Computers & Geosciences Vol. 18, No. 9, pp. 1277–1282, 1992
Printed in Great Britain.

0098-3004/92 $3.00 + 0.00

SHORT NOTE

MORBCAL: A PROGRAM FOR CALCULATING THE COMPOSITIONS OF PRIMARY BASALTIC MELTS PRODUCED BY DECOMPRESSION-INDUCED MELTING BELOW MID-OCEAN RIDGES

YAOLING NIU and RODEY BATIZA
Department of Geology and Geophysics, University of Hawaii at Manoa, 2525 Correa Road, Honolulu, HI 96822, U.S.A.

(Received 24 February 1992; accepted 30 April 1992)

INTRODUCTION

A widely accepted model proposes that mid-ocean ridge basalts (MORB) are produced by decompression-induced partial melting of oceanic upper mantle which adiabatically upwells in response to plate separation (McKenzie, 1984; Klein and Langmuir, 1987; McKenzie and Bickle, 1988). In this model, rising mantle begins to melt as it intersects the solidus at a depth determined by its temperature and melting characteristics. Continued upwelling involves continuous melting, matrix compaction, and melt segregation. To quantitatively evaluate this type of melting, Niu and Batiza (1991) developed an empirical scheme based on the peridotite melting experiments of Jaques and Green (1980), Falloon and Green (1987, 1988), and Falloon and others (1988). We used the experimental data to calculate the bulk partition coefficients (K_d) for the major elements. In addition, we determined pressure and temperature (extent of partial melting) dependance of these K_ds and used these to calculate the compositions of pooled polybaric melts created by incremental melting. Finally, we developed a method for calculating the melting parameters (initial and final melting pressures and temperatures, plus total extent of melting) for actual MORB melt compositions. This method assumes that primary polybaric pooled melts fractionate only at low pressure and employs the chemical back-tracking method of Klein and Langmuir (1987).

The purpose of this Short Note is to present the MORBCAL program. This program is an easy-to-use tool for readers interested in mid-ocean ridge processes and igneous petrogenesis. For details of the melting model, readers are referred to Niu and Batiza (1991). In the rest of the note, we briefly discuss MORBCAL and its availability.

MORBCAL

The program MORBCAL, written in Microsoft BASIC (see Appendix), strictly follows the model algorithms of Niu and Batiza (1991) and is highly interactive and self-explanatory. MORBCAL uses MORB-Pyrolite-90, the most reasonable oceanic mantle peridotite for MORB of Falloon and Green (1987), as a default source composition. An option is given for users to input their own peridotite compositions, but the compositions should not be extrapolated beyond the range of available experimental data (see details in Niu and Batiza, 1991). The output results can either be printed or saved as a user-named file. MORBCAL includes the following features:

(1) Calculating the compositions of basaltic melt produced by DYNAMIC melting. DYNAMIC indicates that melting and melt–solid separation occur in a parcel of dynamically upwelling mantle while it is continuously upwelling along an adiabat. Melting begins when upwelling mantle intersects the solidus and continued upwelling is accompanied by incremental melting and melt removal. The incrementally produced melt may be accumulated to produce a pooled melt composition. The composition of each incremental melt is computed with P–T dependant bulk distribution coefficients for each oxide and the composition of the solid residue at each step is determined by mass balance. This residue then serves as the source of the next increment of melting. The composition of the accumulated melt is computed by summing the incremental melts. The DYNAMIC model requires the following input:

(a) Composition of mantle peridotite (optional, if different from MORB-Pyrolite 90);
(b) P_0 (kbar), the depth at which upwelling mantle intersects the solidus or the initial melting depth. Because our model is based on experiments at $P \leqslant 20$ kbar, **PRESSURES GREATLY IN EXCESS OF THIS VALUE WILL NOT YIELD MEANINGFUL RESULTS.**
(c) P_s (kbar), the depth at which users may elect to terminate the DYNAMIC melting. In general, $2\text{ kbar} \leqslant P_s \leqslant P_0$.

