Universidade de São Paulo
Instituto de Geociências
Departamento de Mineralogia e Petrologia

EVOLUÇÃO MAGMÁTICA

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Abril
2018

EVOLUÇÃO MAGMÁTICA

- Conjunto de processos magmáticos que levam à formação da diversidade composicional de um magma parental
- Hein?

CONCEITOS RELACIONADOS À EVOLUÇÃO MAGMÁTICA

- Magma primitivo: aquele que guarda a composição original do magma parental obtido por fusão do manto
- Magma primário: pouco usado, mas seria o termo mais adequado quando se trata de magmas crustais
- Magma parental: aquele que dá origem a outros por diferenciação
- Magma derivado: oriundo do item anterior

UM POUCO MAIS SOBRE MAGMA PARENTAL

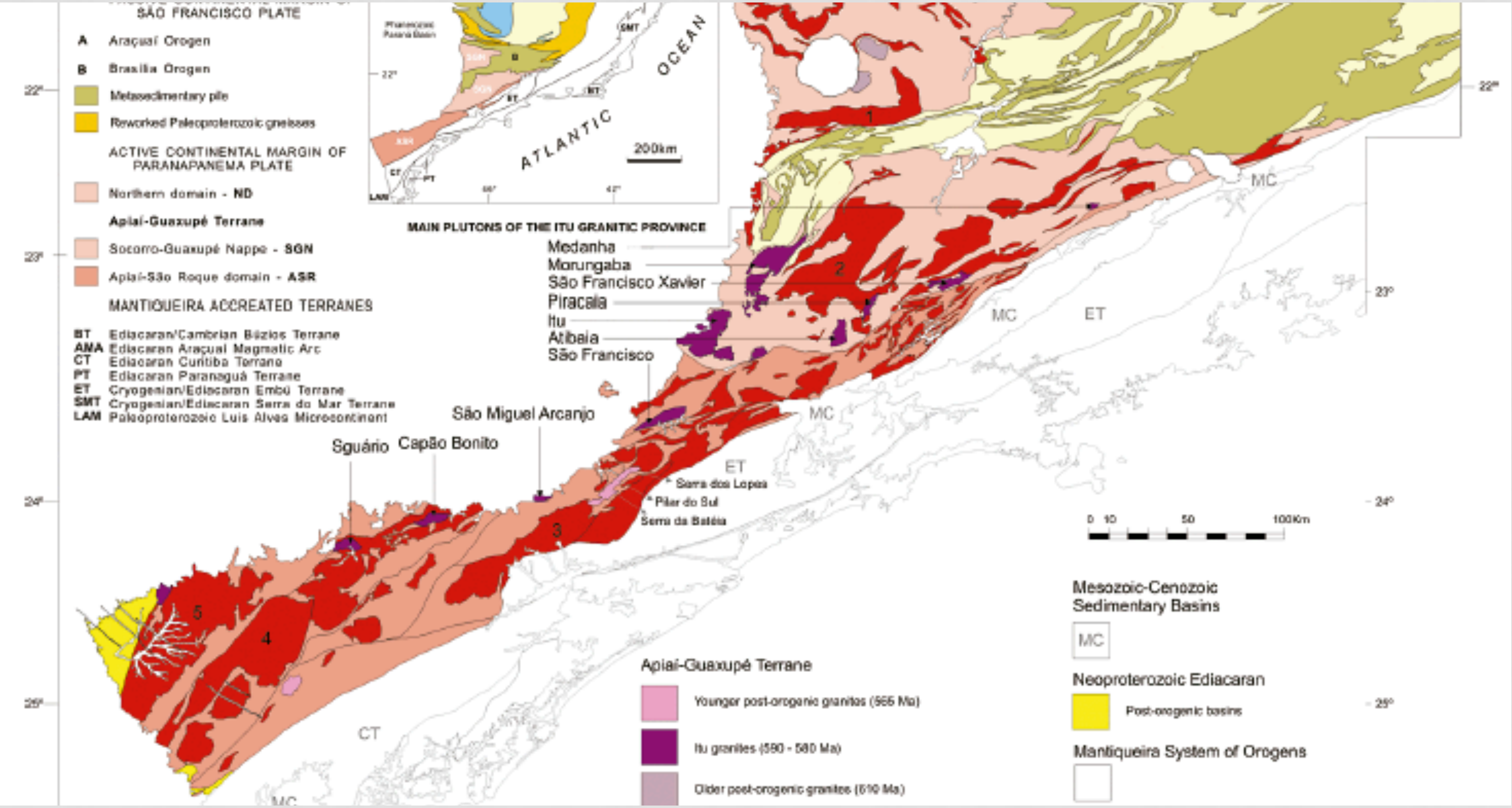
- Magma parental: aquele que dá origem à uma **série** de magmas via diferenciação
- Tem composição <u>mais próxima</u> da original (do saído da fonte)
- Série: por conseguinte, corresponde a um conjunto de rochas cujas composições se relacionam entre si por um ou mais processos de diferenciação

CONCEITOS

- O conceito de **Suíte** magmática e de **Província** magmática

1. Grupo de rochas ígneas aparentemente comagmáticas (idades próximas);
2. Uma coleção de rochas de uma única área, geralmente representando rochas ígneas relacionadas;
3. Coleção de rochas de uma mesma tipologia

PROVÍNCIAS ÍGNEAS/MAGMÁTICAS



Província Ígnea Itu (Janasi et al. 2009)

