter a value `FR` between 0 and 1, which is applied as the Fe_2O_3 proportion of total iron:

```
FeOt   = Fe2O3 / 1.1113 + FeO          (total iron expressed as FeO)
Fe2O3' = FeOt × FR × 1.1113
FeO'   = FeOt × (1 − FR)
```

The remaining oxides are then rescaled by a correction factor so that the analytical total is preserved:

```
Corr = Total / (Total − (Fe2O3 + FeO)old + (Fe2O3' + FeO')new)
```

A value of `FR = 0` leaves the analysis untouched. Common working values are 0.15 for basalts, 0.2–0.3 for intermediate rocks and 0.3–0.5 for oxidised rhyolites, but the honest answer is that the ratio should be measured. When you cannot measure it, state the assumed value alongside the norm.

The TAS module additionally implements the rock-type-specific iron ratios of Middlemost (1989) via an iterative scheme: a provisional TAS name is assigned, the ratio appropriate to that name is applied, and the classification is repeated until the name stops changing. This is the approach of Verma and co-workers in SINCLAS, and it is the more defensible choice when you have no measured ratio at all.

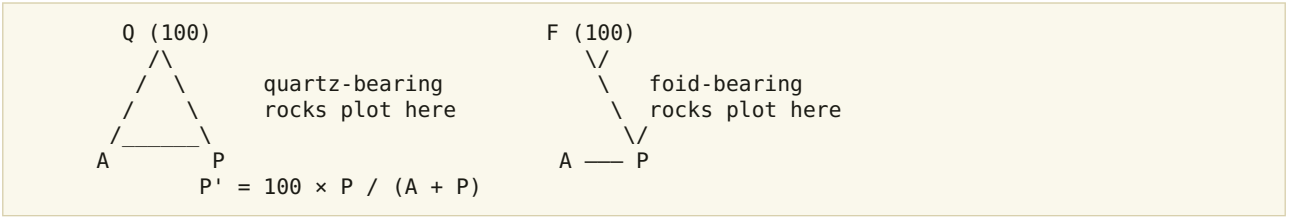
3. The IUGS Modal Classification Schema

3.1 Principles of the QAPF double triangle

The IUGS Subcommission on the Systematics of Igneous Rocks classifies igneous rocks on their *mode* — the measured volume proportions of the minerals actually present — wherever a reliable mode can be obtained. Four apices define the scheme:

- **Q** — quartz and the other SiO_2 polymorphs, tridymite and cristobalite.
- **A** — alkali feldspar: orthoclase, microcline, sanidine, anorthoclase, perthite, and albite up to An_5.
- **P** — plagioclase from An_5 to An_{100}, plus scapolite.
- **F** — feldspathoids: nepheline, leucite, sodalite, nosean, haüyne, cancrinite, analcime and the pseudo-leucites.

Quartz and feldspathoids are mutually exclusive at equilibrium, so a rock plots in either the upper Q–A–P triangle or the lower F–A–P triangle. WinRock therefore offers them as separate diagrams, and the classification routines switch between the two on whether the F column is non-zero.



Only the felsic framework minerals enter the sum. Micas, amphiboles, pyroxenes, olivine, oxides, carbonates and accessories are excluded, and the three remaining values are recalculated to 100 %. The excluded fraction is the **colour index M**, and it re-enters the classification at three specific points documented in §3.10.

3.2 Where to find each diagram

The IUGS diagrams are selected by name in the Graph drop-down of the Classification Plot window. The strings below are exactly as they appear there, so you can match them without guessing.

Graph drop-down entry	Apices	Covered in
QAPF-Plutonic, IUGS	Q – A – P – F	§3.3 and §3.5
QAP-Plutonic, IUGS	Q – A – P	§3.3 (upper triangle only)
FAP-Plutonic, IUGS	F – A – P	§3.5 (lower triangle only)
QAPF-Volcanic, IUGS	Q – A – P – F	§3.4 and §3.6
QAP-Volcanic, IUGS	Q – A – P	§3.4
FAP-Volcanic, IUGS	F – A – P	§3.6
PlagPxOl-Gabbroic, IUGS	P – Px – Ol	§3.7
PlagPxHbl-Gabbroic, IUGS	P – Px – Hbl	§3.7
PlagOPxCPx-Gabbroic, IUGS	P – OPx – CPx	§3.7
OlOpxCpx-UMafic, IUGS	Ol – OPx – CPx	§3.8
OlPxHbl-UMafic, IUGS	Ol – Px – Hbl	§3.8
Charnockites, IUGS	Q – AF – P	§3.9
Carbonatites, IUGS	CaO – MgO – $FeO+Fe_2O_3$+MnO	§3.9

Graph drop-down entry	Apices	Covered in
Melilite-Plutonic, IUGS	Mel – Ol – CPx	§3.9
Melilite-Volcanic, IUGS	Mel – Ol – CPx	§3.9

The QAP and FAP entries plot a single triangle; the QAPF entries plot the full double triangle. The classification result is the same either way — the choice affects only what is drawn.

3.2a What the program actually computes

For each sample WinRock reduces the mode to two numbers, and every field table in this chapter is indexed on them:

```
Q  (or F)  = 100 × Q / (Q + A + P)      vertical position — which horizontal band
P'         = 100 × P / (A + P)          horizontal position — which vertical strip
```

The result panel and the Rockname column report the name; the normalised values are what was actually plotted. Two consequences follow. First, you may enter raw point counts, whole-rock percentages or already-normalised values — only the ratios matter. Second, the mafic minerals must *not* be entered in the three mineral columns; they belong in the Mafics dialog.

> **Boundary convention.** Field tests are written with inclusive comparisons and are evaluated in a fixed sequence, with each successful test overwriting the previous name. A composition landing exactly on a field line therefore takes the name of whichever adjacent field is tested later. In practice this means a point on the Q = 5 line goes to the quartz-bearing field above it, and a point on Q = 20 goes to the granite band above it. Within about half a percent of a boundary, treat the name as provisional and recount.

3.3 Plutonic QAPF

Menu: Calculate ▸ Calc Modal Classification ▸ QAPF Plutonic. Plot: Classification Plot ▸ QAPF-Plutonic, IUGS.

The classic Streckeisen plutonic diagram. Horizontal divisions at Q = 5, 20, 60 and 90; vertical divisions at P′ = 10, 35, 65 and 90.

Q	P′	Rock name	Controlled by
0 – 5	0 – 10	Alkali Feldspar Syenite	
0 – 5	10 – 35	Syenite	
0 – 5	35 – 65	Monzonite	
0 – 5	65 – 90	Monzodiorite (An ≤ 50) / Monzogabbro (An > 50)	An %
0 – 5	90 – 100	Diorite (An ≤ 50) / Gabbro (An > 50) **Anorthosite** if M < 10 **Gabbro** if M + P′ ≥ 90 **Peridotite** if M ≥ 90 and Ol 40–90 **Pyroxenite or Hornblendite** if M ≥ 90 and Ol ≤ 40 **Dunite** if M ≥ 90 and Ol ≥ 90	An %, then M, then olivine
5 – 20	0 – 10	Quartz Alkali Feldspar Syenite	
5 – 20	10 – 35	Quartz Syenite	
5 – 20	35 – 65	Quartz Monzonite	
5 – 20	65 – 90	Quartz Monzodiorite (An ≤ 50) / Quartz Monzogabbro (An > 50)	An %

Q	P′	Rock name	Controlled by
5 – 20	90 – 100	Quartz Diorite (An ≤ 50) / Quartz Gabbro (An > 50) **Quartz Anorthosite** if M < 10	An %, then M
20 – 60	0 – 10	Alkali Feldspar Granite	
20 – 60	10 – 35	Syenogranite	
20 – 60	35 – 65	Monzogranite	
20 – 60	65 – 90	Granodiorite	An % is not used here
20 – 60	90 – 100	Tonalite	includes trondhjemite
60 – 90	any	Quartz Rich Granitoids	whole band
90 – 100	any	Quartzolite	silexite

3.4 Volcanic QAPF

The volcanic equivalents. The andesite/basalt split on this diagram uses **M = 35**.

