



ELSEVIER

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

MetaRep, an extended CMAS 3D program to visualize mafic (CMAS, ACF-S, ACF-N) and pelitic (AFM-K, AFM-S, AKF-S) projections [☆]

Lydéric France ^{a,*}, Christian Nicollet ^{b,c,d}

^a Géosciences Montpellier, Université Montpellier 2—CNRS, 34095 Montpellier Cedex 05, France

^b Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, BP 10448, F-63000 Clermont-Ferrand, France

^c CNRS, UMR 6524, LMV, F-63038 Clermont-Ferrand, France

^d IRD, R 163, LMV, F-63038 Clermont-Ferrand, France

ARTICLE INFO

Article history:

Received 5 March 2009

Received in revised form

5 December 2009

Accepted 19 January 2010

Keywords:

Projections
3D representation
Major element

ABSTRACT

MetaRep is a program based on our earlier program CMAS 3D. It is developed in MATLAB[®] script. MetaRep objectives are to visualize and project major element compositions of mafic and pelitic rocks and their minerals in the pseudo-quaternary projections of the ACF-S, ACF-N, CMAS, AFM-K, AFM-S and AKF-S systems. These six systems are commonly used to describe metamorphic mineral assemblages and magmatic evolutions. Each system, made of four apices, can be represented in a tetrahedron that can be visualized in three dimensions with MetaRep; the four tetrahedron apices represent oxides or combination of oxides that define the composition of the projected rock or mineral. The three-dimensional representation allows one to obtain a better understanding of the topology of the relationships between the rocks and minerals and relations. From these systems, MetaRep can also project data in ternary plots (for example, the ACF, AFM and AKF ternary projections can be generated). A functional interface makes it easy to use and does not require any knowledge of MATLAB[®] programming. To facilitate the use, MetaRep loads, from the main interface, data compiled in a Microsoft Excel[™] spreadsheet. Although useful for scientific research, the program is also a powerful tool for teaching. We propose an application example that, by using two combined systems (ACF-S and ACF-N), provides strong confirmation in the petrological interpretation.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

CMAS 3D developed by France et al. (2009) visualizes CaO–MgO–Al₂O₃–SiO₂ (CMAS) chemical data in three dimensions. Our new program MetaRep is based on the CMAS 3D development, but extended to include 6 projection systems. Calculations of projections are made using a MATLAB[®] script, but a graphic user interface (Fig. 1) allows one to use MetaRep without any modification of the source script. Depending on the system, as many as 13 oxides can be used for projections (see Table 1). Projection information is exported in the Virtual Reality Modeling Language (VRML) format (Carey et al., 1997) to visualize results in 3D using a VRML browser. This visualisation is totally new for chemical data representations and easily allows precise observations in 3D. Addition of points as mineral and whole rock compositions, lines connecting two of these and planes connecting three of them are also possible. It facilitates discussions about chemical equilibration of metamorphic reactions and exsolution, and helps

in visualizing chemical trends (Fig. 2). MetaRep is therefore a complementary tool to thermodynamic models such as MELTS (Ghiorso and Sack, 1995; Ghiorso et al., 2002) or Perpel_X (Connolly, 2005; <http://www.perplex.ethz.ch/>). Furthermore, MetaRep generates projections on any planes (Fig. 3); the projection apices of these planes and the projection pole can be any points: minerals, whole rocks or virtual compositions in or outside the tetrahedra.

The MetaRep program includes the CMAS, ACF-S, ACF-N, AFM-K, AFM-S and AKF-S systems (see “projection systems” part for details on these systems; for pitfalls using projection diagram for statistical analyses, see e.g., Buccianti et al., 2006). The CMAS system is largely used for mafic and ultramafic compositions (O'Hara, 1968, 1976; France et al., 2009). ACF-S and ACF-N are particularly adapted to represent Na-rich high pressure metabasites (Spear, 1995); AFM-K, AFM-S and AKF-S systems are adapted and largely used for metapelites (e.g., Bucher and Frey, 2002). Therefore MetaRep can represent nearly all metamorphic and magmatic rocks.

2. Projection systems

Bucher and Frey (2002), Thompson (1957), Winkler (1979) and Spear (1995) summarize the classical pseudo-quaternary

^{*} Code available from server at <<http://www.iamg.org/CGEditor/index.htm>>.

^{*} Corresponding author. Tel.: +33 687504717; fax: +33 467143603.

E-mail addresses: lyderic.france@u-cergy.fr, lfrance@um2.fr (L. France).

¹ Now at: Géosciences et Environnement Cergy, Université Cergy-Pontoise, 5 Mail Gay Lussac, Neuville sur Oise, 95031 Cergy-Pontoise Cedex, France.