- Batólito Itu

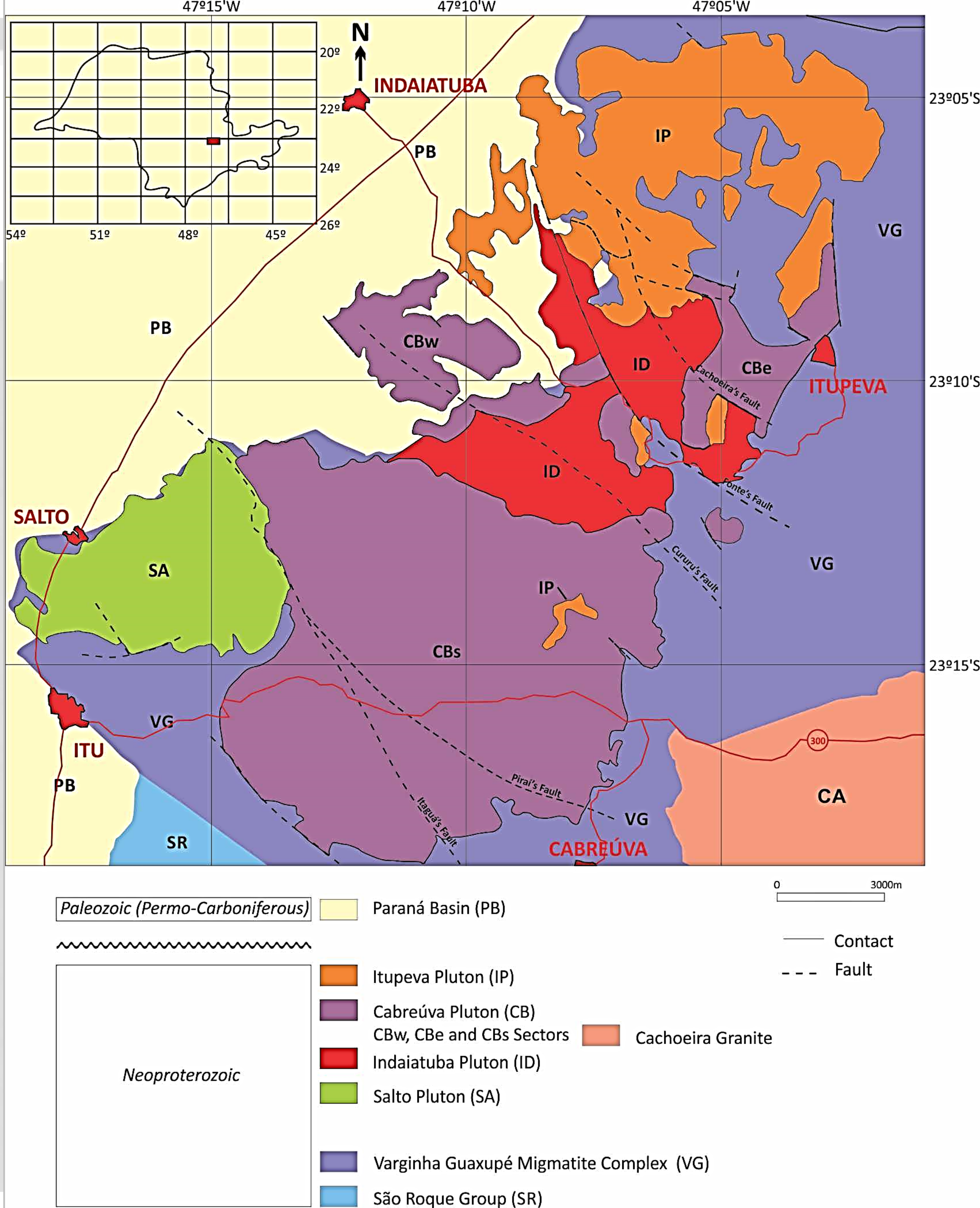
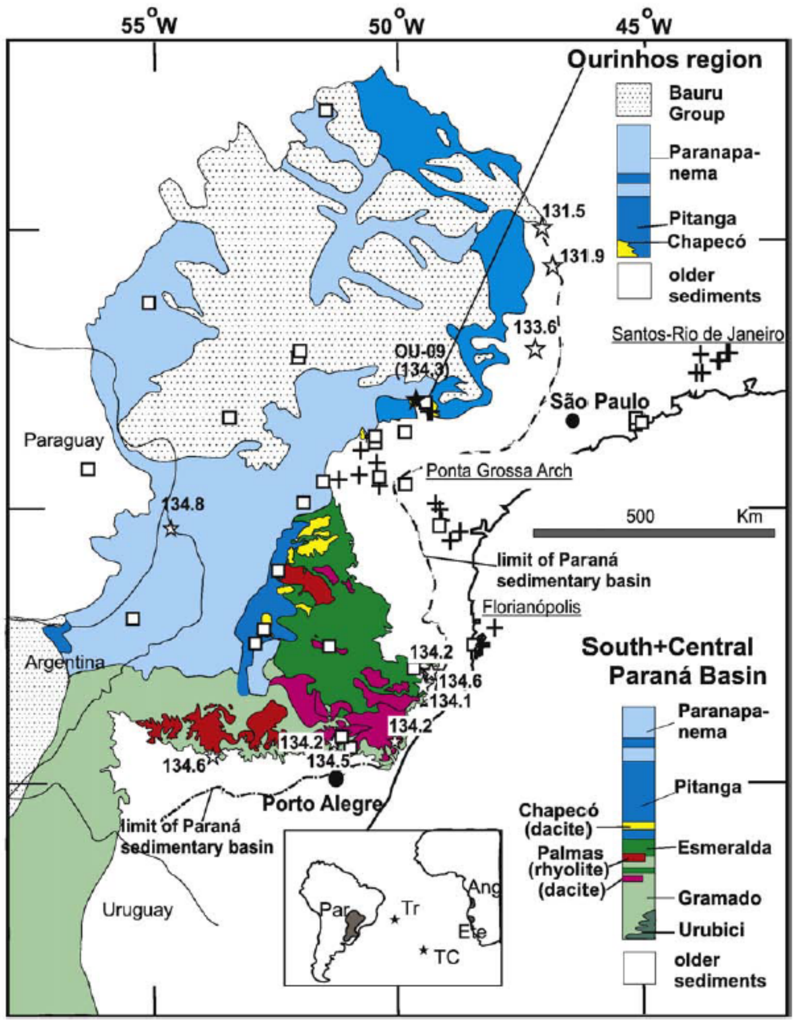
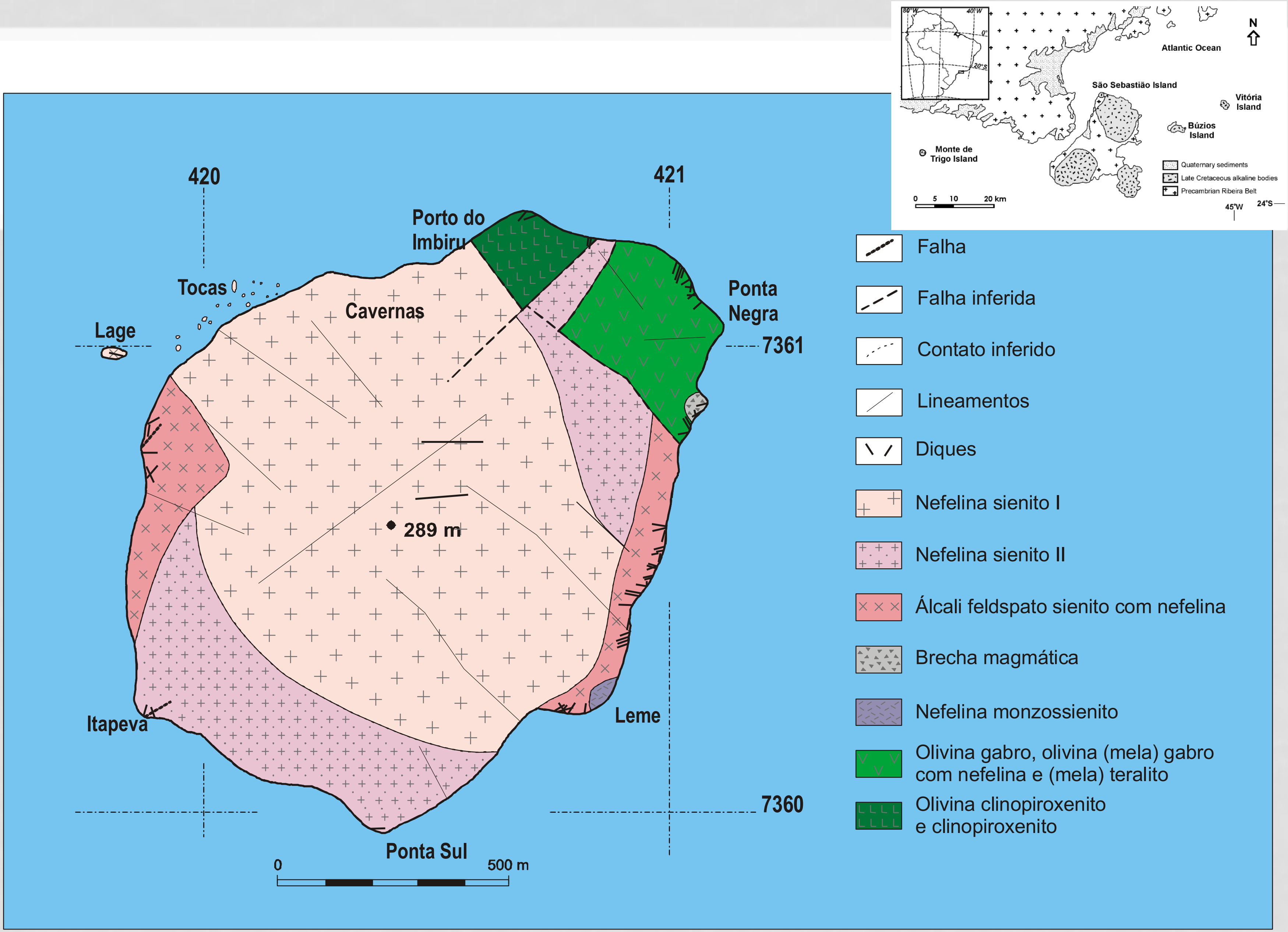


Figura 1 - Mapa pré-drift da Província Magmática do Paraná-Etendeka. Legenda: 1. basaltos, 2. vulcânicas ácidas do tipo Chapecó, 3. vulcânicas ácidas do tipo Palmas, 4. diques, 5. área adjacente. Modificado de Milner el al. (1995), Stewart el al. (1996), Peate (1997) e Nardy (2002).



Província Magmática Paraná- Etendeka



Suite Alcalina da Ilha Monte de Trigo (SP)

DIFERENCIAÇÃO MAGMÁTICA

- Processos de **DIFERENCIAÇÃO**
  - Sistema Fechado
    a. Fracionamento cristal-líquido
    b. Separação física de fundidos imiscíveis
    c. Separação fundido-fluído

  - Sistema Aberto
    a. Assimilação de um contaminante inicialmente sólido
    b. "Mistura" entre dois ou mais magmas de composições similares
    c. "Mistura" entre dois ou mais magmas de composições contrastantes