Q	P′	Rock name	Controlled by
0 – 5	0 – 10	Alkali Feldspar Trachyte	
0 – 5	10 – 35	Trachyte	
0 – 5	35 – 65	Latite	
5 – 20	0 – 10	Quartz Alkali Feldspar Trachyte	strict: 5 < Q < 20
5 – 20	10 – 35	Quartz Trachyte	
5 – 20	35 – 65	Quartz Latite	
0 – 20	65 – 100	Andesite (M ≤ 35) / Basalt (M > 35)	M
20 – 60	10 – 65	Rhyolite	
20 – 60	65 – 100	Dacite	

> A blank Mafics entry is treated as M = 0 and therefore returns *Andesite*. On the volcanic diagram this is the single most consequential omission you can make — every basalt will come back as an andesite. Always supply M for volcanic rocks.

3.5 Plutonic foid (FAP)

Reached automatically when the F column is non-zero. Horizontal divisions at F = 10 and 60; note that the vertical division inside the foid-rich band sits at P′ = 50, not at 35 and 65.

F	P′	Rock name	Controlled by
0 – 10	0 – 10	Foid-Bearing Alkali Feldspar Syenite	
0 – 10	10 – 35	Foid-Bearing Syenite	
0 – 10	35 – 65	Foid-Bearing Monzonite	
0 – 10	65 – 90	Foid-Bearing Monzodiorite / Foid-Bearing Monzogabbro	An %
0 – 10	90 – 100	Foid-Bearing Diorite / Foid-Bearing Gabbro **Foid-Bearing Anorthosite** if M ≤ 10	An %, then M
10 – 60	0 – 10	Foid Syenite	nepheline syenite, sodalite syenite

F	P′	Rock name	Controlled by
10 – 60	10 – 50	Foid Monzosyenite	plagifoyaite
10 – 60	50 – 90	Foid Monzodiorite / Foid Monzogabbro	An %; essexite, theralite
10 – 60	90 – 100	Foid Diorite / Foid Gabbro	An %
> 60	any	Foidolite	ijolite–urtite–melteigite series

3.6 Volcanic foid (FAP)

Two thresholds differ from the other diagrams: the andesite/basalt split uses **M = 50** here rather than 35, and the tephrite/basanite split uses **olivine > 10 % of the mafics**.

F	P′	Rock name	Controlled by
0 – 10	0 – 10	Foid-Bearing Alkali Feldspar Trachyte	
0 – 10	10 – 35	Foid-Bearing Trachyte	
0 – 10	35 – 65	Foid-Bearing Latite	
0 – 10	65 – 100	Andesite (M ≤ 50) / Basalt (M > 50)	M
10 – 60	0 – 10	Phonolite	
10 – 60	10 – 50	Tephritic Phonolite	
10 – 60	50 – 90	Phonolitic Tephrite (Ol ≤ 10) / Phonolitic Basanite (Ol > 10)	olivine
10 – 60	90 – 100	Tephrite (Ol ≤ 10) / Basanite (Ol > 10)	olivine
60 – 90	0 – 50	Phonolitic Foidite	
60 – 90	50 – 100	Tephritic Foidite	
> 90	any	Foidite	nephelinite, leucitite, analcimite

3.7 Gabbroic diagrams

The QAPF triangle can only say "gabbro" or "diorite" for a rock in the plagioclase corner. The gabbroic triangles resolve it further. Three are supplied; enter the three named minerals as percentages of those three phases only.

Plag–Px–Ol

Vertical coordinate is the olivine ratio `Ol′ = 100 × Ol / (Px + Ol)`.

Plagioclase	Ol′	Rock name
0 – 10	any	Ultramafic Rock — reclassify on §3.8
10 – 35	0 – 5	Norite
10 – 35	5 – 90	Olivine Norite
35 – 65	0 – 5	Gabbronorite
35 – 65	5 – 90	Olivine Gabbronorite
65 – 90	0 – 5	Gabbro
65 – 90	5 – 90	Olivine Gabbro
10 – 90	90 – 100	Troctolite
90 – 100	any	Anorthosite

> In the published IUGS scheme, norite, gabbronorite and gabbro are separated by the orthopyroxene : clinopyroxene ratio, not by plagioclase content. This diagram uses plagioclase as its horizontal axis, so the three names come out on plagioclase content instead. Use the **Plag–OPx–CPx** diagram to check the pyroxene ratio before relying on the distinction.

Plag–Px–Hbl

Vertical coordinate is `Hbl′ = 100 × Hbl / (Px + Hbl)`.

Plagioclase	Hbl′	Rock name
0 – 10	0 – 10	Plagioclase Bearing Pyroxenite
0 – 10	10 – 50	Plagioclase Bearing Hornblende Pyroxenite
0 – 10	50 – 90	Plagioclase Bearing Pyroxene Hornblendite
0 – 10	90 – 100	Plagioclase Bearing Hornblendite
10 – 35	0 – 5	Norite
10 – 35	5 – 90	Pyroxene Hornblende Norite
35 – 65	0 – 5	Gabbronorite
35 – 65	5 – 90	Pyroxene Hornblende Gabbronorite
65 – 90	0 – 5	Gabbro
65 – 90	5 – 90	Pyroxene Hornblende Gabbro
10 – 90	90 – 100	Hornblende Gabbro
90 – 100	any	Anorthosite

Plag–OPx–CPx

The diagram to use when you need the orthopyroxene : clinopyroxene distinction that defines norite, gabbronorite and gabbro in the published scheme. Enter plagioclase, orthopyroxene and clinopyroxene.

3.8 Ultramafic diagrams

For rocks with M ≥ 90. Choose Ol–OPx–CPx when the mafics are olivine and pyroxenes, Ol–Px–Hbl when hornblende is a major phase.

Ol–OPx–CPx

Vertical coordinate is `Opx′ = 100 × Opx / (Opx + Cpx)`. Opx′ = 100 is pure orthopyroxene; Opx′ = 0 is pure clinopyroxene.

Olivine	Opx′	Rock name
90 – 100	any	Dunite
40 – 90	95 – 100	Harzburgite
40 – 90	5 – 95	Lherzolite
40 – 90	0 – 5	Wehrlite
5 – 40	95 – 100	Olivine Orthopyroxenite
5 – 40	5 – 95	Olivine Websterite
5 – 40	0 – 5	Olivine Clinopyroxenite
0 – 5	90 – 100	Orthopyroxenite
0 – 5	10 – 90	Websterite

Olivine	Opx′	Rock name
0 – 5	0 – 10	Clinopyroxenite

Ol–Px–Hbl

Olivine	Hbl′	Rock name
0 – 10	0 – 10	Pyroxenite
0 – 10	10 – 50	Hornblende Pyroxenite
0 – 10	50 – 90	Pyroxene Hornblendite
0 – 10	any, Px ≤ 10	Hornblendite (this test overrides the three above)
10 – 40	0 – 5	Olivine Pyroxenite
10 – 40	5 – 50	Olivine Hornblende Pyroxenite
10 – 40	50 – 95	Olivine Pyroxene Hornblendite
10 – 40	95 – 100	Olivine Hornblendite
40 – 90	0 – 5	Pyroxene Peridotite
40 – 90	5 – 95	Pyroxene Hornblende Peridotite
40 – 90	95 – 100	Hornblende Peridotite
90 – 100	any	Dunite