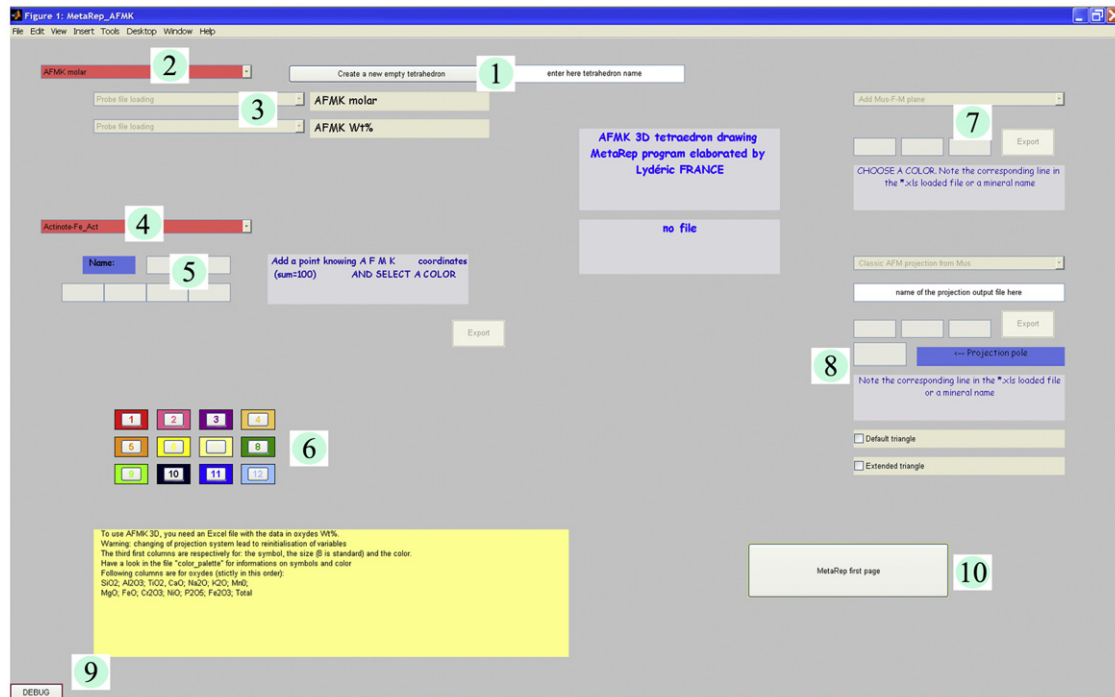


Fig. 1. Metarep interface for AFM-K system. Numbers are discussed in part 4.

Table 1

Example of a “data.xls” type file; data are for samples presented in part 5 (WR: whole rock composition; Ch: Chenaillet; Q: Queyras). “Symbol” value is 1 for a sphere and 2 for a cube, average size is 8 and 12 colors are available (see file “C:\MetaRep_1.1\colors&symbols.jpg” in supplementary material).

Sample	Symbol	Size	Color	SiO ₂	Al ₂ O ₃	TiO ₂	CaO	Na ₂ O	K ₂ O	MnO	MgO	FeO	Cr ₂ O ₃	NiO	P ₂ O ₅	Fe ₂ O ₃	Total
Rch	2	15	6	51.00	15.16	1.19	10.54	4.10	0.11	0.14	8.33	5.89	0.00	0.00	0.00	0.00	100.00
Rq	2	15	11	50.66	17.12	0.25	9.74	3.66	0.59	0.09	8.01	4.52	0.00	0.00	0.00	0.00	100.00
Cpx	1	10	5	52.09	3.58	0.55	22.65	0.52	0.01	0.14	15.79	3.83	0.00	0.00	0.00	0.00	100.00
Pl	1	10	12	58.10	26.44	0.00	7.84	6.48	1.10	0.00	0.03	0.15	0.00	0.00	0.00	0.00	100.00
Hbl	1	10	8	49.99	7.13	1.01	12.09	1.54	0.18	0.12	18.42	7.08	0.00	0.00	0.00	0.00	100.00
Glc	1	10	3	59.61	10.17	0.00	0.74	6.96	0.01	0.19	11.36	8.40	0.00	0.00	0.00	0.00	100.00
Zo	1	10	1	38.66	29.92	0.13	24.37	0.02	0.00	0.05	0.00	4.64	0.00	0.00	0.00	0.00	100.00

projections and how to generate each by defining the following ACFS, ACFN, AFMK, AFMS and AKFS components in terms of mole fractions of oxides with these equations:

ACFS (Winkler, 1979):

$$A_0 = (Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O); C_0 = (CaO - 3.3P_2O_5); F_0 = (FeO + MgO + MnO); S_0 = (SiO_2) \text{ and } A = A_0/sum; C = C_0/sum; F = F_0/sum; S = S_0/sum \text{ with } sum = A_0 + C_0 + F_0 + S_0$$

ACFN (Spear, 1995):

$$A_0 = (Al_2O_3); C_0 = (CaO); F_0 = (FeO + MgO); N_0 = (Na_2O) \text{ and } A = A_0/sum; C = C_0/sum; F = F_0/sum; N = N_0/sum \text{ with } sum = A_0 + C_0 + F_0 + N_0$$

AFMK (Bucher and Frey, 2002):

$$A_0 = (Al_2O_3); F_0 = (FeO); M_0 = (MgO); K_0 = (K_2O) \text{ and } A = A_0/sum; F = F_0/sum; M = M_0/sum; K = K_0/sum \text{ with } sum = A_0 + F_0 + M_0 + K_0$$