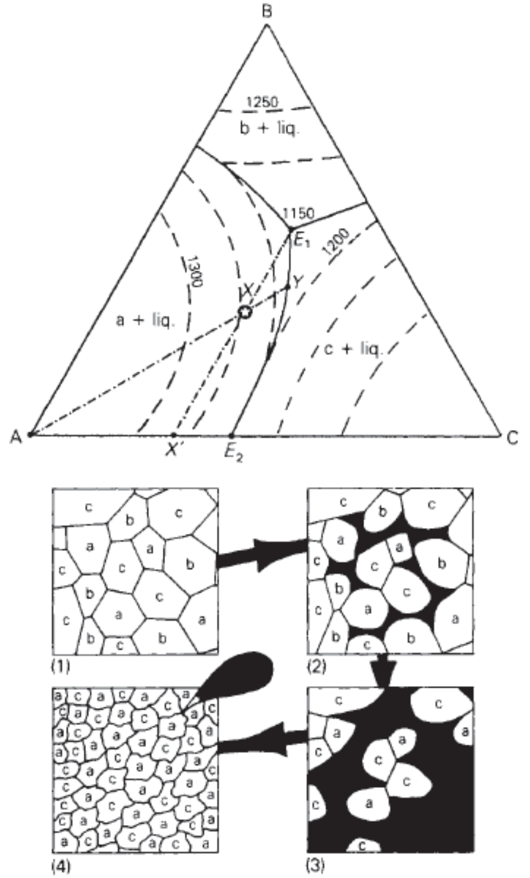
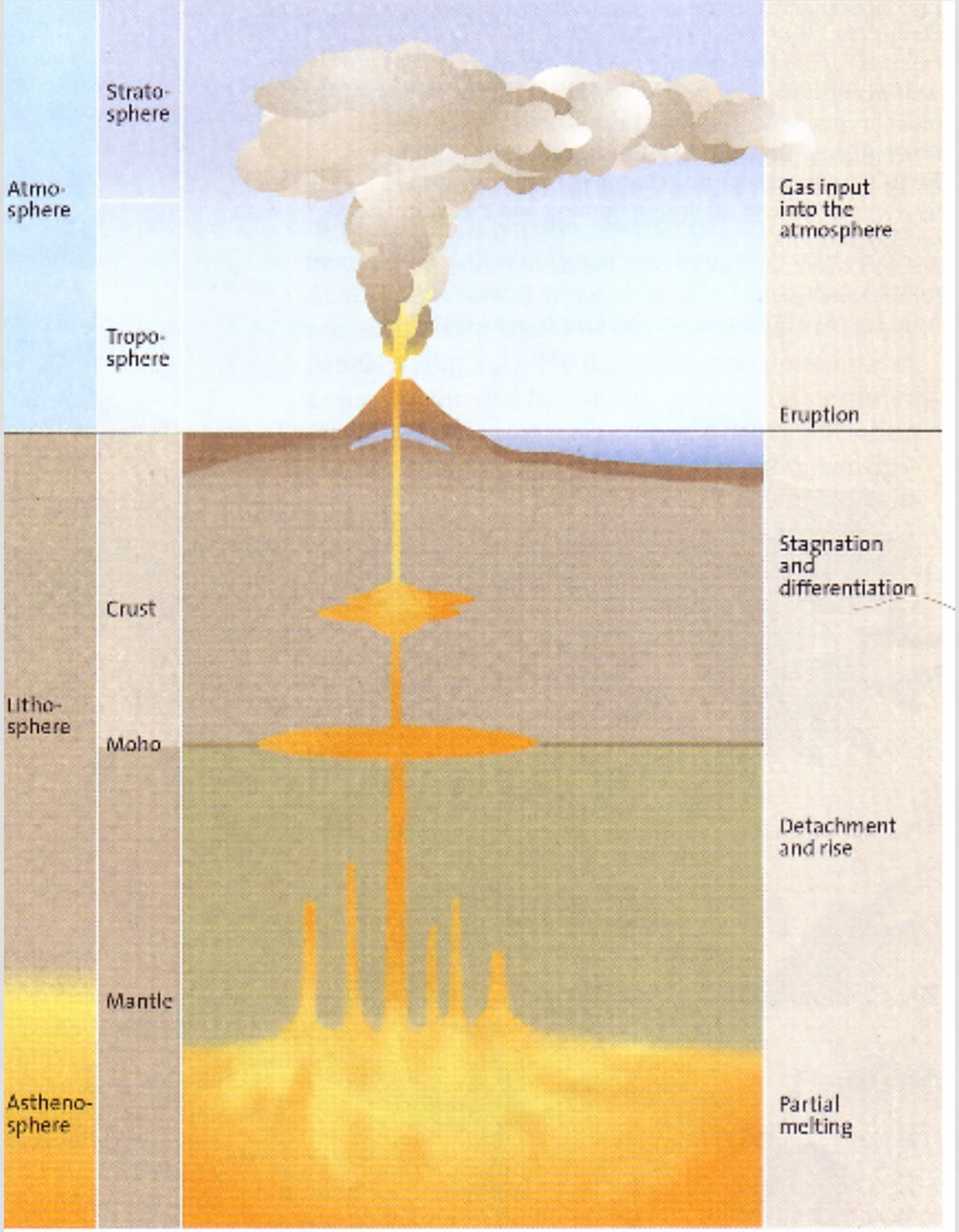
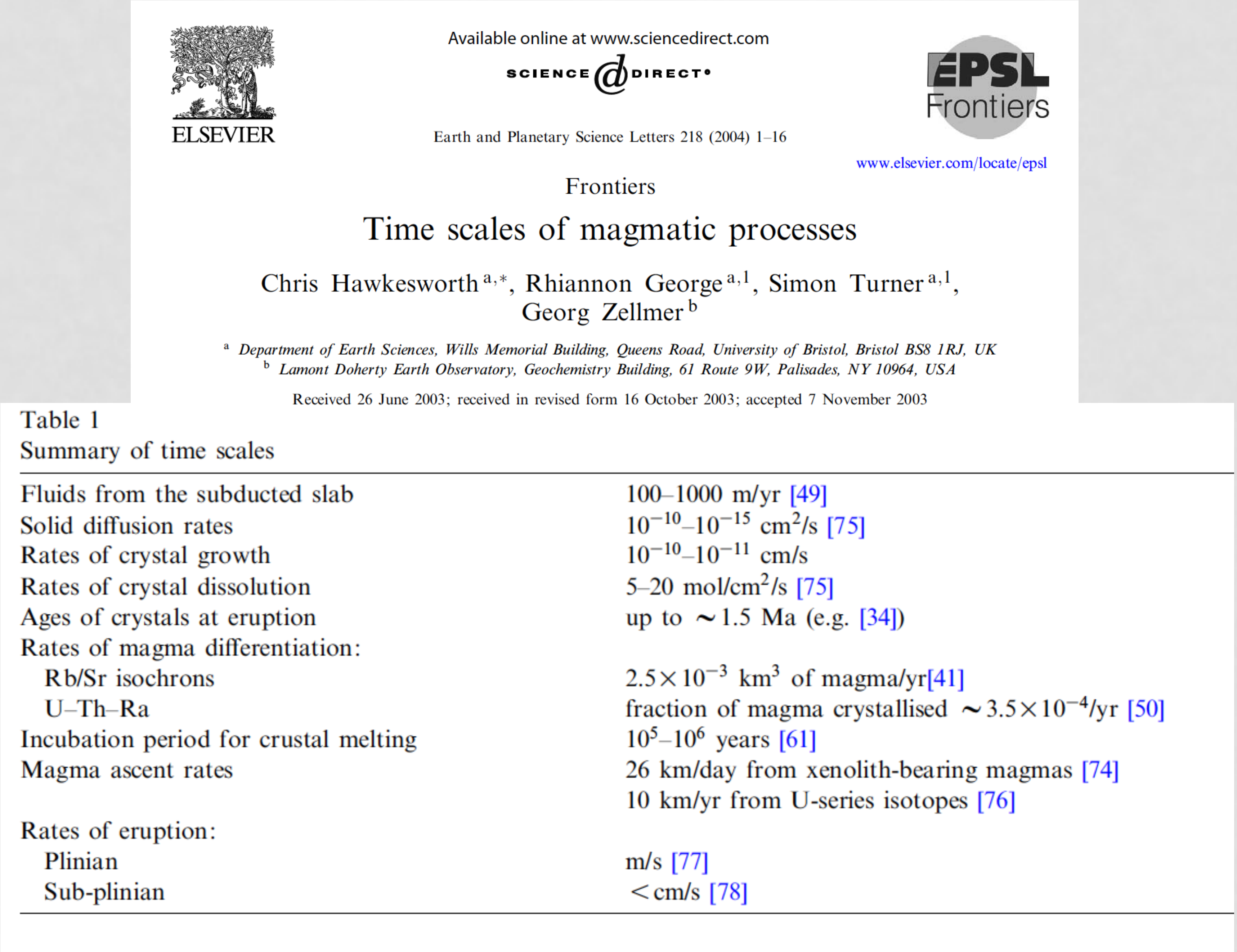


Figure 3.20 Partial fusion in a model ternary system A–B–C, in which the solid phases a, b and c are pure A, B and C respectively (after Barker 1983, Fig. 7.1, p.125):
(1) Appearance of bulk composition *X* at a temperature below that of the ternary eutectic E_1 i.e. the subsolidus assemblage.
(2) Partial fusion has begun to produce liquid (black) with a composition E_1 at those points where the three phases a, b and c are in mutual contact.
(3) More advanced melting, still at E_1, at the point at which all of the phase b is used up.
(4) Liquid escapes as b is consumed, leaving a crystalline residue of a and c of bulk composition *X′*. This residue will only be able to melt further if the temperature is raised to that of the binary eutectic E_2.