3.9 Charnockites, carbonatites and melilite rocks

Diagram	Apices	Notes
Charnockites, IUGS	Q – AF – P	The orthopyroxene-bearing granitoid series of granulite terranes. Fields: alkali feldspar charnockite, charnockite, opdalite / charno-enderbite, enderbite in the Q 20–60 band; hypersthene alkali feldspar syenite, hypersthene syenite, mangerite, jotunite and norite below Q = 20. M < 10 in the plagioclase corner gives anorthosite.
Carbonatites, IUGS	CaO – MgO – ($FeO+Fe_2O_3+MnO$)	The only chemical diagram in the IUGS set. Enter oxide weight percent. CaO′ ≥ 80 gives calciocarbonatite (sövite, alvikite); below that, MgO ≥ ΣFe gives magnesiocarbonatite (beforsite) and MgO < ΣFe gives ferrocarbonatite. Establish first that the rock has > 50 modal % primary carbonate and < 20 wt % SiO_2.
Melilite-Plutonic, IUGS	Mel – Ol – CPx	Melilitolite, olivine melilitolite (kugdite), pyroxene melilitolite (uncompahgrite) and the intermediate fields; below 10 % melilite, melilite-bearing peridotite or pyroxenite.
Melilite-Volcanic, IUGS	Mel – Ol – CPx	Melilitite and olivine melilitite, separated by a single sloping field line; below 10 % melilite as above.

3.10 The Mafics dialog

The three secondary discriminants — colour index, anorthite content and olivine proportion — are collected sample by sample through the Mafics dialog when a modal classification runs. They are not read from the spreadsheet.

Quantity	Definition	Where it acts
M, colour index	Total mafic and accessory minerals as vol % of the *whole rock*	M < 10 → anorthosite; M ≥ 90 → ultramafic names; andesite vs basalt on both volcanic diagrams
An	Anorthite molecule percent of the plagioclase	An > 50 selects the gabbroic name series; An ≤ 50 selects the dioritic series
Olivine	Olivine as a percentage of *M*, not of the rock	Splits the M ≥ 90 field into pyroxenite / peridotite / dunite; splits tephrite from basanite at 10 %

> If you counted 55 % olivine, 38 % pyroxene and 7 % plagioclase, then M = 93 and the olivine entry is 55/93 = 59, not 55.

3.11 Running a modal classification

1. Enter the modal mineral percentages in the columns nominated through *Define Columns*.
2. Choose *Calculate* ▸ *Calc Modal Classification* and pick the diagram.
3. Supply M, An and olivine in the Mafics dialog as each sample is processed, or suppress the dialog to accept the defaults.
4. The rock name is written into column 2 and can be exported or plotted with the data.

The same field logic is also driven from a chemical analysis: *Calculate* ▸ *Calc Chemical Classification* runs a CIPW norm first and then plots the normative Q, or, ab+an and ne+lc into the same QAPF fields. The result is a normative rock name, which is not the same as a modal one and should be labelled as such.

4. Norm Calculations

4.1 Mode, norm and why both exist

The **mode** is what a rock is made of: the measured volume proportions of the minerals present. The **norm** is what a rock would be made of if it had crystallised completely, anhydrously, at low pressure, into a fixed set of idealised minerals. The norm is a recalculation of a chemical analysis, not an observation.

Norms exist because they make chemically similar rocks comparable regardless of cooling history, alteration or grain size. A glassy obsidian and a coarse granite of identical composition have wildly different modes and identical norms. They also give a chemical route into the IUGS classification for rocks too fine grained to count.

A norm is not a prediction of mineralogy. Normative hypersthene in a rock containing only amphibole is not an error; it is the point of the exercise.

4.2 Choosing a norm

Command	Use for	Method
CIPW Norm (Classic)	Ordinary silicate igneous rocks; comparison with older literature	Cation-percent method after Kelsey (1965). Reports 38 normative minerals plus a large suite of indices.
IUGS CIPW Norm	Current work; anything to be published or audited	Molecular method with substituting-oxide corrections and explicit silica-deficiency reporting. This is the recommended default.
Alkali-Carb Norm	Strongly alkaline rocks and carbonatites	Extends the mineral set with sodium and potassium carbonates, melilite-group minerals, perovskite and the calcium silicates that the standard norms cannot accommodate.

> If you are unsure, use the IUGS norm. It is the more rigorous of the two general routines, it corrects for the minor oxides that substitute in the major-mineral structures, and — most usefully — it tells you when it has failed.

4.3 CIPW Norm (Classic) — the cation method

Menu: Calculate ▸ CIPW Norm (Classic).

4.3.1 Preparation

The analysis is read from columns 5–30. If an iron ratio has been set, it is applied first and the remaining oxides rescaled (§2.6). Oxides are then converted to cation proportions by dividing by the molecular weight per cation:

Oxide	Divisor	Oxide	Divisor	Oxide	Divisor
SiO_2	60.0843	MgO	40.3044	Cl	35.45
TiO_2	79.8988	CaO	56.0794	F	18.9984
Al_2O_3	50.9806	Na_2O	30.9895	S	32.06
Fe_2O_3	79.8461	K_2O	47.098	Cr_2O_3	151.992
FeO	71.8464	P_2O_5	70.9723	ZrO_2	123.22
MnO	70.9374	CO_2	44.0098		

The cation proportions are summed and rescaled to 100. Manganese is added to ferrous iron, so all subsequent references to Fe^{2+} mean FeO + MnO.

4.3.2 Allocation sequence

Minerals are formed in the order below. Each step consumes cations from the pool; once a cation is exhausted the later minerals that need it cannot form. This ordering is the norm.

```
1   apatite      ap = 2.667·P          Ca −= 1.667·P
2   halite       hl = 2·Cl             Na −= Cl
3   fluorite     fl = 1.5·F            Ca −= F/2
4   thenardite   th = 3·SO             Na −= 2·SO
5   pyrite       pr = 1.5·S            Fe2+ −= pr/3
6   chromite     cm = 1.5·Cr           Fe2+ −= 0.5·Cr
7   zircon       zn = 2·Zr             Si −= Zr
8   calcite      cc = 2·CO2            Ca −= CO2
9   ilmenite     il from Fe2+ and Ti, whichever is limiting
10  orthoclase   or = 5·K              Al −= K
      · if Al runs out, the excess K forms K metasilicate (ks)
11  albite       ab = 5·min(Na, Al)
      · if Na exceeds Al, the excess reacts with Fe3+ to give acmite (ac),
        and any Na still left forms Na metasilicate (ns)
12  anorthite    an from Al and Ca, whichever is limiting
      · surplus Al becomes corundum (c)
13  sphene       tn from Ti and Ca; surplus Ti becomes rutile (ru)
14  magnetite    mt from Fe3+ and Fe2+; surplus Fe3+ becomes haematite (hm)
15  diopside     di from Ca and (Fe2+ + Mg); surplus Ca becomes wollastonite (wo)
16  hypersthene  hy = 2·(remaining Fe2+ + Mg)
17  quartz       qz = whatever silica is left over
```

4.3.3 The desilication cascade

If step 17 gives a negative quartz value the rock is silica-undersaturated, and the norm must be rebuilt using less silica-rich minerals. The program works down this cascade, stopping as soon as the deficiency is satisfied:

```
hypersthene → olivine        (2 MgSiO3 → Mg2SiO4 + free SiO2)
sphene      → perovskite
albite      → nepheline
orthoclase  → leucite
wollastonite→ dicalcium silicate
diopside    → dicalcium silicate + olivine
leucite     → kaliophilite
```

Each conversion releases silica. If the cascade runs to the end and the rock is *still* short of silica, the analysis is not a valid igneous composition — see §4.8.