AFMS (Bucher and Frey, 2002):

$$A_0 = (Al_2O_3); F_0 = (FeO); M_0 = (MgO); S_0 = (SiO_2) \text{ and } A = A_0/sum; F = F_0/sum; M = M_0/sum; S = S_0/sum \text{ with } sum = A_0 + F_0 + M_0 + S_0$$

AKFS (Bucher and Frey, 2002):

$$A_0 = (Al_2O_3 + Fe_2O_3) - (Na_2O + K_2O + CaO); K_0 = (K_2O); F_0 = (FeO + MgO + MnO); S_0 = (SiO_2) \text{ and } A = A_0/sum; K = K_0/sum; F = F_0/sum; S = S_0/sum \text{ with } sum = A_0 + K_0 + F_0 + S_0$$

All are molar quantities (except if “weight projection” option is used; see Section 4). These values, when calculated for the mineral or whole-rock compositions in question, are the projected point coordinates in the ACFS, ACFN, AFMK, AFMS and AKFS tetrahedra, respectively.

3. Starting the program

MetaRep can be used on a PC; Microsoft Excel™ and a version of Matlab 6.5 or more recent are required. VRML software is also necessary to read the result files (*.wrl); “Flux Player”, a freely downloadable software, is provided with the supplementary material.

No installation procedure is required but the folder “MetaRep_1.1” has to be located on the “C:” directory.

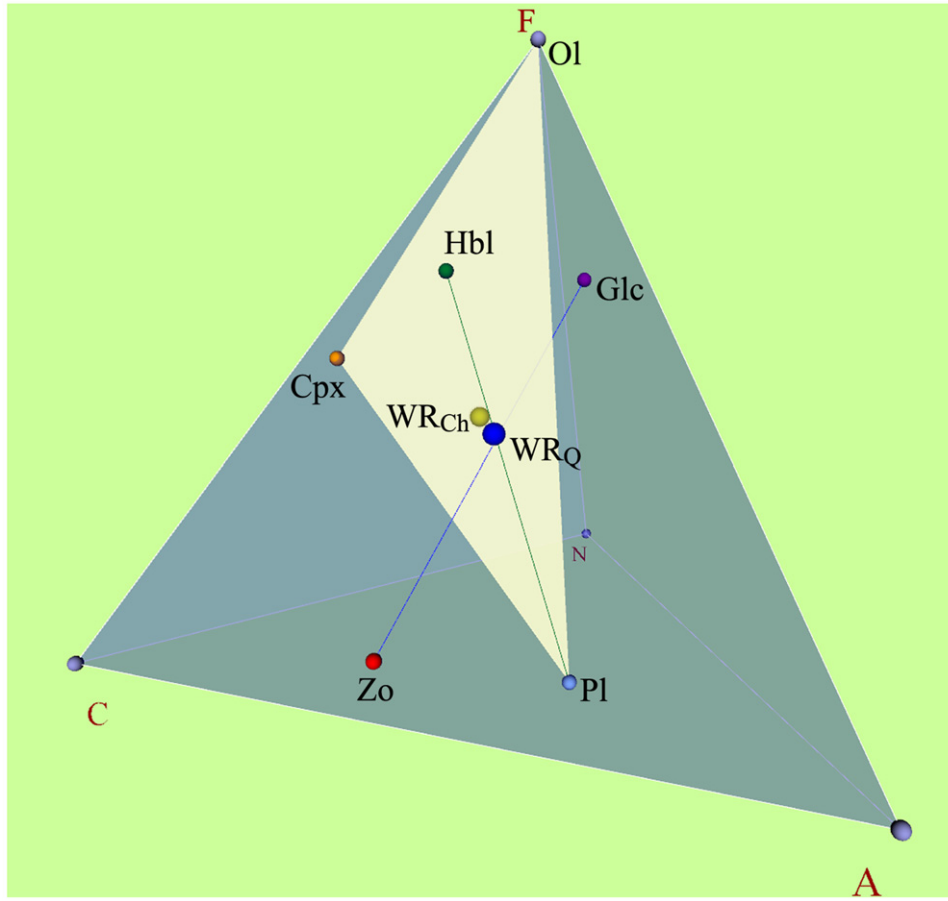


Fig. 2. Three-dimensional visualization of an ACFN tetrahedron. Whole rock compositions of coronitic metagabbros from Chenaillet (WR_{Ch}) and Queyras (WR_Q) ophiolites are shown. Both samples and Hbl–Pl tie line (amphibolite facies paragenesis) are on Cpx–Ol–Pl plane (magmatic paragenesis). Glc–Zo tie line (blueschist facies paragenesis) crosscuts Cpx–Ol–Pl plane and Hbl–Pl tie line at the whole rock composition location. All data without Ol are from Table 1; Ol is from library (Table 2). To be interactively examined, the VRML file (3D) is available on our personal homepage < <http://christian.nicollet.free.fr/page/Figures/3D/MetaRep/metarep.html> >.