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Time scales of magmatic processes

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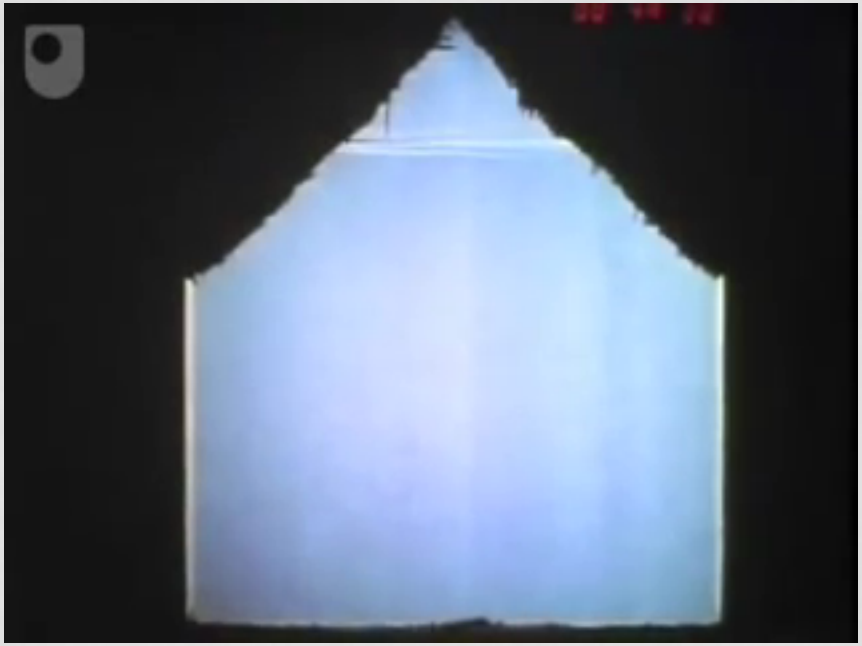
Table 1
Summary of time scales

Fluids from the subducted slab	100–1000 m/yr [49]
Solid diffusion rates	10^{-10}–10^{-15} cm^2/s [75]
Rates of crystal growth	10^{-10}–10^{-11} cm/s
Rates of crystal dissolution	5–20 $mol/cm^2/s$ [75]
Ages of crystals at eruption	up to ∼1.5 Ma (e.g. [34])
Rates of magma differentiation:	
Rb/Sr isochrons	2.5×10^{-3} km^3 of magma/yr[41]
U–Th–Ra	fraction of magma crystallised $\sim 3.5 \times 10^{-4}$/yr [50]
Incubation period for crustal melting	10^5–10^6 years [61]
Magma ascent rates	26 km/day from xenolith-bearing magmas [74]
	10 km/yr from U-series isotopes [76]
Rates of eruption:	
Plinian	m/s [77]
Sub-plinian	< cm/s [78]

FRACIONAMENTO EM SISTEMA FECHADO

- Cristalização Fracionada



MECANISMOS DE SEPARAÇÃO DE CRISTAIS

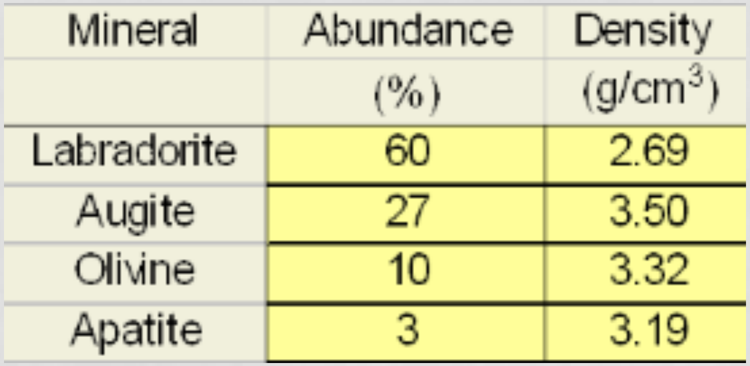
- Afundamento (*settling*)

$$v = \frac{2gr^2(d_s - d_L)}{9\eta}$$

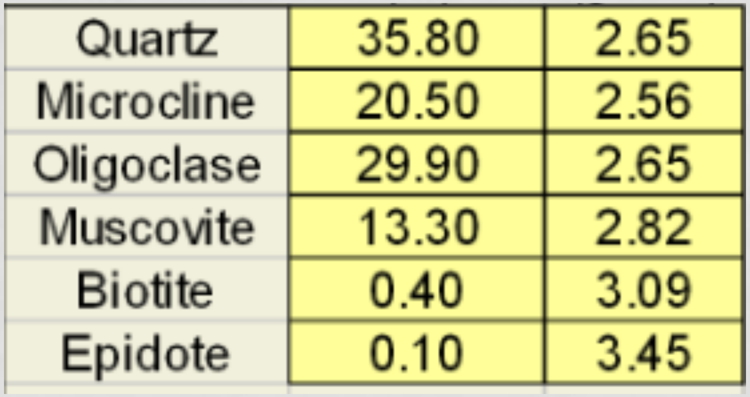
V = Velocidade de afundamento (cm/sec)
g = Aceleração da gravidade (980 cm/sec^2)
r = Raio do mineral aproximado para uma esfera(cm)
d_s = Densidade do mineral (g/cm^3)
d_{Ll} = the density of the liquid (g/cm^3)
η = viscosidade do magma (1 g/cm sec = 1 poise)

DENSIDADES DE CRISTAIS E MAGMAS

- Minerais

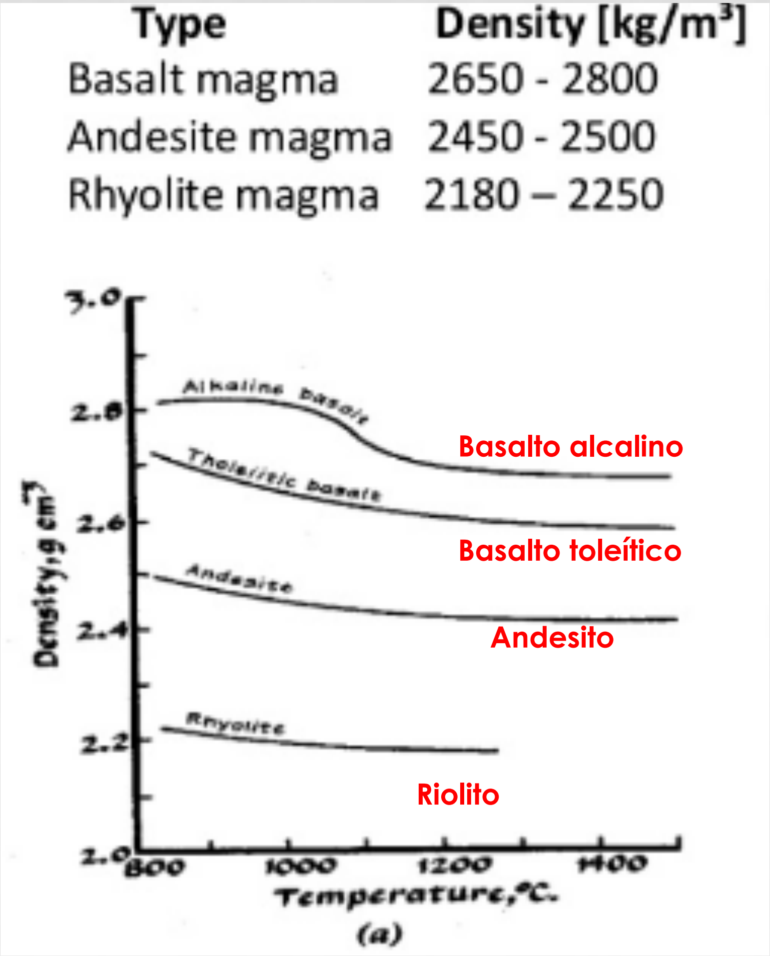


Mineral	Abundance (%)	Density (g/cm^3)
Labradorite	60	2.69
Augite	27	3.50
Olivine	10	3.32
Apatite	3	3.19



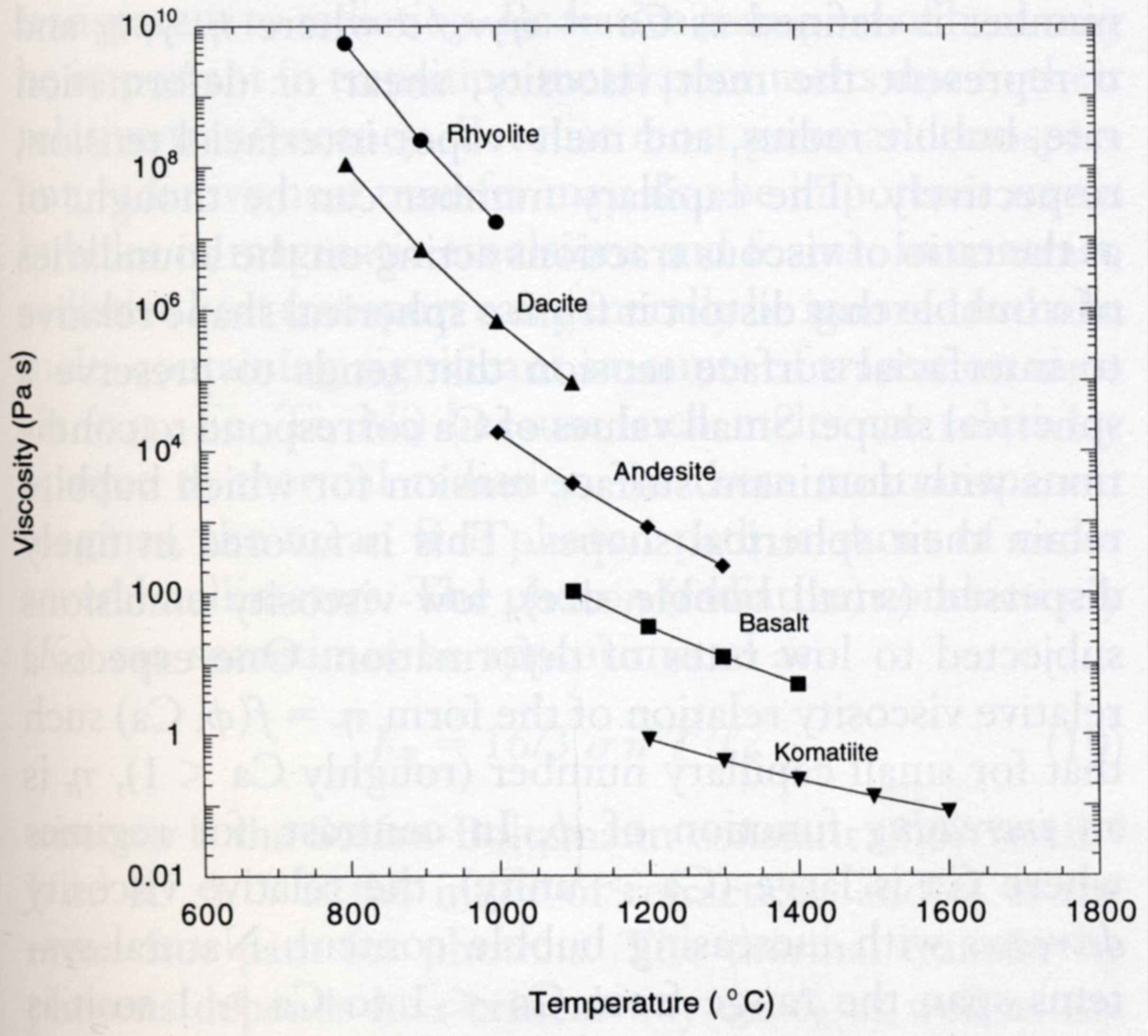
Quartz	35.80	2.65
Microcline	20.50	2.56
Oligoclase	29.90	2.65
Muscovite	13.30	2.82
Biotite	0.40	3.09
Epidote	0.10	3.45