4.3.4 Output

Thirty-eight normative minerals are written, in the order below. The left column is the column heading the program writes; several are abbreviated or misspelled, so the correct mineral name is given alongside.

Column heading	Mineral	Column heading	Mineral
quartz	quartz	na metasilicate	sodium metasilicate
albite	albite	k metasilicate	potassium metasilicate
anorthite	anorthite	corundum	corundum
orthoclase	orthoclase	perovskite	perovskite
apatite	apatite	magnetite	magnetite

Column heading	Mineral	Column heading	Mineral
halite	halite	diopside	diopside
thenardite	thenardite	olivine	olivine
pyrite	pyrite	melanite	melanite
chromite	chromite	**hematite**	haematite
calcite	calcite	rutile	rutile
magnesite	magnesite	fluorite	fluorite
ilmenite	ilmenite	wollastonite	wollastonite
na carbonate	sodium carbonate	akermanite	åkermanite
k carbonate	potassium carbonate	**dicalcsilicate**	dicalcium silicate (larnite)
kaliophilite	kaliophilite	zircon	zircon
nepheline	nepheline	**badylleite**	baddeleyite
kalsilite	kalsilite	sphene	sphene (titanite)
carnegiete	carnegieite	leucite	leucite
acmite	acmite (aegirine)	hypersthene	hypersthene

Excess CO_2 and the total follow.

The routine then appends the derived parameters of §8: AMF and CMAS projections, Q–Ab–Or, the differentiation index, alkalinity ratio, Larsen index, solidification index, total alkalis, FeOt, Mg ratio, felsic and mafic indices, and the silica grade.

4.4 IUGS CIPW Norm — the molecular method

Menu: Calculate ▸ IUGS CIPW Norm.

This routine follows the method of Kelsey (1965) as refined in the IUGS-recommended implementations of Verma and co-workers. It differs from the classic routine in four important ways: it works in molecular rather than cation proportions; it folds the minor oxides into the major ones and then corrects the molecular weights for the substitution; it offers three CO_2 allocation policies; and it reports the silica deficiency explicitly instead of silently producing an impossible norm.

4.4.1 Atomic weights

All molecular weights are derived from these, so a norm can be reproduced exactly.

Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	P	O	C
28.086	47.9	26.98154	55.847	54.938	24.305	40.08	22.98977	39.098	30.97376	15.9994	12.011

H	Zr	Cr	V	Ni	Co	Ba	Sr	Rb	F	Cl	S
1.0079	91.22	51.996	50.9414	58.71	58.9332	137.34	87.62	85.4678	18.9984	35.453	32.06

Oxides are converted to moles on a one-cation basis — SiO_2 as Si + 2O, Al_2O_3 as Al + 1.5O, Na_2O as Na + 0.5O, and so on — so that the allocation arithmetic works in whole cations throughout.

4.4.2 Substituting oxides

Six minor oxides substitute for major ones in the normative minerals rather than forming minerals of their own. They are added to their host before allocation begins:

```
K2O   += Rb2O
CaO   += SrO + BaO
Fe2O3 += V2O3
FeO   += MnO + NiO + CoO
```

The molecular weights of the affected minerals are then corrected in proportion to the substitution, so that mass is conserved. For example the orthoclase molecular weight is increased by

```
corFac(2) = (molWt_Rb2O − molWt_K2O) × Rb2O / K2O
```

and comparable factors are applied to anorthite, wollastonite, sphene, perovskite, apatite and calcite (for Sr and Ba), to acmite and haematite (for V), to chromite, ilmenite, pyrite and siderite (for Mn, Ni and Co), and to diopside, hypersthene and olivine (for the Fe^{2+}/Mg substitution). This is the main numerical difference between this routine and the classic one, and it matters most for rocks rich in Ba, Sr or Mn.

4.4.3 Allocation sequence

Each step forms the smaller of the two available reactants, then subtracts what it consumed. The notation `min(a, b)` means exactly that.

```
1  Z    = ZrO2                                  zircon takes all zirconium
2  ap   = min(0.2·CaO, P2O5/3, F)                fluorapatite
       CaO −= 5·ap    P2O5 −= 3·ap    F −= ap
3  fr   = min(0.5·F, CaO)                        fluorite
       CaO −= fr      F −= 2·fr
4  hap  = min(0.2·CaO, P2O5/3)                   hydroxyapatite
       CaO −= 5·hap   P2O5 −= 3·hap   H2O+ −= hap
```

```
 5  hl   = min(Na2O, Cl)                          halite
 6  pr   = min(0.5·S, FeO)                        pyrite
       FeO −= pr      S −= 2·pr
 7  CO2 allocation — see §4.5
 8  cm   = min(FeO, 0.5·Cr2O3)                    chromite
 9  il   = min(FeO, TiO2)                         ilmenite
10  or   = min(K2O, Al2O3)                        orthoclase
       ks = 0.5·(K2O − or)                       K metasilicate from surplus K
11  ab   = min(Na2O, Al2O3)                       albite
12  ac   = min(Fe2O3, Na2O)                       acmite from surplus Na
       ns = 0.5·(Na2O − ac)                      Na metasilicate from what is left
13  an   = min(0.5·Al2O3, CaO)                    anorthite
       C  = Al2O3 − 2·an                         corundum from surplus Al
14  tn   = min(TiO2, CaO)                         sphene
       ru = TiO2 − tn                            rutile from surplus Ti
15  mt   = min(FeO, 0.5·Fe2O3)                    magnetite
       hm = Fe2O3 − 2·mt                         haematite from surplus Fe3+
16  di   = min(FeO + MgO, CaO)                    diopside
       wo = CaO − di                             wollastonite
       hy = (FeO + MgO) − di                     hypersthene
```

4.4.4 Silica balance

The silica required by the minerals just formed is then totalled:

```
SiReq = or + ab + ns + ks + tn + wo + Z + hy
        + 2·(or + ab + an + ac + di)
```

If SiO_2 exceeds SiReq the rock is oversaturated and the excess becomes quartz. Otherwise the deficiency `SiDef = SiReq − SiO2` is worked off down the cascade below, each step consuming as much of the deficiency as that conversion can supply:

```
hypersthene → olivine            ol = min(0.5·hy, SiDef)
sphene      → perovskite         pf = min(SiDef, tn)
albite      → nepheline          ne = 0.5·SiDef, capped at ab
orthoclase  → leucite            lc = min(SiDef, or)
wollastonite→ dicalcium silicate cs = min(SiDef, 0.5·wo)
diopside    → cs + olivine       consumes 2 units of deficiency per unit
leucite     → kaliophilite       kp = min(SiDef, lc)
still short → Fsd                the silica deficiency that could not be met
```

The molecular quantities are then multiplied by the corrected molecular weights to give weight percent.

4.4.5 Output

Forty-six values are written per sample:

Group	Values
Felsic	Q, C (corundum), Z (zircon), or, ab, an, ne, lc, kp
Sodic and potassic	hl, nc (Na carbonate), ac, ns, ks
Mafic	di, hy, wo, ol, cs (dicalcium silicate)
Oxides and accessories	cm, hm, mt, il, tn, pf, ru
Phosphates, halides, sulphides	ap, hap, fr (fluorite), pr (pyrite)

Group	Values
Carbonates	cc (calcite), mag (magnesite), sid (siderite)
Volatiles and residue	H_2O+, H_2O-, Other
Diagnostics	**Fsd**, excess P_2O_5, CO_2, Cr_2O_3, F, Cl and S; Total; Mg/(Mg+Fe); **SiUnd**

Two of these need explaining, because their names invite the wrong reading:

- **SiUnd** is the *silica undersaturation* — the size of the deficiency at the moment it was detected, before the cascade ran. It is non-zero for every undersaturated rock and says nothing about whether the norm succeeded. A perfectly valid nepheline syenite norm carries SiUnd near 40.
- **Fsd** is meant to be the deficiency the cascade could *not* satisfy — the genuine failure flag. See the caution in §4.8.