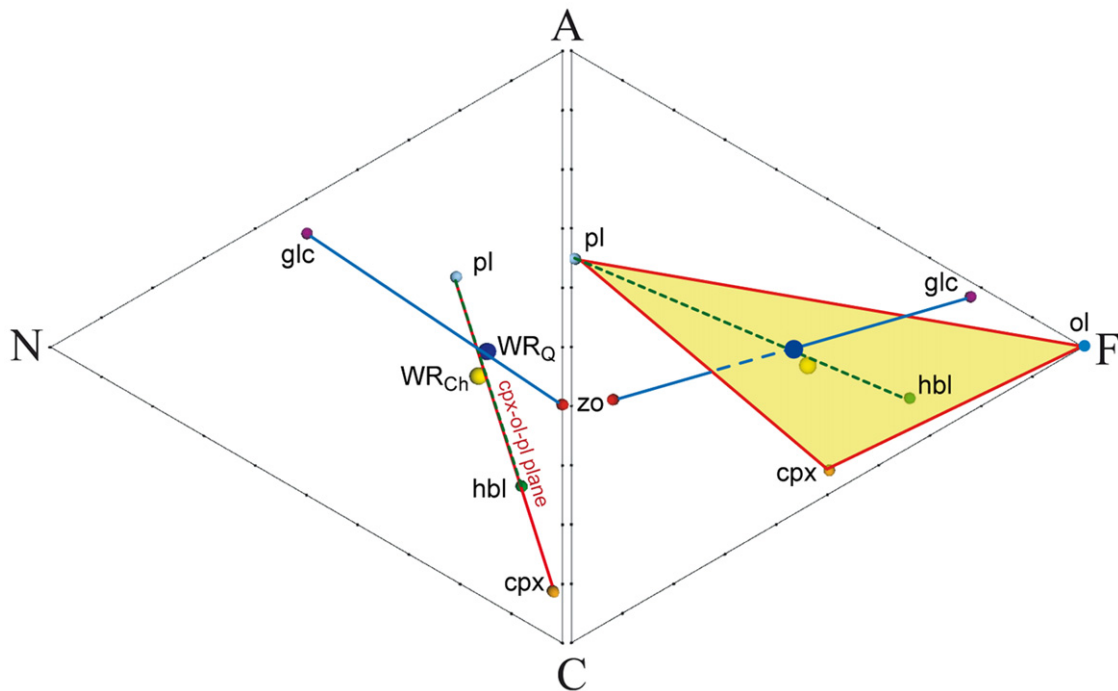


Fig. 3. Ternary projections of data presented in Fig. 2, in system ACFN. Projections are made on ACN and ACF triplots from F and N, respectively.

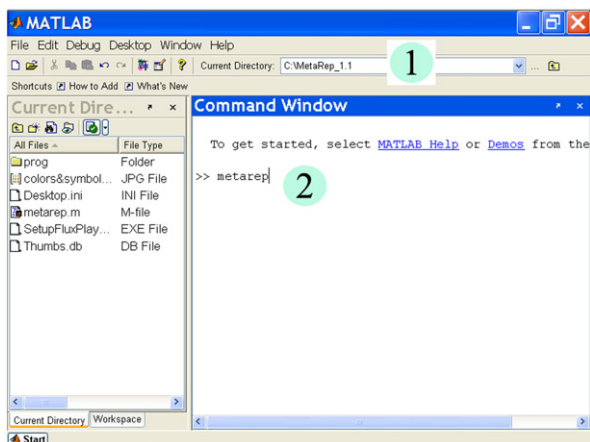


Fig. 4. Matlab[®] interface showing (1) “Current Directory” where C:\MetaRep_1.1” should be written and (2) “Command Window” where metarep should be written to start MetaRep.

MetaRep loads the data to project from an Excel spreadsheet (hereafter data.xls, but another file name can be used by the user). The organization required for “data.xls” is presented in Table 1. Columns should be presented in this order. The value cells can be numerical, blank or text (e.g., “n.d.” or “b.d.l.”), which will be considered as representing a null value.

To start MetaRep from Matlab:

- Write “C:\MetaRep_1.1” in the “Current Directory” (No. 1, Fig. 4),
- Write “metarep” in the “Command Window” (No. 2, Fig. 4),
- A window is then opened and one of the 6 projection system has to be chosen. The main MetaRep interface (Fig. 1) is then opened.

4. Functionalities

MetaRep functions are similar to the ones in CMAS 3D (France et al., 2009). Detailed instructions can be found in the “ReadMe” file. Brief descriptions of the different options are:

- A file (*.wrl) containing an empty tetrahedron can be generated. It will be used to export new pseudo-quaternary projections (No. 1, Fig. 1).
- “mole” or “weight” projection system can be used. Select it in No. 2 of Fig. 1.
- Load the “data.xls” file (from No. 3, Fig. 1).
- Select the option you want to use: “add a point”, “draw lines and planes” or “projections” (from No. 3, Fig. 1).
- If option “add a point” is selected (in No. 3, Fig. 1), several stoichiometric minerals can be added within the generated tetrahedra from the library (select the mineral name in No. 4, Fig. 1), or the 4 coordinates in the tetrahedra of a single point can be entered (indicate coordinates in boxes of No. 5, Fig. 1), the wanted color of plotted points has to be selected (press color boxes in No. 6, Fig. 1).
- If the option “draw lines and planes” is selected (in No. 3, Fig. 1), lines and planes can be added. To proceed, determine the end points or apices. To use a point from the “data.xls”, note the corresponding line number of the “data.xls” file in the boxes (No. 7, Fig. 1). To use minerals from the library, use corresponding names or abbreviations (Table 2). Select a color for the line or plane (press color boxes in No. 6, Fig. 1).