- Magmas



Type	Density [kg/m^3]
Basalt magma	2650 - 2800
Andesite magma	2450 - 2500
Rhyolite magma	2180 – 2250

VISCOSIDADE DOS MAGMAS



Nota: 1 Pa.s = 10 poise

PARA PENSAR

- Por que feições cumuláticas são mais comuns em rochas de composição basáltica em comparação com rochas de composição riolítica?

DARWIN, AQUELE MESMO

- *One side of Freshwater Bay* [sic; this is an error in Darwin's publication and should be Buccaneer Cove], *in James Island, is formed by the wreck of a large crater, mentioned in the last chapter, of which the interior has been filled up by a pool of basalt, about two hundred feet in thickness. This basalt is of grey colour, and contains many crystals of glassy albite, which become much more numerous in the lower, scoriaceous part.... At James Island, the crystals of albite, though no doubt of less weight than the grey basalt, in the parts where compact, might easily be of greater specific gravity than the scoriaceous mass, formed of melted lava and bubbles of heated gas.*

Darwin, 1844; p. 244.

CRISTALIZAÇÃO FRACIONADA

- Bowen popularizou a ideia

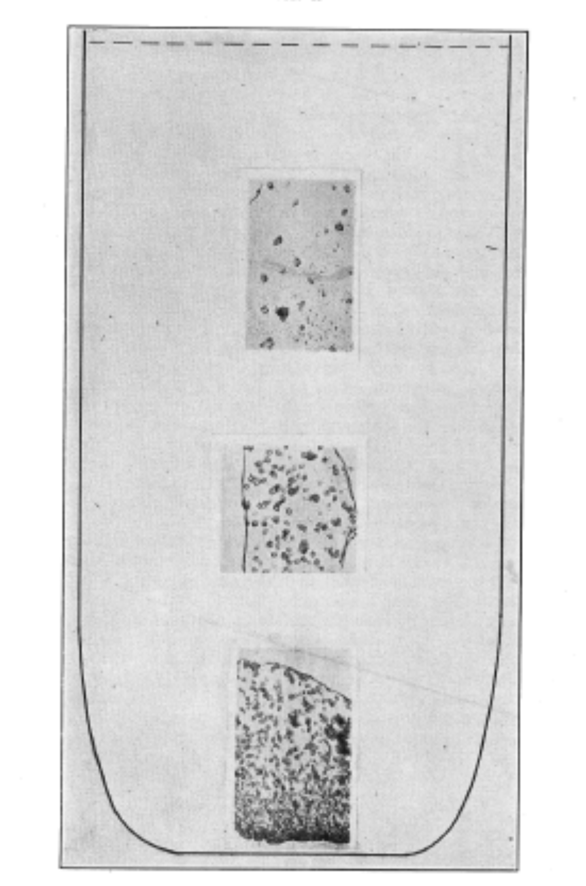


FIG. 1. Olivine (forsterite) crystals in glass showing position of sections in the crucible. × 10.

N. L. Bowen—Crystallization. 175

ART. X. — *Crystallization — Differentiation in Silicate Liquids ;* by N. L. BOWEN.

Introduction.

EVER since Darwin pointed out the possible importance of the sinking of crystals in a fluid magma, this process has received some attention from geologists when considering the causes that have brought about the observed variety of igneous rocks. Though having a few ardent advocates like Schweig, the process has met on the whole with little favor. The question is not infrequently dismissed with the statement that there is no evidence that crystals sink in magmas. This summary rejection of the process is quite inconclusive. Such a statement, to have any weight, should be accompanied by a fair discussion of the kind of evidence that would be expected and a convincing proof that such evidence is absent. The importance of the process must be judged by the extent to which observed results agree with the results to be expected if such a process were operative. Examined in this way it soon becomes apparent that the subject cannot be dismissed in a sentence, for many igneous bodies showing density stratification forbid it. In the writer's opinion the sinking of crystals will not only escape summary rejection as a result of such examination, but will be accepted as of very fundamental importance. In this paper discussion will be avoided of the whole question of the extent to which observed field-facts indicate the importance of the sinking of crystals in magmas. The purpose of the paper is principally to describe a few experiments which illustrate the operation of the process in mineral solutions from which crystals are forming and to apply the results to one or two occurrences.

In a recent paper on "The Ternary System : Diopside-Forsterite-Silica," the writer discussed the results which would follow from the sinking of crystals in some of the liquids of the system.* These liquids are rather more fluid than most *artificial anhydrous* melts, and among such melts should be rather favorable for the sinking of crystals. It was determined, therefore, to hold a small crucible of one of these melts at a temperature at which it should consist of liquid and crystals and to observe what effects of this kind could be obtained. The advantages of using artificial melts which had formerly been completely investigated are many. It was known at what temperature the mixture should be held to obtain the desired effect. No com-

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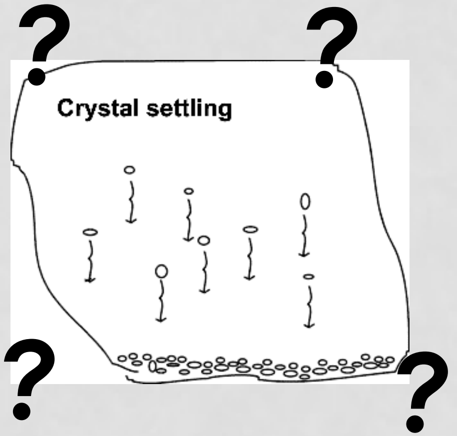
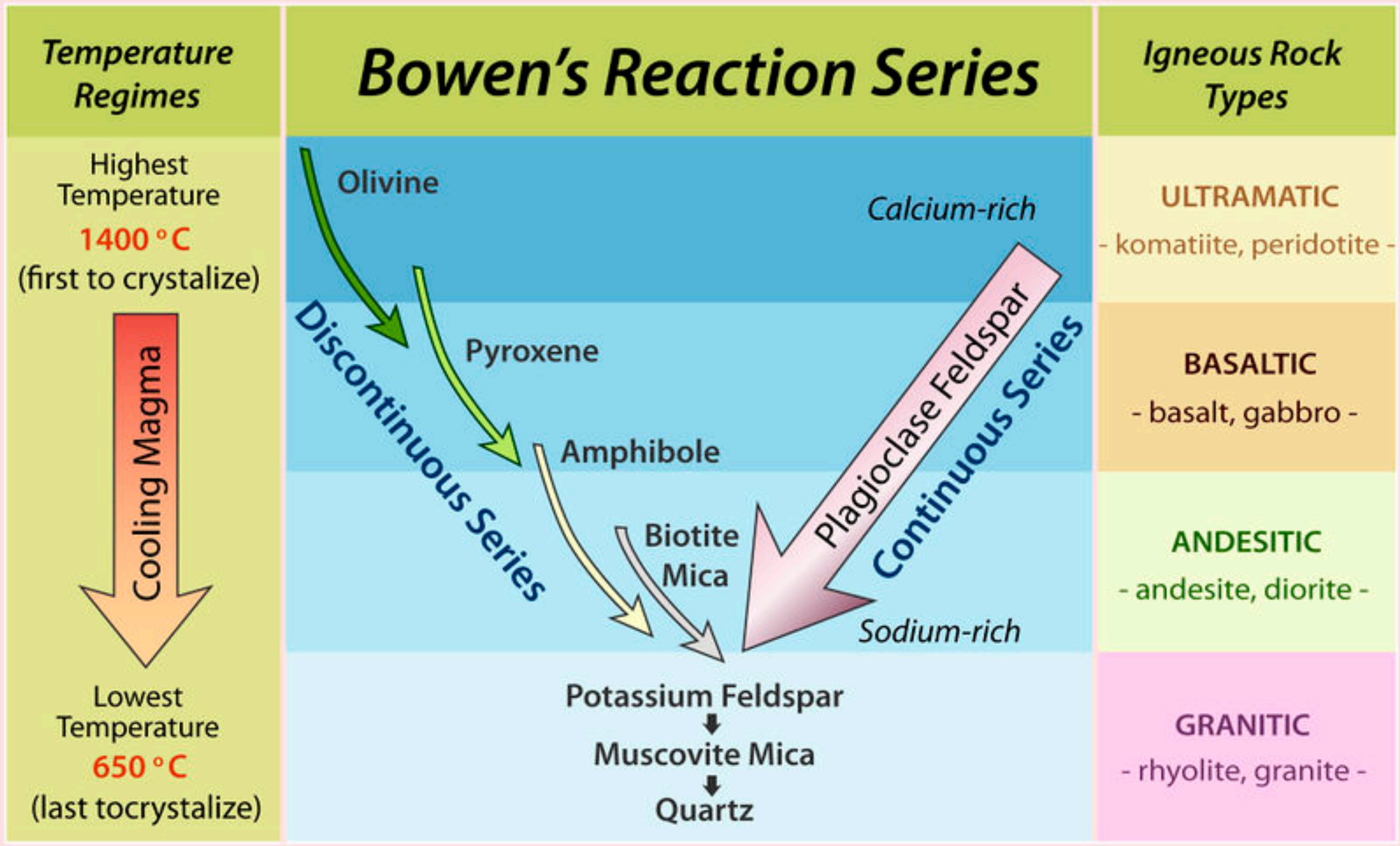
* This Journal (4), xxxviii, 258, 1914.