The excess columns are not decoration. If `excess CO2` is non-zero, the rock had more carbon dioxide than there were cations to bind it. Excess oxides are reported separately and are *not* included in the normative total, which is why a phosphorus-rich rock with little calcium shows a normative total below its oxide sum.

4.5 CO_2 allocation

When the IUGS norm runs it asks how carbon dioxide should be handled. The choice changes the norm substantially for any carbonate-bearing rock.

Option	Effect
Do not allocate CO_2	CO_2 is moved into the "Other" residue and forms no minerals. Appropriate when the carbonate is demonstrably secondary — vein fill, weathering product — and you want the norm of the primary rock.
Allocate as Na_2CO_3, excess to Ca/Mg/Fe carbonate	Sodium carbonate forms first, consuming 2 Na per CO_2; anything left goes to calcite, then magnesite, then siderite. For natrocarbonatites and strongly peralkaline rocks.
Allocate as $CaCO_3$, $MgCO_3$, $FeCO_3$	Calcite first, then magnesite, then siderite. The usual choice for ordinary carbonate-bearing igneous rocks and the default for most work.

Because calcite is formed before the feldspars, allocating CO_2 removes calcium that would otherwise have made anorthite. A limestone-contaminated basalt will therefore show markedly less normative anorthite once CO_2 is allocated — which is the correct result, and the reason the choice is offered.

4.6 Alkali–Carb Norm

Menu: Calculate ▸ Alkali-Carb Norm.

Standard norms assume that all calcium ends up in apatite, calcite, anorthite, sphene, diopside or wollastonite, and that all alkalis end up in feldspars or feldspathoids. Strongly alkaline rocks and carbonatites break both assumptions. The Alkali–Carb norm extends the mineral set to include sodium and potassium carbonate, kalsilite, carnegieite, akermanite, melanite, perovskite, baddeleyite and dicalcium silicate, which allows a sensible norm for compositions the general routines cannot handle.

> **Use it whenever the rock is a carbonatite, a natrocarbonatite, a foidolite or a melilitite.** Running the standard norm on such a composition produces a large silica deficiency and a normative total that does not match the analysis — see the worked case in §4.8.

4.7 Worked example

Three rocks from the supplied sample data, run through the IUGS norm with CO_2 allocated as Ca/Mg/Fe carbonate.

Nepheline syenite — undersaturated, valid

```
Input   SiO2 44.76  TiO2 2.28  Al2O3 21.96  Fe2O3 7.38  MgO 1.85
        CaO 6.89  Na2O 8.67  K2O 6.15                   oxide sum  99.94

Norm    ne 39.74   lc 16.80   or 14.92   di 9.94
        hm 7.38    wo 4.44    pf 3.88    an 2.84        norm total 99.94
        Q 0        SiUnd 39.96      deficiency fully satisfied
```

Exactly what a nepheline syenite should give: no normative quartz, abundant nepheline and leucite, and a normative total reproducing the oxide sum to two decimal places. SiUnd of 40 records how strongly undersaturated the rock is — it is not a warning.

Granodiorite — oversaturated, valid, but note the total

```
Input   SiO2 67.20  TiO2 0.12  Al2O3 15.31  FeO 0.64  MgO 0.20
        CaO 0.98  Na2O 2.02  K2O 6.63  P2O5 2.64        oxide sum  95.74

Norm    or 39.18   Q 29.33    ab 17.09   C 4.81
        hap 1.76   hy 1.48    il 0.23                   norm total 93.88
        excess P2O5 1.90                                SiUnd 0
```

The normative total falls 1.86 below the oxide sum, which looks alarming until you read the excess column. With only 0.98 % CaO there is not enough calcium to take up 2.64 % P_2O_5 as apatite, so 1.90 % is reported as excess and excluded from the total. The norm is correct; the analysis is simply phosphorus-rich relative to its calcium.

Carbonatite — invalid

```
Input   SiO2 14.87  TiO2 2.44  Al2O3 6.28  Fe2O3 5.68  FeO 8.14
        MgO 3.53  CaO 29.78  Na2O 2.40  K2O 2.12
        P2O5 1.03  H2O+ 2.38  CO2 (not reported)         oxide sum  78.72

Norm    cs 43.62   ne 11.00   ol 9.55    mt 8.24
        kp 7.12    il 4.63    hap 2.43                  norm total 89.03
        SiUnd 45.84      11.8 % of the deficiency never satisfied
```

The normative total *exceeds* the oxide sum by more than ten percent, which is impossible. The cause is the missing CO_2 analysis: with 29.8 % CaO and no carbon dioxide to make calcite, the calcium is forced into dicalcium silicate, and the norm demands silica the rock does not contain. The remedy is to enter the measured CO_2 and use the Alkali–Carb norm.

4.8 Diagnostics and failure modes

Three checks will catch almost every bad norm.

Does the normative total match the oxide sum?

It should, to within rounding. A normative total that *exceeds* the oxide sum means the allocation produced minerals containing more silica than the rock actually has — the cascade was exhausted. A total well below the oxide sum usually means volatiles or minor oxides were not allocated.

Do not rely on the Fsd column alone

> **Known issue.** The unsatisfied silica deficiency is stored as a negative quantity and then passed through a filter that zeroes any value below 0.001. The result is that `Fsd` reads zero in precisely the case it is meant to flag. Until this is corrected, use the total-versus-oxide-sum comparison above as your check — it catches the same failures reliably.

The table below shows all four diagnostics across the supplied sample data. Note that SiUnd is large for two perfectly valid norms and that Fsd is zero for the one invalid norm.

Sample	Oxide sum	Norm total	SiUnd	Fsd	Verdict
Rhyolite	100.41	100.41	0	0	Valid, oversaturated
Nepheline syenite	99.94	99.94	39.96	0	Valid, undersaturated
Ijolite	98.77	98.84	39.45	0	Valid, undersaturated
Cape Verde volcanic	99.82	99.82	12.04	0	Valid, undersaturated
Granodiorite	95.74	93.88	0	0	Valid; shortfall is excess P_2O_5
Carbonatite	**78.72**	**89.03**	45.84	**0**	**Invalid** — total exceeds oxide sum by 10.3

> **Blank is not the same as "not determined".** Every empty major-oxide cell is read as zero. An analysis with FeO left blank because only total iron was reported will produce a norm with no hypersthene and far too much haematite. Put total iron in the Fe_2O_3 column and set an iron ratio, or split it yourself — but do not leave it blank.

Do the minerals make sense together?

Some pairs cannot coexist in a valid norm, and their appearance together is a reliable sign of a data problem:

- **Quartz with nepheline, leucite or kalsilite** — impossible; silica cannot be both in excess and deficient.
- **Quartz with olivine but no hypersthene** — indicates the cascade ran when it should not have.
- **Large corundum in a mafic rock** — normally means the alkalis are under-reported or the alumina over-reported. A few percent of normative corundum in a peraluminous granite is expected; ten percent in a basalt is not.
- **Large acmite or sodium metasilicate** — genuine in peralkaline rocks, but otherwise suggests a sodium analysis that is too high, or an alumina value that is too low.

5. Chemical Classification Diagrams

These diagrams name a rock from its chemistry rather than its mineralogy. They are the right tool when the rock is too fine grained, too glassy or too altered for a reliable mode — and the wrong tool when a mode is available, because a chemical name is always a weaker statement than a modal one.