- If the option “projections” is selected (in No. 3, Fig. 1), ternary projections can be generated by selecting a default projection (No. 8, Fig. 1) or by determining the 3 apices of the projection plane and the projection pole (fill boxes in No. 8, Fig. 1).
- In case of error in the MetaRep use, it may be blocked. In this case, press the “DEBUG” button (No. 9, Fig. 1).
- To change the projection system, press the “MetaRep first page” button (No. 10, Fig. 1; the “data.xls” file will have to be reloaded).

Results of ACF-N projections are in the folder “C:\MetaRep_1.1\prog\ACFN_1.1\Results” for the tetrahedra and in “C:\MetaRep_1.1\prog\ACFN_1.1\triangle” for the ternary projections. For the other systems, results are in the corresponding folders. The coordinates of the projected points (from the “data.xls” file), in the quaternary systems and in the ternary projections are automatically written in the “Command Window” of Matlab (No. 2, Fig. 1) in percent, when a projection is generated.

5. Example

The Chenaillet and the Queyras ophiolites (French Alps) are relicts of the Ligurian paleo-oceanic lithosphere between Europe and Apulie during the Jurassic. During the Alpine convergence, the Chenaillet massif has been obducted on continental crust whereas the Queyras one has been subducted in the accretional prism (e.g., Lemoine et al., 1987). These ophiolites have recorded the intra-oceanic evolution, showing hydration during an isobaric cooling from magmatic conditions to the greenschist facies (Fig. 5). The Queyras samples have also recorded metamorphism during subduction (blueschist facies conditions; Fig. 5).

In the Chenaillet massif, the magmatic paragenesis found in gabbros and coronitic metagabbros is clinopyroxene, plagioclase and olivine (usually serpentinized). Clinopyroxene is rimmed by brown hornblende (indicating amphibolite facies), which is locally transformed to actinolite (indicating greenschist facies). A fine grained albite–epidote assemblage replaces former plagioclases (indicating greenschist facies). This mineralogical evolution shows partial hydration during the cooling of the gabbros. The Queyras metagabbros display magmatic texture with partially preserved coronitic pyroxenes (Fig. 6). The corona is made of glaucophane (Fig. 6) and plagioclase that is replaced by fine grained zoisite (and minor lawsonite–jadeite assemblage; blueschist facies). The presence of brown hornblende relicts in the glaucophane corona shows that the hydrous high pressure assemblage is not developed from the magmatic assemblage, but from hydrous metagabbros similar to those of the Chenaillet (i.e., oceanic hydration; Fig. 6).

The compositions of these rocks and of their constituent minerals (Table 1) are projected in the ACF-N system (Fig. 2) and in ternary plots (Fig. 3), which allow demonstration of the mineralogical evolution. In the ACF-N system, the whole rock compositions are included in the plane joining clinopyroxene–F–plagioclase (Cpx–F–Pl). The ACF-N system does not take SiO₂ into account and the F apex could represent either olivine or orthopyroxene. In the ACF-S system (Fig. 7), SiO₂ is included and olivine and orthopyroxene are not located at the same point. Only the Cpx–Ol–Pl plane contains the gabbro whole rock compositions. It therefore represents the magmatic paragenesis. In Figs. 2 and 3, the amphibolite facies paragenesis is represented by the tie line joining the brown hornblende and the plagioclase (Hbl–Pl); this tie line is included in the Cpx–Ol–Pl plane and crosscuts the whole rock. The blueschist facies paragenesis is represented by the tie line joining glaucophane and zoisite

Table 2

Library abbreviations that must be used for common minerals to add lines and planes in 3D representations. Abbreviations are from Kretz (1983).