Crystallization-Differentiation in Silicate Liquids (1915)
Am. J. Sci., s4-39(230):175-191

CRISTALIZAÇÃO FRACIONADA



O PAPEL DA DIFERENCIAÇÃO POR CRISTALIZAÇÃO

- **Série toleítica**:

basalto toleítico→andesito→dacito→riolito

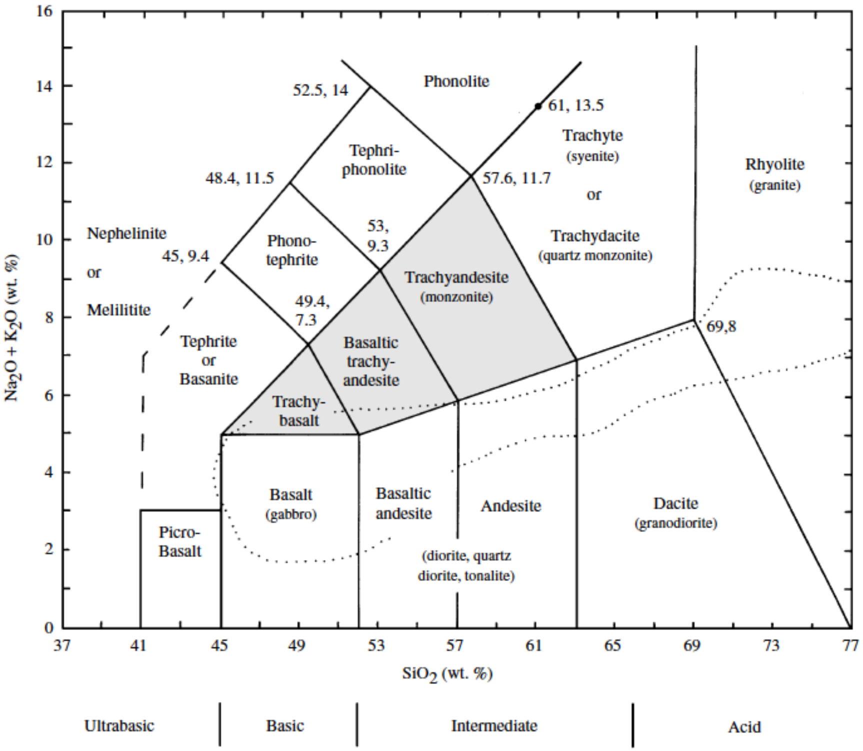
- **Série alcalina**:

basalto alcalino→traquibasalto→traquito→fonolito

- **Série cálcio - alcalina**:

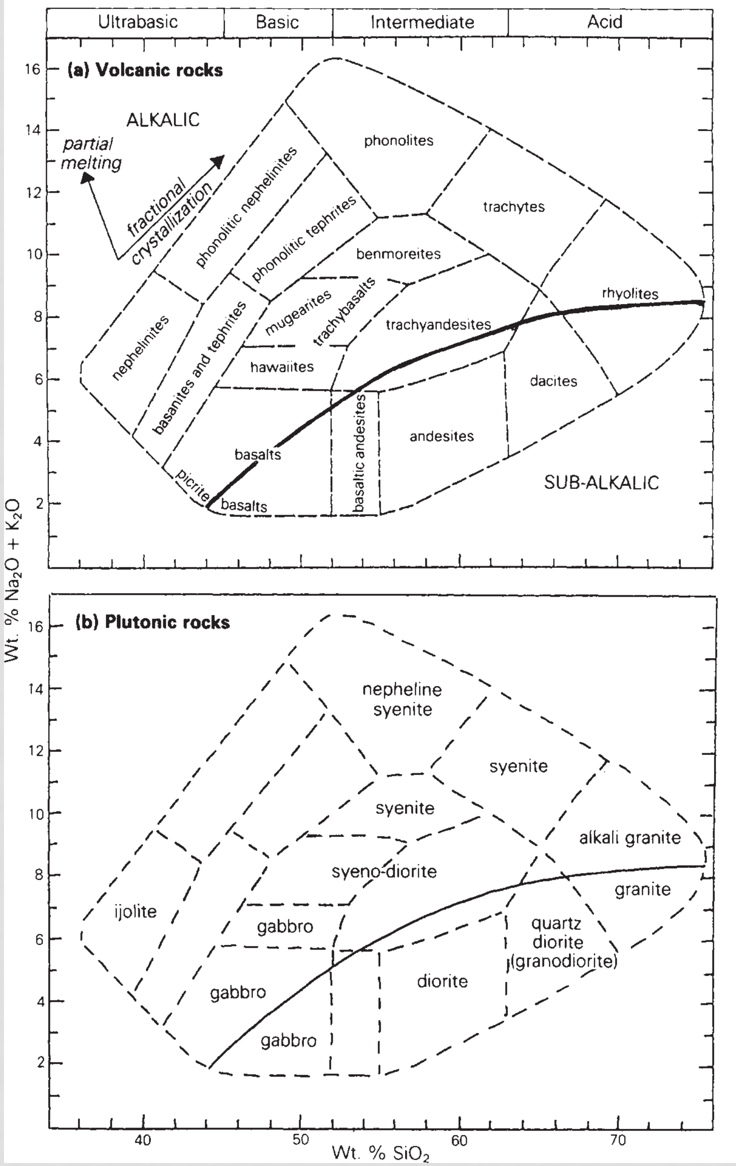
basalto→andesito→dacito→riolito

Série Magmáticas – Variações Composicionais



Further subdivisions of shaded fields	Trachybasalt	Basaltic trachyandesite	Trachyandesite
$Na_2O - 2.0 \geq K_2O$	Hawaiite	Mugearite	Benmoreite
$Na_2O - 2.0 \leq K_2O$	Potassic trachybasalt	Shoshonite	Latite

2.12 IUGS classification of aphanitic and glassy volcanic rock types. Coordinates of critical points are indicated as, for example, SiO_2 wt.% = 69 and ($Na_2O + K_2O$) wt.% = 8 at the common corner of the fields of trachyte, rhyolite, and dacite. Rocks plotting in the shaded area may be further subdivided into sodic and potassic rock types as shown in the box below the main part of the diagram. Figure 2.18 shows an alternate classification based on K_2O versus SiO_2. The distinction between trachyte ($Q < 20\%$) and trachydacite ($Q > 20\%$) is based on the amount of normative quartz, Q, from a recalculation in which $Q + An + Ab + Or = 100$. The amount of normative olivine, Ol, in the rock distinguishes tephrite (<10%) from basanite (> 10%). Rock-type names for more or less corresponding common phaneritic rocks are indicated in parentheses. Dotted line encloses 53% of the rocks plotted in Figure 2.4. (Redrawn from Le Maitre, 1989.)