All are reached from *Plot* ▸ *Classification Plot* and selected by name in the Graph drop-down. The table below is the complete catalogue, with the variables each one plots.

The middle column gives the axis or apex labels exactly as the program writes them, so that a plot can be matched to this table without ambiguity.

Graph drop-down entry	Type	Labels as drawn	Meaning
TAS-Le Bas, 1986	XY	`SiO2` / `K2O+Na2O`	Silica vs total alkalis
TAS-Middlemost, 1994	XY	`SiO2` / `K2O+Na2O`	Revised volcanic boundaries
TAS-Plutonic, Middlemost, 1994	XY	`SiO2` / `K2O+Na2O`	Plutonic equivalents
Nb/Y-Zr/TiO2-Winchester and Floyd 1977	Log	`Nb/Y` / `Zr/TiO2*0.0001`	Immobile-element classification
Zr/TiO2-SiO2, Winchester and Floyd 1977	Log	`Zr/TiO2*0.0001` / `SiO2`	Immobile-element classification
Jensen Cation, 1976	Ternary	`Fet+Ti` — `Al` — `Mg`	Cation percent
AFM	Ternary	`F` — `A` — `M`	FeOt — alkalis — MgO
AnAbOr-Barker, 1979	Ternary	`An` — `Ab` — `Or`	Normative feldspar
ACF	Ternary	`A` — `C` — `F`	Eskola metamorphic projection
AKF	Ternary	`A'` — `K` — `F`	Eskola metamorphic projection
Sandstones, Selley, 1984	Ternary	`Quartz` — `Clay` — `Felds`	Matrix as an apex
Sandstones, Pettijohn, 1975	Ternary	`Quartz` — `Felds` — `RF`	QFR, whole family
Arenites, Pettijohn, 1975	Ternary	`Quartz` — `Felds` — `RF`	Matrix-poor
Wackes, Pettijohn, 1975	Ternary	`Quartz` — `Felds` — `RF`	Matrix-rich

5.1 TAS — Le Bas and Middlemost

The total alkali–silica diagram is the IUGS-recommended chemical classification for volcanic rocks. It plots Na_2O+K_2O against SiO_2, both recalculated to 100 % volatile free, and divides the plane into named fields.

WinRock implements the field boundaries as explicit border equations, and it does something more sophisticated than a simple plot: because the position of a sample depends on the iron ratio assumed, and the appropriate iron ratio depends on the rock type, the classification is **iterative**. A provisional name is assigned, the Middlemost (1989) iron ratio for that rock type is applied, and the classification is repeated until the name stops changing. The high-magnesium rocks — komatiite, meimechite, boninite and picrite — are separated first, following Le Bas (2000), since for these no iteration is required.

The complete field set the routine can return:

Foidite · Basanite · Tephrite · Phonolite · Peralkaline Phonolite · Melanephelinite · Nephelinite · Melilite Nephelinite · Melilitite · Potassic Melilitite · Melilite Leucite · Basalt · Subalkali Basalt · Alkali Basalt · Trachybasalt · Potassic Trachybasalt · Hawaiite · Basaltic Trachyandesite · Mugearite · Shoshonite · Trachyandesite · Benmoreite · Latite · Trachyte · Comenditic Trachyte · Pantelleritic Trachyte · Trachydacite · Rhyolite · Comenditic Rhyolite · Pantelleritic Rhyolite

Note that the sodic and potassic series names — hawaiite, mugearite, benmoreite versus potassic trachybasalt, shoshonite, latite — are separated on the $Na_2O - 2$ relation to K_2O, and that the peralkaline rhyolite and trachyte fields are subdivided into comenditic and pantelleritic on the agpaitic index. Both refinements are applied automatically.

> **Recalculate volatile free before plotting on TAS.** A few percent of undeclared water shifts a sample by an amount comparable to the width of a field boundary. This is the most common source of disagreement between two people classifying the same analysis.

Middlemost (1994) revised several boundaries and added a plutonic version of the diagram, in which the volcanic names are replaced by their intrusive equivalents. Use the plutonic version for coarse-grained rocks, but prefer a modal QAPF determination when you can get one.

5.2 Winchester and Floyd

Two log–log plots based on elements considered immobile during alteration and low-grade metamorphism — Nb, Y, Zr and Ti. This is the classification of choice for altered volcanic rocks, including greenstone-belt and sea-floor-altered material, where the alkalis and silica can no longer be trusted.

```
Nb/Y  vs  Zr/TiO2 × 0.0001      (the more widely used of the two)
Zr/TiO2 × 0.0001  vs  SiO2
```

The Nb/Y axis is essentially an alkalinity index, and Zr/TiO_2 a differentiation index, so the diagram reproduces the TAS field arrangement using elements that survive alteration. If your rocks plot sensibly on Winchester and Floyd but scatter wildly on TAS, alteration is the likely explanation, and the immobile-element classification is the one to report.

5.3 Jensen cation plot

A ternary in cation percent with apices Fe_t+Ti, Al and Mg, designed by Jensen (1976) for subalkaline volcanic rocks and particularly useful in Archaean greenstone terranes. It separates the tholeiitic, calc-alkaline and komatiitic series more cleanly than AFM does, and it resolves the high-Mg komatiite field that AFM compresses against the M apex.

5.4 AFM

The classical ternary separating the tholeiitic from the calc-alkaline trend:

```
A = Na2O + K2O
F = total iron as FeO  =  Fe2O3/1.1113 + FeO
M = MgO
```

WinRock computes A, F and M during every CIPW norm run and writes them to the derived columns, so the plot is available immediately after a norm. Remember that AFM shows a *trend*, not a rock name: a single sample on an AFM diagram tells you very little, and the diagram is only informative for a suite.

5.5 An–Ab–Or

Barker (1979) plotted normative anorthite, albite and orthoclase to classify granitoids, separating tonalite, granodiorite, trondhjemite and granite. Because the apices are normative, a CIPW norm must be run first. This diagram is the chemical counterpart of the plutonic QAPF triangle and is a useful cross-check on a modal determination made on a rock with fine-grained or altered feldspar.

5.6 ACF and AKF

Eskola's metamorphic projections, used to display mineral assemblages in metamorphic facies. ACF handles calcic assemblages, AKF the potassic ones. They classify an *assemblage*, not a rock, and are used with tie-lines joining coexisting minerals rather than as field diagrams.

5.7 Sandstone schemes

Four schemes are supplied, all ternary and all plotted from point-count data rather than chemistry.

Scheme	Apices	Use
Selley, 1984	Quartz — Clay — Feldspar	General-purpose, with the matrix content as an explicit apex
Pettijohn, 1975 (sandstones)	Quartz — Feldspar — Rock fragments	The standard QFR scheme covering the whole sandstone family
Pettijohn, 1975 (arenites)	Quartz — Feldspar — Rock fragments	For matrix-poor sandstones (< ~15 % matrix): quartz arenite, subarkose, sublitharenite, arkose, litharenite
Pettijohn, 1975 (wackes)	Quartz — Feldspar — Rock fragments	For matrix-rich sandstones (> ~15 % matrix): quartz wacke, feldspathic wacke, lithic wacke

Decide first whether the rock is an arenite or a wacke on its matrix content, then use the matching diagram. Plotting a wacke on the arenite diagram will name it, but the name will be wrong.

6. Tectonic Discrimination Diagrams

Discrimination diagrams assign a tectonic setting from bulk chemistry, using empirical fields drawn around suites of known provenance. They are reached from *Plot* ▸ *Discrimination Plot*, or from the same Classification Plot list.

> **Read this before using any of them.** These diagrams are statistical, not deterministic. The fields were drawn around modern analogues, they overlap substantially, and a single sample falling in a field is weak evidence. They are also sensitive to alteration, to crustal contamination and to the iron ratio assumed. Use several diagrams, use a suite rather than a sample, and treat a consistent answer across independent element groups as the only result worth reporting.