The output of DYNAMIC includes:

(a) Composition (SiO_2, TiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, K_2O) of the accumulated melt created at each new increment (1%) of melting along an adiabatic path.
(b) F%, the total amount of melt that has been produced and may have been pooled; and
(c) P_f (kbar) and T_f (°C), the depth and temperature at which melting may stop.

(2) For comparison, MORBCAL also calculates the composition of basaltic melt produced by equilibrium BATCH melting. BATCH melting indicates that melting occurs in a static situation where melt is in equilibrium with the solid at a single P–T condition and melt segregation involves removal of the entire BATCH from the solid residue. The BATCH model requires the following input;

(a) Composition of mantle peridotite (optional, if different from MORB-Pyrolite 90);
(b) T (°C) and P (kbar), temperature and pressure at which melting occurs.

The output of BATCH includes:

(a) F%, the extent of partial melting; and
(b) Composition (SiO_2, TiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, K_2O) of the melt.

(3) MORBCAL also provides an additional option for calculating the melting parameters from natural MORB melt compositions. The input includes $Si_{(8)}$, $Fe_{(8)}$, $Ca_{(8)}$, $Al_{(8)}$, and $Na_{(8)}$ which are contents (wt%) of the corresponding oxides of natural MORB melts, corrected for crustal level fractionation to MgO = 8.0 wt% following Klein and Langmuir (1987) (see Niu and Batiza, 1991 for details). These elements are important indicators of pressure [$Si_{(8)}/Fe_{(8)}$] and extent of partial melting [$Ca_{(8)}/Al_{(8)}$, and $Na_{(8)}$]. The output includes P_0, P_f, T_0, T_f, and F, denoting the initial and final depths (kbar) and temperatures (°C) of melting in a DYNAMIC melting process, and the extent of melt production (wt%). Because of inevitable analytical uncertainties of MORB glass data and the somewhat arbitrary choice of fractionation functions plus the model uncertainties, we do not recommend calculating melting parameters using a single analysis. Instead, we suggest using many analyses for areas where dense sampling is available. These computed melting parameters are useful especially when making interridge (or intersegment) comparison and for evaluating along-axis differences along densely sampling lengths of ridges.

AVAILABILITY

Although MORBCAL originally was written in Microsoft BASIC for Macintosh, a ready-to-run BASIC code in standard language also is available for any other BASIC interpreters and computers. Free copies of the MORBCAL code and application with RUNTIME for Macintosh are available from either of the authors, but please send a formatted (Macintosh or PCs) 3.5″ disk along with your request.

Acknowledgments—We acknowledge financial support for this study from the NSF (OCE 89-03296 and OCE 90-00193) and the Office of Navy Research. School of Ocean and Earth Science and Technology contribution 2680.

REFERENCES

Falloon, T. J., and Green, D. H., 1987, Anhydrous partial melting of MORB pyrolite and other peridotite compositions at 10 kbar: implications for the origin of MORB glasses: Mineral. Petrol., v. 37, no. 3–4, p. 181–219.

Falloon, T. J., and Green, D. H., 1988, Anhydrous partial melting of peridotite from 8 to 35 kb and the petrogenesis of MORB: Jour. Petrol., Special Lithosphere Issue, p. 379–414.

Falloon, T. J., Green, D. H., Hatton, C. J., and Harris, K. L., 1988, Anhydrous partial melting of a fertile and depleted peridotite from 2 to 30 kb and application to basalt petrogenesis: Jour. Petrology, v. 29, no. 6. p. 1257–1282.

Jacques, A. L., and Green, D. H., 1980, Anhydrous melting of peridotite at 0–15 kb pressures and genesis of tholeiitic basalts: Contrib. Mineral. Petrol., v. 73, no. 3, p. 287–310.

Klein, E. M., and Langmuir, C. H., 1987, Global correlations of ocean ridge basalt chemistry with axial depth and crustal thickness: Jour. Geophys. Res., v. 92, no. B8, p. 8089–8115.