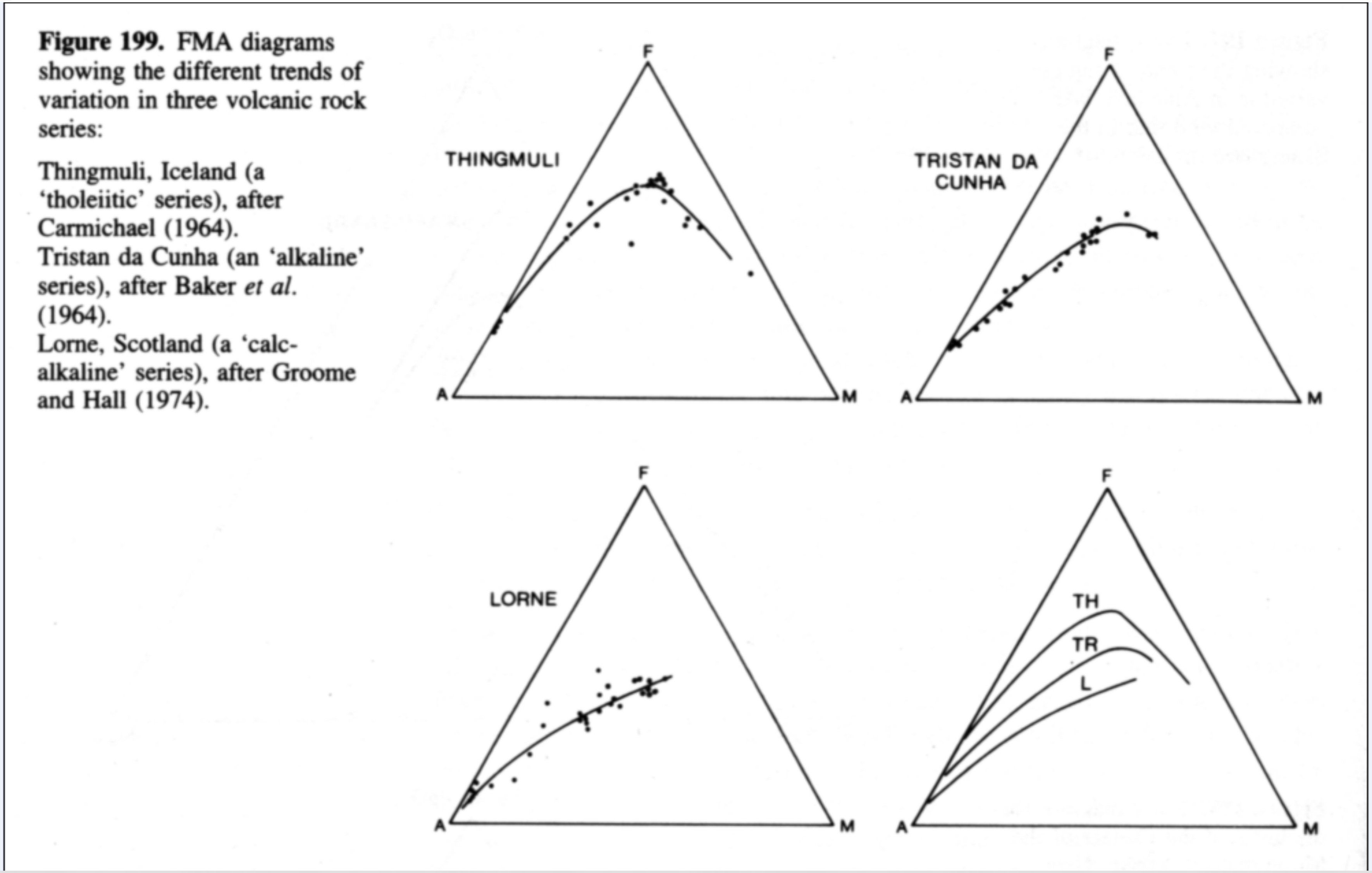
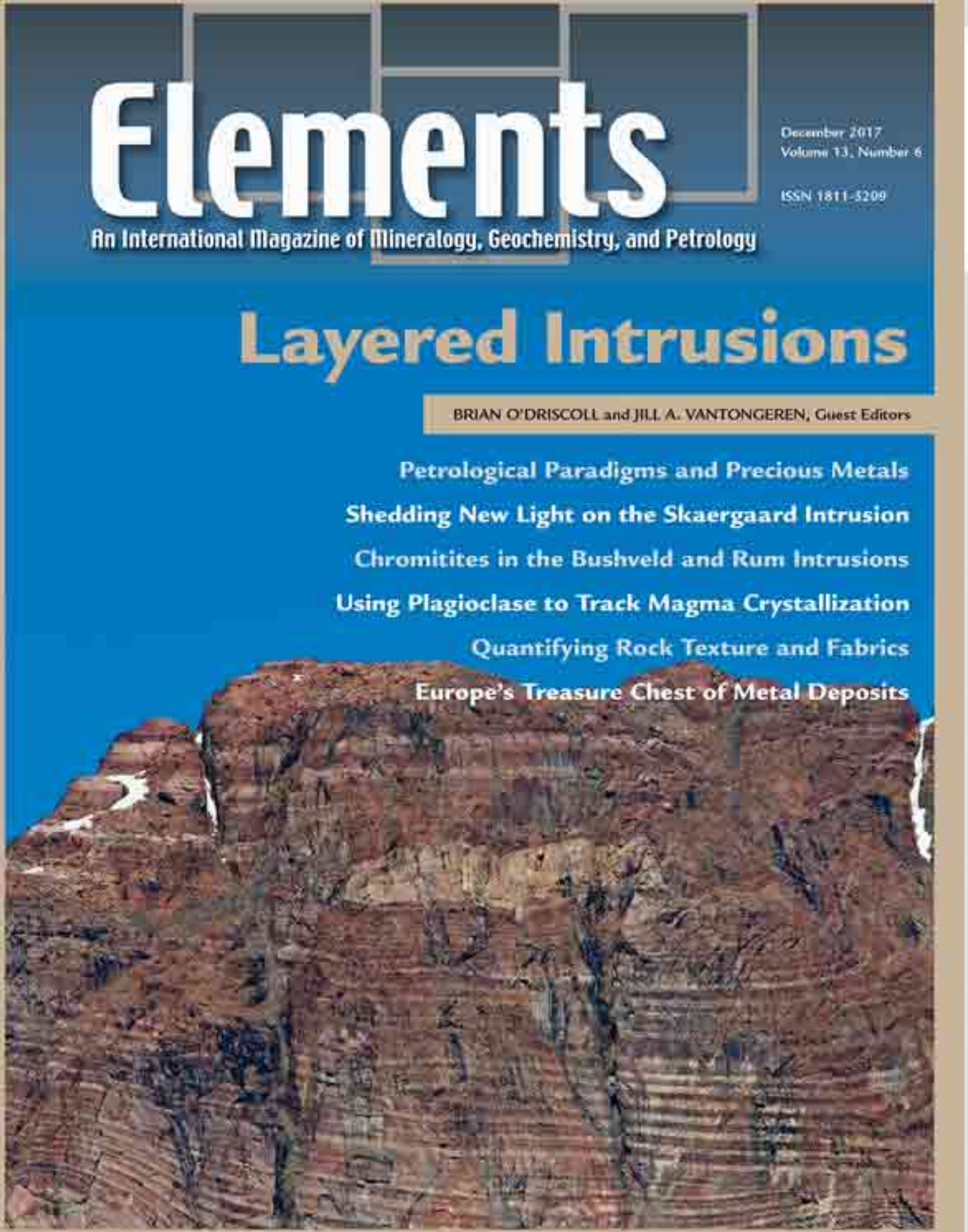


Figure 199. FMA diagrams showing the different trends of variation in three volcanic rock series:

Thingmuli, Iceland (a 'tholeiitic' series), after Carmichael (1964).
Tristan da Cunha (an 'alkaline' series), after Baker *et al*. (1964).
Lorne, Scotland (a 'calc-alkaline' series), after Groome and Hall (1974).