As in §5, the middle column reproduces the drop-down entry and the axis labels verbatim. Note that the Pearce and Cann entries are spelled `PearceCann` as a single word in the menu.

Graph drop-down entry	Type	Labels as drawn	Discriminates
Ti/Zr, PearceCann, 1973	XY	`Zr (ppm)` / `Ti (ppm)`	OFB, LKT, CAB
Ti/Zr/Y, PearceCann, 1973	Ternary	`Ti/100` — `Zr` — `Yx3`	adds within-plate basalt
Nb/Zr/Y, Meschede, 1986	Ternary	`2xNb'` — `Zr/4` — `Y`	MORB types, WPB, VAB
MnO/TiO2/P2O5, Mullen, 1983	Ternary	`TiO2` — `10xMnO` — `10xP2O5`	IAT, CAB, OIT, OIA, boninite
MgO/FeOt/Al2O3, Pearce et al, 1977	Ternary	`FeOt` — `MgO` — `Al2O3`	basalt settings
R1/R2, Batchelor and Bowden, 1985	XY	`R1=4*Si-11*(Na + K)-2*(Fe + Ti)` `R2=6*Ca+2*Mg+Al`	granitoid orogenic stage
Y+Nb vs Rb, Pearce et al, 1984	Log	`Y + Nb` / `Rb`	ORG, VAG, WPG, syn-COLG
Y vs Nb, Pearce et al, 1984	Log	`Y` / `Nb`	resolves ORG
Ta+Yb vs Rb, Pearce et al, 1984	Log	`Ta + Yb` / `Rb`	ORG, VAG, WPG, syn-COLG
Yb vs Ta, Pearce et al, 1984	Log	`Yb` / `Ta`	resolves ORG
Rb/Hf/Ta, Harris et al, 1986	Ternary	`Rb/10` — `Hf` — `Ta*3`	collision-zone granites

6.1 Pearce and Cann

The original basalt discrimination diagrams, based on Ti, Zr and Y — elements chosen for their immobility. The Ti–Zr binary separates ocean-floor basalt, low-potassium tholeiite and calc-alkali basalt; the Ti/100–Zr–Y×3 ternary adds within-plate basalt as a distinct field.

The multipliers in the ternary are not decoration: they scale the three elements into a comparable numerical range so the fields occupy a usable part of the triangle. Enter raw ppm values — the program applies the scaling.

6.2 Meschede Nb–Zr–Y

Meschede (1986) revised the Pearce and Cann approach by substituting niobium for titanium, which is less susceptible to fractionation of Fe–Ti oxides. Fields AI and AII are within-plate alkali basalt, AII and C within-plate tholeiite, B P-type MORB, D N-type MORB, and C and D volcanic-arc basalt. The overlapping labels are inherent to the scheme, not a limitation of the implementation.

6.3 Mullen MnO–TiO_2–P_2O_5

Mullen (1983) used three minor oxides to separate island-arc tholeiite (IAT), calc-alkaline basalt (CAB), ocean-island tholeiite (OIT), ocean-island alkali basalt (OIA) and boninite. Because it uses major-element oxides rather than trace elements it is available for older analyses that lack trace data — but for the same reason it is more vulnerable to alteration than the immobile-element schemes.

6.4 Pearce, Gorman and Birkett

The MgO–FeOt–Al_2O_3 ternary of Pearce et al. (1977) discriminates basalt from spreading-centre, orogenic, ocean-island, continental and other settings. It shares the alteration sensitivity of any major-element scheme.

6.5 Batchelor and Bowden R1–R2

A cation-parameter plot for granitoids, after the multicationic scheme of De la Roche:

```
R1 = 4·Si − 11·(Na + K) − 2·(Fe + Ti)
R2 = 6·Ca + 2·Mg + Al                        (millication proportions)
```

The plane is divided into fields representing stages of an orogenic cycle: mantle fractionates, pre-plate collision, post-collision uplift, late orogenic, anorogenic, syn-collision and post-orogenic. Because both parameters are combinations of the major elements, the diagram uses the whole analysis rather than a handful of elements, which makes it robust to a single bad determination but sensitive to the iron ratio.

6.6 Pearce, Harris and Tindle granite plots

Four log–log plots, all discriminating the same four granite types from trace-element ratios:

- **ORG** — ocean ridge granite
- **VAG** — volcanic arc granite
- **WPG** — within-plate granite
- **syn-COLG** — syn-collision granite

Y+Nb vs Rb and Ta+Yb vs Rb are the primary discriminants; Y vs Nb and Yb vs Ta are used to resolve the ORG field, which the Rb plots handle poorly. The convention is to plot all four and report the setting only where they agree.

6.7 Harris, Pearce and Tindle Rb–Hf–Ta

A ternary alternative to the Pearce granite plots, with apices Rb/10, Hf and Ta×3. It resolves syn-collision, volcanic-arc, within-plate and late/post-collision granites, and is often the more decisive of the two approaches for collision-zone suites.

7. Spider and REE Diagrams

7.1 How normalisation works

A spider diagram plots element abundances divided by the abundances in a reference reservoir, on a logarithmic vertical axis, with the elements arranged along the horizontal axis in an order chosen to make petrological sense — usually by increasing compatibility.

```
plotted value for element i  =  sample(i) / normaliser(i)
```

The point of normalising is to remove the sawtooth pattern that raw abundances show as a result of the Oddo–Harkins effect (elements of even atomic number are more abundant than their odd-numbered neighbours). Against a chondritic or mantle reference the sawtooth cancels and genuine anomalies — a europium trough, a niobium notch — become visible.

WinRock reads its normalising values from `.rok` files in the `spider` folder, each a plain tab-delimited list of elements and abundances with a descriptive first line. You can add your own by copying an existing file and editing it.

7.2 Reference reservoirs supplied

File	Reservoir	Source
Chond1980.rok	Chondrites	Sun et al., 1980
Chond1982.rok	Chondrites	Thompson, 1982
REE.rok, REE1974.rok	REE chondrite	Nakamura, 1974
REEeu.rok	Chondrite (REE with Eu)	—
PrimitiveMantle1989.rok	Primitive mantle	Sun and McDonough, 1989
PrimitiveMantle1995.rok	Primitive mantle	McDonough and Sun, 1995
REEPrimitiveMantle1995.rok	REE primitive mantle	McDonough and Sun, 1995
PrimorMan1979.rok	Primordial mantle	Wood et al., 1979
PRIMMANTLE1.rok	Primordial mantle	—
NMORB1989.rok	N-type MORB	Sun and McDonough, 1989
EMORB1989.rok	E-type MORB	Sun and McDonough, 1989
MORB1996.rok	MORB	Pearce, 1996
OIB1989.rok	Ocean island basalt	Sun and McDonough, 1989
UpContCrust1995.rok	Upper continental crust	Taylor and McLennan, 1995
LowerContCrust1995.rok	Lower continental crust	Taylor and McLennan, 1995
BulkContCrust1995.rok	Bulk continental crust	Taylor and McLennan, 1995
UppCrust.rok	Upper crust	Taylor and McLennan, 1985
AvCrust.rok	Average crust	Weaver and Tarney, 1984
LowCrust1984.rok	Lower crust	Weaver and Tarney, 1984
PGEChondrite1996.rok	PGE chondrite	Jochum, 1996
HSEChondrite1996.rok	HSE chondrite	Jochum, 1996
PGEPrimMantle1995.rok	PGE primitive mantle	McDonough and Sun, 1995

File	Reservoir	Source
HSEPrimMantle2006.rok	HSE primitive mantle	Becker et al., 2006

7.3 Choosing a normaliser

The choice is not cosmetic — it determines what the diagram can show.