McKenzie, D., 1984, The generation and compaction of partially molten rock: Jour. Petrology, v. 25, no. 3, p. 713–765.

McKenzie, D., and Bickle, M. J., 1988, The volume and composition of melt generated by extension of the lithosphere: Jour. Petrology, v. 29, no. 3, p. 625–679.

Niu, Y., and Batiza, R., 1991, An empirical method for calculating melt compositions produced beneath mid-ocean ridges: application for axis and off-axis (seamounts) melting: Jour. Geophys. Res, v. 96, no. B13, p. 21,753–21,777.

APPENDIX

Microsoft BASIC Code for MORBCAL

MORBCAL calculates compositions of primary magmas parental to mid-ocean ridge basalts (MORBs) as a function of melting conditions: Depth of melting and melting temperature.

First version:	04/20/1990
Second version:	02/20/1991
Final version:	07/15/1991

by Yaoling Niu & Rodey Batiza
Department of Geology and Geophysics
University of Hawaii at Manoa
2525 Correa Road
Honolulu, Hawaii 96822
U.S.A.

Telephone: 808-956-5036
FAX: 808-956-2538

```
WINDOW 1,,(6,28)-(506,330),2
DIM OXN$(8),OXMTL(8),OXLIQ(8),BOXLIQ(8),OXSOL(8),DCEF(8),DE(8)
DIM DF(8),DRF(8),DH(8),DI(8),FPT(8),FPTN$(8)

MAINMENU:
CALL TEXTFONT(0):CALL TEXTSIZE(12)
PRINT TAB(3)"*****************************MENU*********************************"
PRINT
PRINT TAB(3)"Type a number to make choice":PRINT
PRINT TAB(5)"1","Equilibrium BATCH Melting Model"
PRINT TAB(5)"2","Decompression-induced DYNAMIC Melting Model"
PRINT TAB(5)"3","Melting parameters: F(%), Po(kb), Pf(kb), To(°C), and Tf(°C)"
PRINT TAB(5)"4","Quit":PRINT
INPUT "What is your choice";CHOICE
ON CHOICE GOTO BATCH,DYNAMIC,FPPTT,QUIT
QUIT:
END

BATCH:
CLS
CALL TEXTFONT(0):CALL TEXTSIZE(12)
PRINT TAB(3)"******************Equilibrium BATCH Melting model******************"
PRINT
PRINT TAB(1)"1)BATCH model requires input of pressure (kb) & Temperature (°C) at"
PRINT TAB(3)"which melting may occur. IF your INPUT is a subsolidus condition,"
PRINT TAB(3)"MORBCAL will prompt you because no melting will occur.":PRINT"
PRINT TAB(1)"2)In this model, each oxide concentration is computed independently and"
PRINT TAB(3)"no normalization is invoked":PRINT
PRINT TAB(1)"3)Because of the limitation by available experimental data, the best"
PRINT TAB(3)"results are warranted at the conditions of P = 7 - 22 Kbars with 8 -"
PRINT TAB(3)"30 % of melting.":PRINT
GOSUB WaitKey