CMAS, ACFs, ACFN		AFMK, AFMS, AKFS	
Mineral	Abbreviations	Mineral	Abbreviations
Actinote-Fe	Actinote, Act, actinote, act	Actinote-Fe	Actinote, Act, actinote, act
Albite	Albite, Ab, albite, ab	Aegirine	Aegirine, Agi, aegirine, agi
Almandine	Almandine, almandine, Alm, alm	Alumino-silicate	Al-Sil, Ky, Sil, And, al-sil, ky, sil, and
Alumino-silicate	Al-Sil, Ky, Sil, And, al-sil, ky, sil, and	Albite	Albite, Ab, albite, ab
Annite	Annite, annite, Ann, ann	Almandine	Almandine, Alm, almandine, alm
Anorthite	Anorthite, An, anorthite, an	Anorthite	Anorthite, An, anorthite, an
Anthophyllite-cummingtonite	Anthophyllite, Cummingtonite, Ath, Cum, anthophyllite, cummingtonite, ath, cum	Anthophyllite-cummingtonite	Anthophyllite, Cummingtonite, Ath, Cum, anthophyllite, cummingtonite, ath, cum
Fe-carpholite	Fe-Carpholite, fe-carpholite, Fe-carpholite, Fecar, fecar	Ca-Tschemmack	Ca-Tschemmack, CaTs, ca-tschemmack, cats
Mg-carpholite	Mg-Carpholite, mg-carpholite, Mg-carpholite, Mgcar, mgcar	Chlorite s.s.	Chlorite, Chl, chlorite, chl
Chlorite s.s.	Chlorite, Chl, chlorite, chl	Chlorite1	Chlorite2, Chl2, chlorite2, chl2
Chlorite2	Chlorite2, Chl2, chlorite2, chl2	Chromite	Chromite, Chr, chromite, chr
Fe-Chloritoid	Chloritoid, chloritoid, Cld, cld	Cordierite	Cordierite, Crd, cordierite, crd
Chromite	Chromite, Chr, chromite, chr	Corindon	Corindon, Crn, corindon, crn
Clintonite	Clintonite, clintonite, Clt, clt	Diopside	Diopside, Di, diopside, di
Mg-cordierite	Cordierite, Crd, cordierite, crd	Edenite	Edenite, Ed, edenite, ed
Corindon	Corindon, Crn, corindon, crn	Enstatite	Enstatite, En, enstatite, en
Diopside	Diopside, Di, diopside, di	Fayalite	Fayalite, Fa, fayalite, fa
Edenite	Edenite, Ed, edenite, ed	Ferrosilite	Ferrosilite, Fs, ferrosilite, fs
Enstatite	Enstatite, En, enstatite, en	Mg-Gegrite	Gegrite, Ged, gedrite, ged
Fayalite	Fayalite, Fa, fayalite, fa	Glaucofane	Glaucofane, Gln, Glaucofane, Gln
Ferrosilite	Ferrosilite, Fs, ferrosilite, fs	Grossular	Grossular, Grs, Grossular, Grs
Mg-Gegrite	Gegrite, Ged, gedrite, ged	Hedenbergite	Hedenbergite, Hd, Hedenbergite, Hd
Glaucofane	Glaucofane, Gln, Glaucofane, Gln	Hematite	Hematite, Hem, hematite, hem
Grossular	Grossular, Grs, Grossular, Grs	Hornblende	Hornblende, Hbl, hornblende, hbl
Hedenbergite	Hedenbergite, Hd, Hedenbergite, Hd	Ilmenite	Ilmenite, Ilm, ilmenite, ilm
Hematite	Hematite, Hem, hematite, hem	Jadeite	Jadeite, Jd, jadeite, jd
Hornblende	Hornblende, Hbl, hornblende, hbl	Lawsonite	Lawsonite, Lws, lawsonite, lws
Ilmenite	Ilmenite, Ilm, ilmenite, ilm	Magnetite	Magnetite, Magmagnetite, mag
Jadeite	Jadeite, Jd, jadeite, jd	Marialite	Marialite, Mar, marialite, mar
K-feldspar	K-Feldspar, k-feldspar, K-feldspar, Kfs, kfs	Meionite	Meionite, Men, meionite, men
Magnetite	Magnetite, Magmagnetite, mag	Mg-tschemmack	Mg-Tschemmack, MgTs, mg-tschemmack, mgts
Margarite	Margarite, margarite, Mrg, mrg	Omphacite	Omphacite, Omp, omphacite, omp
Muscovite	Muscovite, muscovite, Ms, ms	Orthose	Orthose, Or, orthose, or
Omphacite	Omphacite, Omp, omphacite, omp	Pargasite	Pargasite, Prg, pargasite, prg
Orthose	Orthose, Or, orthose, or	Pleonaste	Pleonaste, Ple, pleonaste, ple
Mg-osumilite	Osumilite, osumilite, Osu, osu	Prehnite	Prehnite, Prh, prehnite, prh
Paragonite	Paragonite, paragonite, Pg, pg	Pumpellyite	Pumpellyite, Pmp, pumpellyite, pmp
Pargasite	Pargasite, Prg, pargasite, prg	Pyrope	Pyrope, Prp, pyrope, prp
Mg-phengite	Phengite, phengite, Phen, phen	Quartz	Quartz, Qtz, quartz, qtz
Phlogopite	Phlogopite, phlogopite, Phl, phl	Riebeckite	Riebeckite, Rbk, riebeckite, rbk
Pleonaste	Pleonaste, Ple, pleonaste, ple	Sapphirine	Sapphirine, Spr, sapphirine, spr
Pyrope	Pyrope, Prp, pyrope, prp	Serpentine	Serpentine, Srp, serpentine, srp
Quartz	Quartz, Qtz, quartz, qtz	Sphene	Sphene, Spn, sphene, spn
Sapphirine	Sapphirine, Spr, sapphirine, spr	Spinel s.s.	Spinel, Spl, spinel, spl
Serpentine	Serpentine, Srp, serpentine, srp	Tremolite	Tremolite, Tr, tremolite, tr
Spinel s.s.	Spinel, Spl, spinel, spl	Tschemmakite	Tschemmakite, Ts, tschemmakite, ts
Staurolite	Staurolite, staurolite, St, st	Vesuvianite	Vesuvianite, Ves, vesuvianite, ves
Talc	Talc, talc, Tlc, tlc	Wollastonite	Wollastonite, Wo, wollastonite, wo
Tremolite	Tremolite, Tr, tremolite, tr	Zoisite-epidote	Zoisite, Epidote, Zo, Ep, zoisite, epidote, zo, ep
Ca-tschemmack	Ca-Tschemmack, CaTs, ca-tschemmack, cats		
Mg-tschemmack	Mg-Tschemmack, MgTs, mg-tschemmack, mgts		
Tschemmakite	Tschemmakite, Ts, tschemmakite, ts		