Question you are asking	Normalise to
How fractionated is this rock relative to the solar system starting composition?	Chondrite (Nakamura 1974 for REE; Sun et al. 1980 or Thompson 1982 for the wider element set)
How much melting or enrichment has the mantle source seen?	Primitive mantle (McDonough and Sun 1995 is the current standard)
How does this basalt compare with normal ocean-ridge melt?	N-MORB (Sun and McDonough 1989)
Is there a crustal contamination signature?	Upper or bulk continental crust (Taylor and McLennan 1995)
What is happening to the platinum-group elements?	PGE or HSE chondrite / primitive mantle

> Always state the normaliser in the figure caption. A pattern normalised to chondrite and the same pattern normalised to primitive mantle differ by roughly a factor of two and a half in absolute level, and REE patterns in particular are frequently compared across papers without checking that the reference is the same.

8. Indices and Derived Parameters

Every CIPW norm run computes the parameters below and writes them into the output columns. They are available for plotting on any XY or ternary diagram.

8.1 Alkali and iron parameters

```
Total alkalis   =  Na2O + K2O

FeOt            =  Fe2O3 / 1.1113  +  FeO          total iron as FeO

Mg ratio        =  100 · (MgO/40.304)
                   ──────────────────────────────────────────────────
                   (MgO/40.304) + 2·(Fe2O3/159.688) + (FeO/71.844)

Felsic index    =  100 · (Na2O + K2O) / (Na2O + K2O + CaO)

Mafic index     =  100 · (Fe2O3 + FeO) / (Fe2O3 + FeO + MgO)
```

The Mg ratio is the molecular Mg/(Mg+Fe_{total}) ratio, conventionally written Mg#. It is the single most useful measure of how primitive a mafic magma is: values above about 68 are consistent with equilibrium with mantle olivine, and values below that indicate fractionation.

8.2 Differentiation indices

```
Differentiation index (Thornton and Tuttle)
      DI  =  Q + or + ab + ne + ks + lc          from the norm

Solidification index (Kuno)
      SI  =  100 · MgO / (MgO + Fe2O3 + FeO + Na2O + K2O)

Larsen index
      LI  =  (1/3)·SiO2 + (K2O − MgO − CaO − FeOt)

Alkalinity ratio
      if SiO2 > 50 and 1 < K2O/Na2O < 2.5
          AR = (Al2O3 + CaO + 2·Na2O) / (Al2O3 + CaO − 2·Na2O)
      otherwise
          AR = (Al2O3 + CaO + Na2O + K2O) / (Al2O3 + CaO − Na2O − K2O)
```

The differentiation index sums the normative salic minerals of the residua system and rises through a fractionation series. The solidification index does the opposite, falling from high values in primitive magmas. The Larsen index is a single-parameter alternative to SiO_2 as the abscissa of a variation diagram, and is more effective than silica for suites in which silica varies little.

The alkalinity ratio switches formula on composition: the first form is applied to potassic silicic rocks, the second to everything else. Be aware of the switch if you are comparing AR values across a suite that straddles the boundary.

8.3 Ternary projections

```
AMF     A = Na2O + K2O      M = MgO      F = Fe2O3/1.1113 + FeO
        each expressed as 100 × itself / (A + M + F)
```

```
CMAS    C = (CaO − 3.33·P2O5 + 2·Na2O + 2·K2O) · 56.08
        M = (FeO + MnO + NiO + MgO − TiO2) · 40.31
        A = (Al2O3 + Cr2O3 + Fe2O3 + Na2O + K2O + TiO2) · 101.96
        S = (SiO2 − 2·Na2O − 2·K2O) · 60.09
        all terms in molecular proportions before the weight factors
```

CMAS is the four-component projection used in experimental petrology to relate natural compositions to phase equilibria in the CaO–MgO–Al_2O_3–SiO_2 system. The corrections remove phosphorus into apatite, titanium into an oxide component and the alkalis into feldspar before projecting.

8.4 Silica grade

A coarse descriptive term written into the output for every sample:

SiO_2 wt %	Term
35 – 45	Ultrabasic
45 – 52	Basic
52 – 63	Intermediate
≥ 63	Acid

Note that a sample below 35 % SiO_2 receives no silica grade. Carbonatites and some ultramafic rocks fall in this gap.

9. Troubleshooting

Symptom	Cause and remedy
Norm gives implausible minerals — huge corundum, huge acmite, no hypersthene	Almost always a column-alignment problem. Check that each oxide sits under the heading the program wrote (§2.1). Re-import from a template if in doubt.
Normative total exceeds the oxide sum	The silica cascade was exhausted; the norm is not valid. Usually a missing CO_2 or a strongly alkaline composition. Use the Alkali–Carb norm (§4.6).
Normative total falls short of the oxide sum	Check the excess columns. Excess P_2O_5, CO_2, F, Cl or S is reported separately and excluded from the total (§4.7).
No normative hypersthene and far too much haematite	FeO was left blank while total iron was reported as Fe_2O_3. Set an iron ratio (§2.6).
Every volcanic rock classifies as andesite	The Mafics colour index was left blank, so M is read as zero. Supply M (§3.10).
Modal name disagrees with the chemical name	Expected, and informative. A modal name describes the rock; a normative name describes its chemistry. Report the modal name and note the normative one.
TAS names shift when the analysis is recalculated	Correct behaviour — TAS is defined on a volatile-free basis. Recalculate to 100 % volatile free before classifying, and do so consistently across the suite.
Trace elements plot in the wrong place on a spider diagram	The trace-element column order is fixed and interleaves Th, Pa and U between Pr and Nd (§2.2). A lanthanide-only paste will be misaligned.
Discrimination diagrams disagree with each other	Normal. Report a setting only where independent element groups agree, and prefer immobile-element schemes for altered rocks (§6).

10. Glossary

Agpaitic index — molecular (Na+K)/Al. Above 1 the rock is peralkaline.

Colour index (M) — total volume percent of mafic and accessory minerals.

Compatible / **incompatible** — an element preferentially retained in the solid residue during melting, or preferentially partitioned into the melt.

Desilication cascade — the ordered sequence of mineral conversions used to build a norm for a silica-deficient composition.

Foid — feldspathoid: nepheline, leucite, sodalite, nosean, haüyne, cancrinite, analcime.

Mode — measured volume proportions of the minerals present.

Norm — idealised mineral assemblage calculated from a chemical analysis.

Oddo–Harkins effect — the tendency of even-atomic-number elements to be more abundant than their odd-numbered neighbours; the reason spider diagrams are normalised.

P′ — plagioclase ratio, 100 × P/(A+P); the horizontal coordinate of QAPF.

Peralkaline / **peraluminous** / **metaluminous** — molecular Al relative to the alkalis and calcium.

QAPF — the double triangle with quartz, alkali feldspar, plagioclase and feldspathoid apices.

Salic / **femic** — the light-coloured normative minerals (quartz, feldspars, feldspathoids) and the dark ones.

Saturation — a rock is silica-oversaturated if it carries normative quartz, undersaturated if it carries normative feldspathoids or olivine with no hypersthene.

TAS — total alkali–silica diagram.

Ultramafic — colour index ≥ 90.

11. References

Sources for the schemes implemented in WinRock. Where the program's field boundaries depart from the published scheme, the departure is noted in the relevant section above.

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This reference guide documents WinRock as built. Field boundaries, allocation sequences, molecular weights and index formulae in §3, §4, §5, §6 and §8 were read from the program source; the norm sequence in §4.4 and the diagnostics in §4.8 were additionally verified by running the documented algorithm against the bundled sample datasets.