RESTORE BATCH
FOR I=1 TO 8:READ OXN$(I):NEXT
DATA SiO2,TiO2,Al2O3,FeO,MgO,CaO,Na2O,K2O
FOR I=1 TO 8:READ OXMTL(I):NEXT
DATA 44.74,0.17,4.37,7.55,38.57,3.38,0.4,0.03
FOR I=1 TO 8:READ DE(I):NEXT
DATA 0.848,0.091,0.196,1.472,5.623,0.327,0.0509,0.0099
FOR I=1 TO 8:READ DF(I):NEXT
DATA -0.0022,-0.002,-0.0065,0,-0.0451,-0.012,-0.0038,-0.0002
FOR I=1 TO 8:READ DRF(I):NEXT
DATA 0,0,-0.025,0.273,0,0.3071,0,0
FOR I=1 TO 8:READ DH(I):NEXT
DATA 0.0055,0,0.0021,-0.035,-0.081,0.0005,0,0
FOR I=1 TO 8:READ DI(I):NEXT
DATA 0,0,0,-0.013,0,0,0,0
PRINT
PRINT "This is the default MORB-Pyrolite-90:"
FOR I=1 TO 8:PRINT TAB(I*6);OXN$(I);:NEXT:PRINT
FOR I=1 TO 8:PRINT TAB(I*6);USING "##.##";OXMTL(I);:NEXT:PRINT:PRINT
INPUT "Do you desire to input your own mantle composition? (Y/N)";MYeh$
IF MYeh$="Y" OR MYeh$="y" THEN GOSUB Mantle:PRINT
LINE INPUT "Give a name to save your results as a disk file:";Filename$
OPEN "A",1,Filename$:PRINT
IF MYeh$="Y" OR MYeh$="y" THEN MMCN$=MCN$ ELSE MMCN$="MPY-90"
PRINT#1, MMCN$;":"
FOR I=1 TO 8:PRINT#1,TAB(I*6);OXN$(I);:NEXT:PRINT
FOR I=1 TO 8:PRINT#1,TAB(I*6);USING "##.##";OXMTL(I);:NEXT
PRINT#1,
BPT:
CALL TEXTFONT(0):CALL TEXTSIZE(12)
INPUT "Pressure (Kb)";P
INPUT "Temperature(°C)";T
```

```
F=-117.149-6.028*P+(.11679+.003023*P)*T
IF F<=0,THEN BEEP ELSE GOTO BDCEF
PRINT "Subsolidus condition!!! Either P is too high or T is too low!":GOTO BPT
BDCEF:
FOR I=1 TO 8:DCEF(I)=DE(I)+DF(I)*F+DRF(I)/F+DH(I)*P+DI(I)*P/F:NEXT
FOR I=1 TO 8:OXLIQ(I)=OXMTL(I)/(F/100+DCEF(I)*(1-F/100)):NEXT
PRINT
PRINT "Equilibrium BATCH melting of";" "MMCN$;":"
CALL TEXTFONT(1):CALL TEXTSIZE(9)
PRINT "T(°C)";TAB(7);"P(kb)";TAB(14);"F(%)";:
FOR I=1 TO 8:PRINT TAB(14+I*7);OXN$(I);:NEXT:PRINT
PRINT T;TAB(7);P;TAB(14);USING"##.##";F;:
FOR I=1 TO 8:PRINT TAB(14+I*7);USING "##.###";OXLIQ(I);:NEXT:PRINT
PRINT#1,"Equilibrium BATCH melting of";" "MMCN$;":"
PRINT#1, "T(°C)";TAB(7);"P(kb)";TAB(14);"F(%)";:
FOR I=1 TO 8:PRINT#1, TAB(14+I*7);OXN$(I);:NEXT:PRINT#1,
PRINT#1, T;TAB(7);P;TAB(14);USING"##.##";F;:
FOR I=1 TO 8:PRINT#1, TAB(14+I*7);USING "##.###";OXLIQ(I);:NEXT
PRINT#1,
INPUT "Do you want a change of pressure and temperature (Y/N)";Yes$
IF Yes$="Y" OR Yes$="y" THEN GOTO BPT:PRINT
PRINT#1, "This job is done at ";TIME$;" on ";DATE$:PRINT
CLOSE 1
GOSUB WaitKey
GOTO MAINMENU

DYNAMIC:
CLS
CALL TEXTFONT(0):CALL TEXTSIZE(12)