(Glc-Zo). This line crosscuts the whole rock point and the plane Cpx-Ol-Pl. The fact that tie lines crosscut the whole rock compositions indicates that, if the coronitic reaction was complete, the paragenesis of the rock would be simply Hbl+Pl in the amphibolite facies conditions and Glc+Zo in the blueschist facies ones.

Combined use of the ACF-S and ACF-N systems makes it possible to propose a paragenesis sequence (valid for complete reactions) compatible with the petrographic observations: Cpx-Ol-Pl, followed by Hbl-Pl and then by Glc-Zo. The coronitic textures and the clinopyroxene persistence show that reactions are not complete, probably because of limited hydration during the early intra-oceanic metamorphic stage. In this particular case,

all the magmatic and metamorphic assemblages represented by lines and planes crosscut each other at the point representing the whole rock composition; the metamorphic parageneses are therefore expected to be biminerals.

6. Conclusion

We present here MetaRep, a new program to project and to visualize major element compositions of minerals, melts and rocks. The program allows one to project data in 4 dimensional tetrahedrons into 3 dimensions. Subsequently, triplot projections can be generated that are traditionally used in publications and

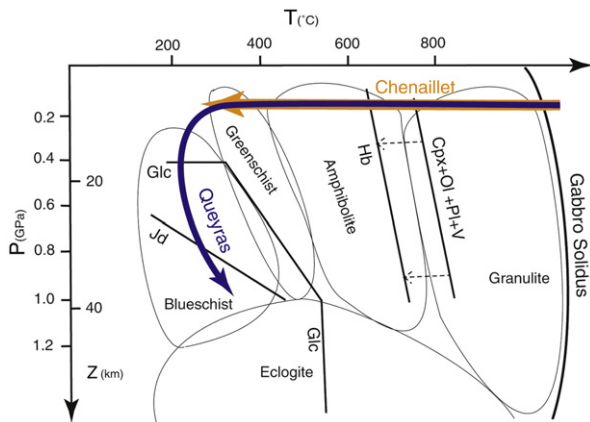


Fig. 5. Pressure–temperature–time (PTt) paths for Chenaillet and Queyras metagabbros. Chenaillet ophiolite rocks record only an isobaric cooling part (through amphibolite and greenschist facies), whereas Queyras ophiolite ones record additionally a subduction event (blueschist facies conditions).

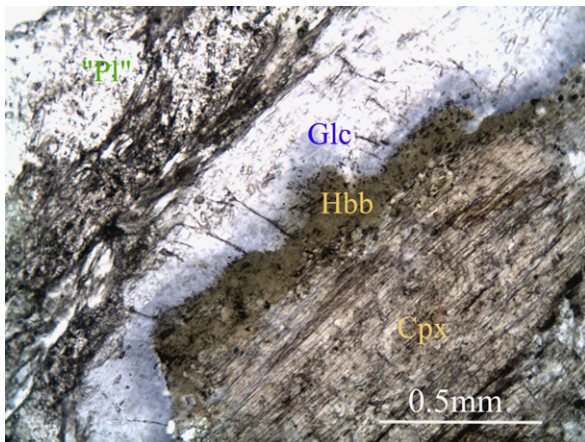


Fig. 6. Microphotography of a coronitic metagabbro from Queyras ophiolite showing different metamorphic stages. During cooling at ridge axis, magmatic clinopyroxene is rimmed by a brown hornblende (Hbb) corona. During subduction event, in accretional prism, brown hornblende is transformed in glaucophane and plagioclase in zoisite (with minor lawsonite and jadeite); plane polarized light.

reports. MetaRep is dedicated to pelitic (with the AFM-K, AFM-S and AKF-S systems) and mafic (with the CMAS, ACF-S and ACF-N systems) rocks. The 3D visualizations are very easy to use and provide a convenient tool for research as well as for teaching purposes in igneous and metamorphic petrology.

Acknowledgment

Nicolas Ouillon is thanked for his advice on VRML programming. Ken Koga is thanked for an early careful review of the manuscript. Constructive reviews by Alexei Fedkin and two anonymous reviewers are gratefully acknowledged.