PRINT TAB(3)"**********Decompression-induced DYNAMIC Melting model**********"
PRINT
PRINT TAB(1)"1)DYNAMIC model requires input of Po, the depth at which melting may"
PRINT TAB(3)"occur across the mantle solidus, and Ps, the depth at which you may"
PRINT TAB(3)"wish to terminate the execution.":PRINT
PRINT TAB(1)"2)Because of the limitation by available experiments, your input of"
PRINT TAB(3)"5kb ≤ Po ≤ 25 with 3kb ≤ Pf ≤ Po will produce the best reliable results":PRINT
PRINT TAB(1)"3)In this model, each oxide concentration is computed independently"
PRINT TAB(3)"and no normalization is invoked.":PRINT
GOSUB WaitKey
RESTORE DYNAMIC
FOR I=1 TO 8:READ OXN$(I):NEXT
DATA SiO2,TiO2,Al2O3,FeO,MgO,CaO,Na2O,K2O
FOR I=1 TO 8:READ OXMTL(I):NEXT
DATA 44.74,0.17,4.34,7.55,38.57,3.38,0.4,0.03
FOR I=1 TO 8:READ DE(I):NEXT
DATA .858,.098,.189,1.442,5.286,.318,0.111,.069
FOR I=1 TO 8:READ DF(I):NEXT
DATA -.004,-.005,-.0051,0,-.064,-.0122,-.007,-.002
FOR I=1 TO 8:READ DRF(I):NEXT
DATA 0,0,-.025,.273,0,.272,0,0
FOR I=1 TO 8:READ DH(I):NEXT
DATA .005,0,.0021,-.0350,-.063,.001,0,0
FOR I=1 TO 8:READ DI(I):NEXT
DATA 0,0,0,-.013,0,0,0,0
CLS
PRINT "This is the default MORB-Pyrolite-90:"
FOR I=1 TO 8:PRINT TAB(I*6);OXN$(I);:NEXT:PRINT
FOR I=1 TO 8:PRINT TAB(I*6);USING"##.##";OXMTL(I);:NEXT:PRINT
INPUT "Do you desire to input your mantle composition? (Y/N)";Yes$
IF Yes$="Y" OR Yes$="y" THEN GOSUB Mantle
LINE INPUT "Please give a name to save your results as a disk file";Filename$
OPEN "A",1,Filename$
IF MYeh$="Y" OR MYeh$="y" THEN MMCN$=MCN$ ELSE MMCN$="MPY-90"
PRINT#1, MMCN$;":"
FOR I=1 TO 8:PRINT#1,TAB(I*6);OXN$(I);:NEXT:PRINT
FOR I=1 TO 8:PRINT#1,TAB(I*6);USING "##.##";OXMTL(I);:NEXT
PRINT#1,
DPo:
INPUT "Enter Po(Kb)";Po
IF Po<5 OR Po>25 THEN BEEP ELSE GOTO DPf
PRINT "The INPUT must be: 5kb <Po <25kb !!!":GOTO DPo
DPf:
INPUT "Enter Pf(Kb)";Pf
IF Pf<3 OR Pf>=Po THEN BEEP ELSE GOTO DDCEF
```

```
PRINT "The INPUT must be: 3kb < Pf <Po":GOTO DPf
DDCEF:
F=4
FOR I=1 TO 8
DCEF(I)=DE(I)+DF(I)*F+DRF(I)/F+DH(I)*Po+DI(I)*Po/F
OXLIQ(I)=OXMTL(I)/(F/100+DCEF(I)*(1-F/100))
OXSOL(I)=(OXMTL(I)-OXLIQ(I)*F/100)/(1-F/100)
NEXT
CLS
Pff=Po
Tf=1119.7+13.098*Po-.23065*Po^2+6*Pff
PRINT "Dynamic Melting of";" ";MMCN$;" ";"from";"  Po =";Po;"Kb";" & ";"To =";:
PRINT USING"####.##";Tf;:PRINT"°C":PRINT
PRINT#1, "Dynamic Melting of";" ";MMCN$;" ";"from";"  Po =";Po;"Kb";" & ";"To =";:
PRINT#1, USING"####.##";Tf;:PRINT#1, "°C":PRINT
CALL TEXTFONT(1):CALL TEXTSIZE(9)
PRINT "Pf";TAB(7);"Tf";TAB(16);"F%";:FOR I=1 TO 8: PRINT TAB(I*7+16);OXN$(I);:NEXT:PRINT
PRINT#1, "Pf";TAB(7);"Tf";TAB(16);"F%";:FOR I=1 TO 8: PRINT#1,TAB(I*7+16);OXN$(I);:NEXT
PRINT#1,
WHILE Pff>=Pf
F=F+1
Pfa=-1.2811+1.1006*Po
Pfb=.45858059322#-.04765420539#*Po+.00093799868842#*Po^2
Pfc=-.026007077679#+.0012312026894#*Po-.000038694385217#*Po^2
Pff=Pfa+Pfb*F+Pfc*F^2
Tf=1119.7+13.098*Po-.23065*Po^2+6*Pff
FOR I=1 TO 8
IF OXSOL(I)<0 OR DCEF(I) <= 0 THEN OXSOL(I)=0
DCEF(I)=DE(I)+DF(I)*F+DRF(I)/F+DH(I)*Pff+DI(I)*Pff/F
BOXLIQ(I)=OXSOL(I)/(DCEF(I)+.01*(1-DCEF(I)))
OXLIQ(I)=(OXLIQ(I)*(F-1)+BOXLIQ(I))/F
OXSOL(I)=(OXMTL(I)-OXLIQ(I)*F/100)/(1-F/100)
NEXT
PRINT USING"##.##";Pff;:
PRINT TAB(7);USING"####.##";Tf;:
PRINT TAB(16);USING"##.##";F;:
FOR I=1 TO 8: PRINT TAB(I*7+16);USING"##.###";OXLIQ(I);:NEXT
PRINT
PRINT#1, USING"##.##";Pff;:
PRINT#1, TAB(7);USING"####.##";Tf;:
PRINT#1, TAB(16);USING"##.##";F;:
FOR I=1 TO 8: PRINT#1, TAB(I*7+16);USING"##.###";OXLIQ(I);:NEXT:PRINT#1,
WEND
CALL TEXTFONT(0):CALL TEXTSIZE(12):PRINT
PRINT#1, "This job is done at ";TIME$;" on ";DATE$:PRINT
INPUT "Do you want a change of Po and Pf (Y/N)";Yes$
IF Yes$="Y" OR Yes$="y" THEN GOTO DPo ELSE CLOSE 1
GOTO MAINMENU

FPPTT:
RESTORE FPPTT
FOR I=1 TO 5:READ FPTN$(I):NEXT
DATA Si(8),Fe(8),Al(8),Ca(8),Na(8)
FOR I=1 TO 5:PRINT FPTN$(I);" ";:INPUT FPT(I):NEXT
F=19.202-5.175*FPT(5)+15.537*FPT(4)/FPT(3)
Po=25.98+.967*F+45.277/F-5.186*FPT(1)/FPT(2)
Pf=(1.3613*Po+3.9103)+(-1.3458*Po-13.592)/F+(-.03015*Po-.2929)*F
T=1119.7+13.098*Po-.23065*Po^2+6*Po
Tf=1119.7+13.098*Po-.23065*Po^2+6*Pff
PRINT "F(%)";TAB(7);"Po";TAB(14);"Pf";TAB(21);"To";TAB(28);"Tf"
PRINT USING  "##.##";F;:PRINT TAB(7);USING"##.##";Po;:
PRINT TAB(14)USING"##.##";Pf;:PRINT TAB(21);USING"####.##";T;:
PRINT TAB(28)USING"####.##";Tf
INPUT "Do you want to input another set of composition? (Y/N)";Yes$
IF Yes$="Y" OR Yes$="y" THEN GOTO FPPTT
PRINT:PRINT "This job is done at ";TIME$;" on ";DATE$:PRINT
GOSUB WaitKey
GOTO MAINMENU

WaitKey:
PRINT TAB(3) "********************Press any Key to continue**********************"
a$=INKEY$:WHILE a$="":a$=INKEY$:WEND
RETURN
```

```
Mantle:
LINE INPUT "Please give a name of your model mantle:";MCN$
FOR I = 1 TO 8:PRINT OXN$(I);" ";:INPUT OXMTL(I):NEXT:RETURN
```