Appendix A. Supporting material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.cageo.2010.01.001.

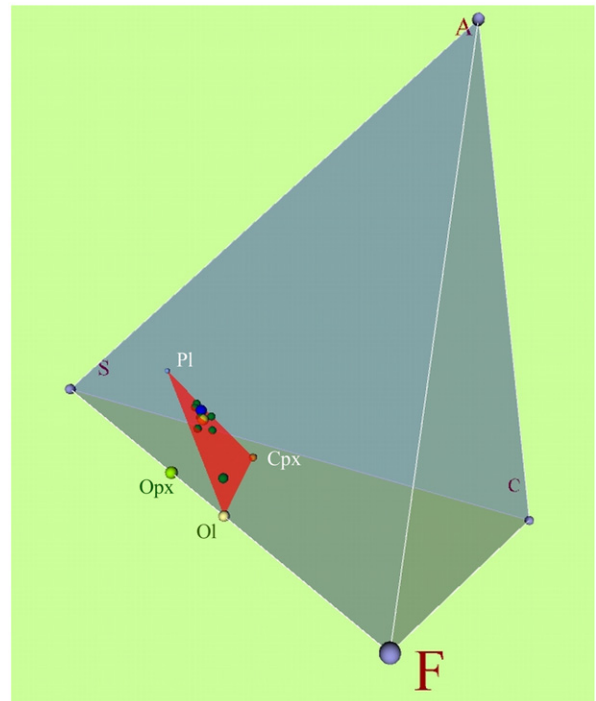


Fig. 7. Three-dimensional visualization in ACF-S system. Whole rock compositions of nine gabbros from Chenaillet and Queyras ophiolites are added (dark green points). They are situated in Cpx–Ol–Pl plane, which includes samples WR_Q and WR_{Ch} (blue and yellow points, respectively). Ol and Opx compositions are taken from the library (Table 2). To be interactively examined, the VRML file (3D) is available on our personal homepage <<http://christian.nicollet.free.fr/page/Figures/3D/MetaRep/metarep.html>>.

References

- Buccianti, A., Mateu-Figueras, G., Pawlowsky-Glahn, V. (Eds.), 2006. Compositional Data Analysis in the Geosciences: From Theory to Practice. Geological Society Special Publications 264, London 224pp.
- Bucher, K., Frey, M., 2002. Petrogenesis of Metamorphic Rocks 7th ed. Springer-Verlag, Berlin, Heidelberg, New York 341pp.
- Carey, R., Bell, G., Marrin, C., 1997. Virtual reality modeling language (VRML97). ISO/IEC 14772-1, <<http://www.web3d.org>>.
- Connolly, J.A.D., 2005. Computation of phase equilibria by linear programming: a toll for geodynamic modeling and its application to subduction zone decarbonation. Earth and Planetary Science Letters 236, 524–541.
- France, L., Ouillon, N., Chazot, G., Kornprobst, J., Boivin, P., 2009. CMAS 3D, a new program to visualize and project major elements compositions in the CMAS system. Computers & Geosciences 35, 1304–1310, doi:10.1016/j.cageo.2008.07.002.
- Ghiorso, M.S., Hirschmann, M.M., Reiners, P.W., Kress, V.C., 2002. The pMELTS: a revision of MELTS for improved calculation of phase relations and major element partitioning related to partial melting of the mantle to 3 GPa. Geochemistry Geophysics Geosystems 3 (5), 1030, doi:10.1029/2001GC000217.
- Ghiorso, M.S., Sack, R.O., 1995. Chemical mass transfer in magmatic processes IV. A revised and internally consistent thermodynamic model for the interpolation and extrapolation of liquid–solid equilibria in magmatic systems at elevated temperatures and pressures. Contributions to Mineralogy and Petrology 119, 197–212, doi:10.1007/BF00307281.
- Kretz, R., 1983. Symbols for rock forming minerals. American Mineralogist 68, 277–279.
- Lemoine, M., Tricart, P., Boillot, G., 1987. Ultramafic and gabbroic ocean floor of the Ligurian Tethys (Alps, Corsica, Apennines): in search of a genetic model. Geology 15, 622–625.
- O'Hara, M.J., 1968. The bearing of phase equilibria studies in synthetic and natural systems on the origin and evolution of basic and ultrabasic rocks. Earth-Science Reviews 4, 69–133.
- O'Hara, M.J., 1976. Data reduction and projection schemes for complex compositions. In: Progress in Experimental Petrology, 6. N.E.R.C. (National Environment Research Council), Publication Series D, pp. 103–126.
- Spear, F.S., 1995. Metamorphic Phase Equilibria and Pressure–Temperature–Time Paths. Mineralogical Society of America, Washington 799pp.
- Thompson Jr, J.B., 1957. The graphical analysis of mineral assemblages in Pelitic Schists. American Mineralogist 42, 842–858.
- Winkler, H.G.F., 1979. Petrogenesis of Metamorphic Rocks. 5th ed. Springer-Verlag, Berlin, Heidelberg, New York 348pp.