PRODUTOS

- *Liquid line of descent*
- *Cumulatos*
- *Vocês viram algum exemplo?*



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Layered Intrusions

BRIAN O'DRISCOLL and JILL A. VANTONGEREN, Guest Editors

Petrological Paradigms and Precious Metals

Shedding New Light on the Skaergaard Intrusion

Chromitites in the Bushveld and Rum Intrusions

Using Plagioclase to Track Magma Crystallization

Quantifying Rock Texture and Fabrics

Europe's Treasure Chest of Metal Deposits

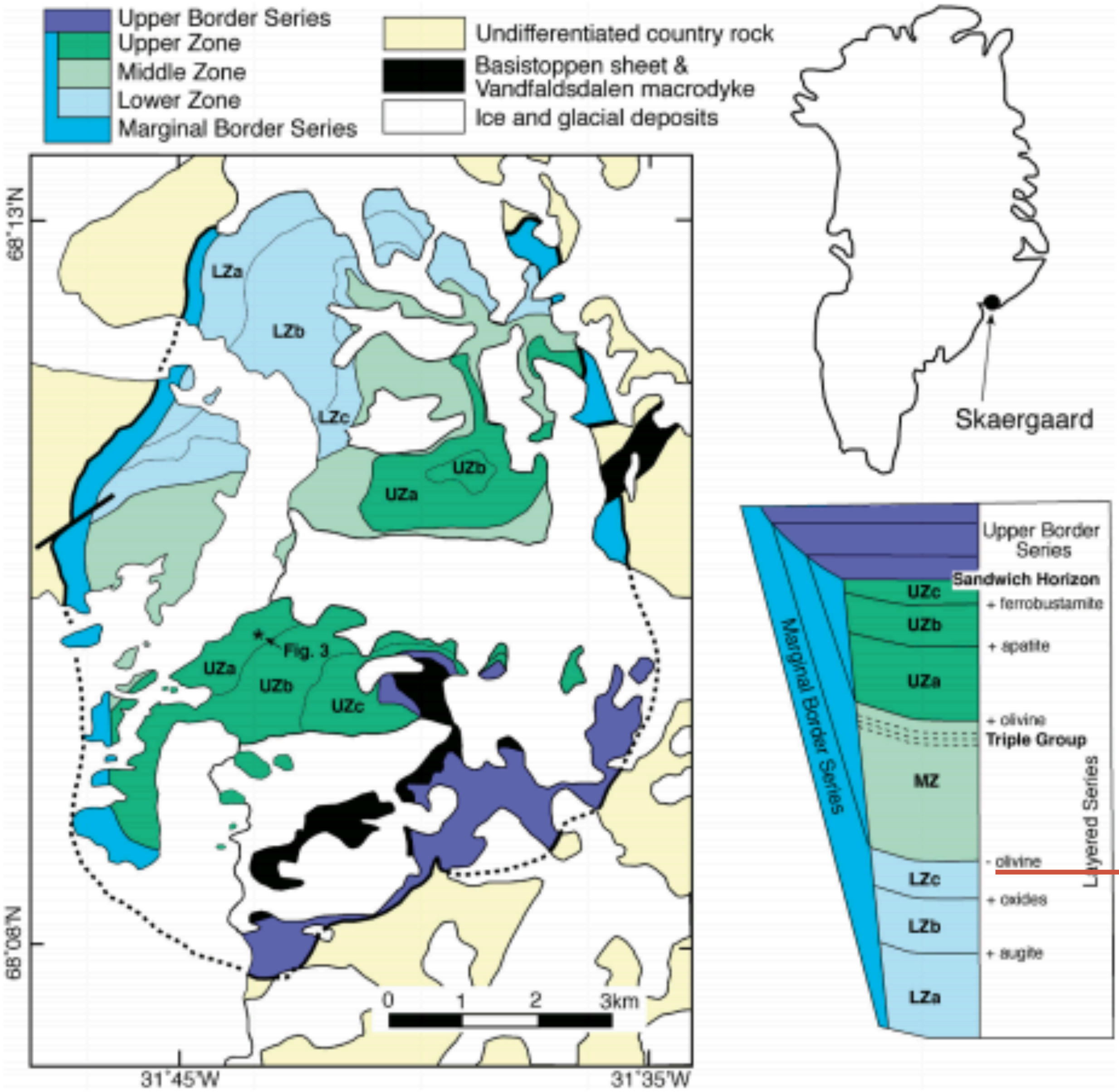
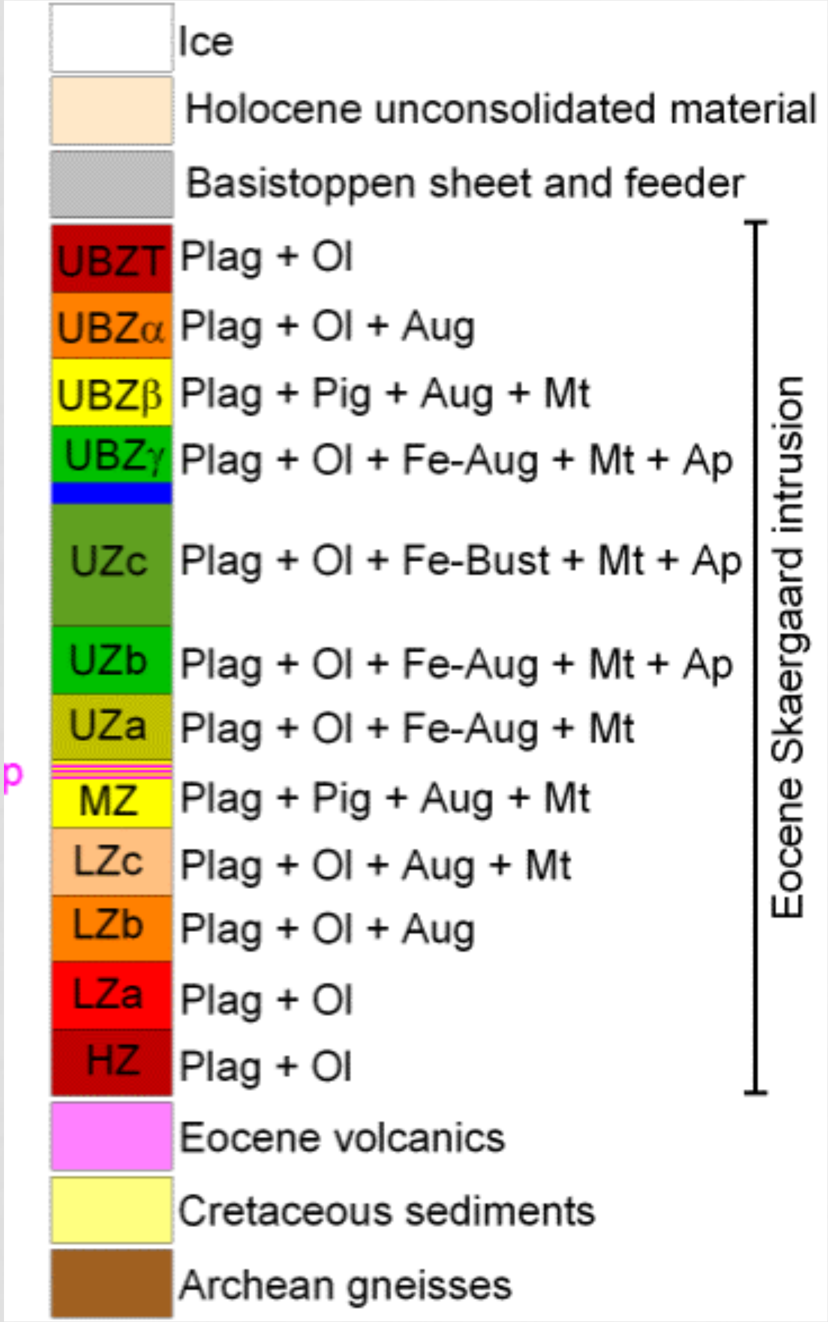


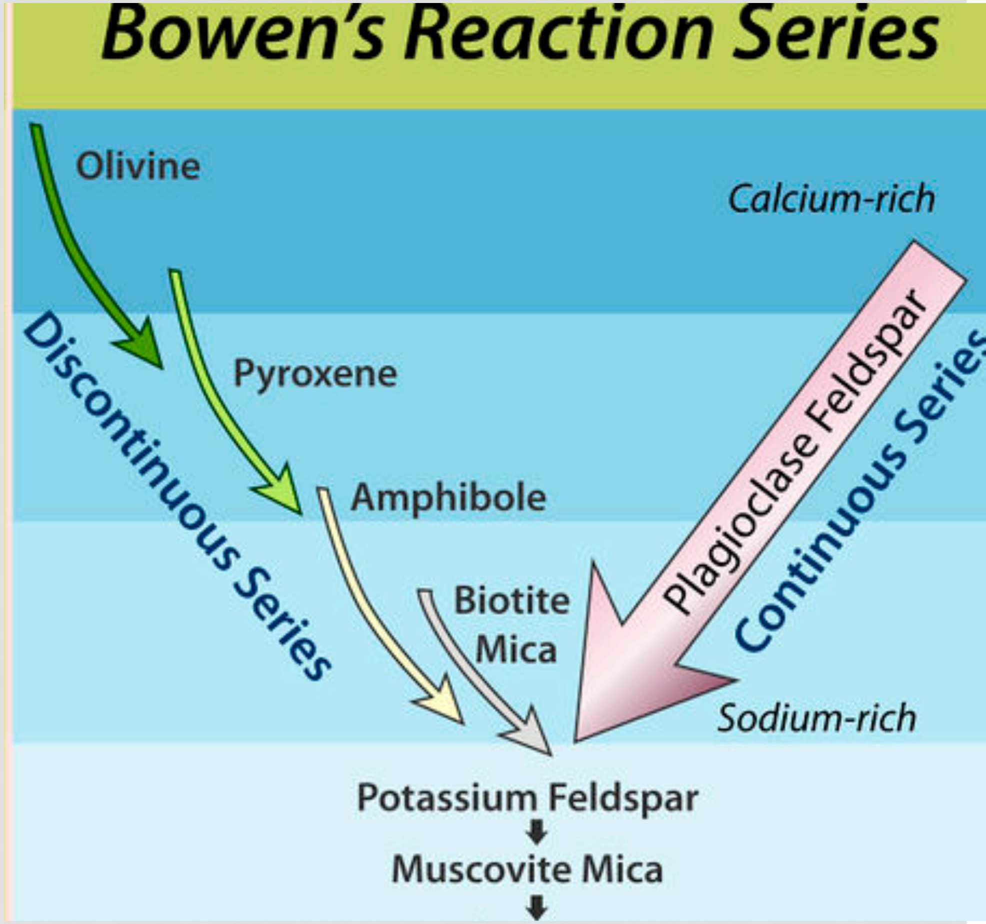
FIGURE 1 Sketch map of the Skaergaard Intrusion (East Greenland), showing the division into the Marginal Border Series (that crystallised inwards from the walls), the Upper Border Series (that crystallised downwards from the roof) and the Layered Series (which crystallised upwards from the floor). The inset stratigraphic column shows the subdivisions of the Layered Series into Lower Zone (LZ), Middle Zone (MZ) and Upper Zone (UZ) (see main text for definitions) with + and – symbols indicating the addition or removal of phases from the mineral assemblage crystallising from the remaining magma body. The Sandwich Horizon marks the point where the floor and roof series meet. See main text for a description of the Triple Group. The Basistoppen sheet and the Vandfaldsdalen macrodyke are later, related, intrusions. The location of the trough bands illustrated in FIGURE 3 is shown. GEOLOGICAL MAP AFTER MCBIRNEY (1989).

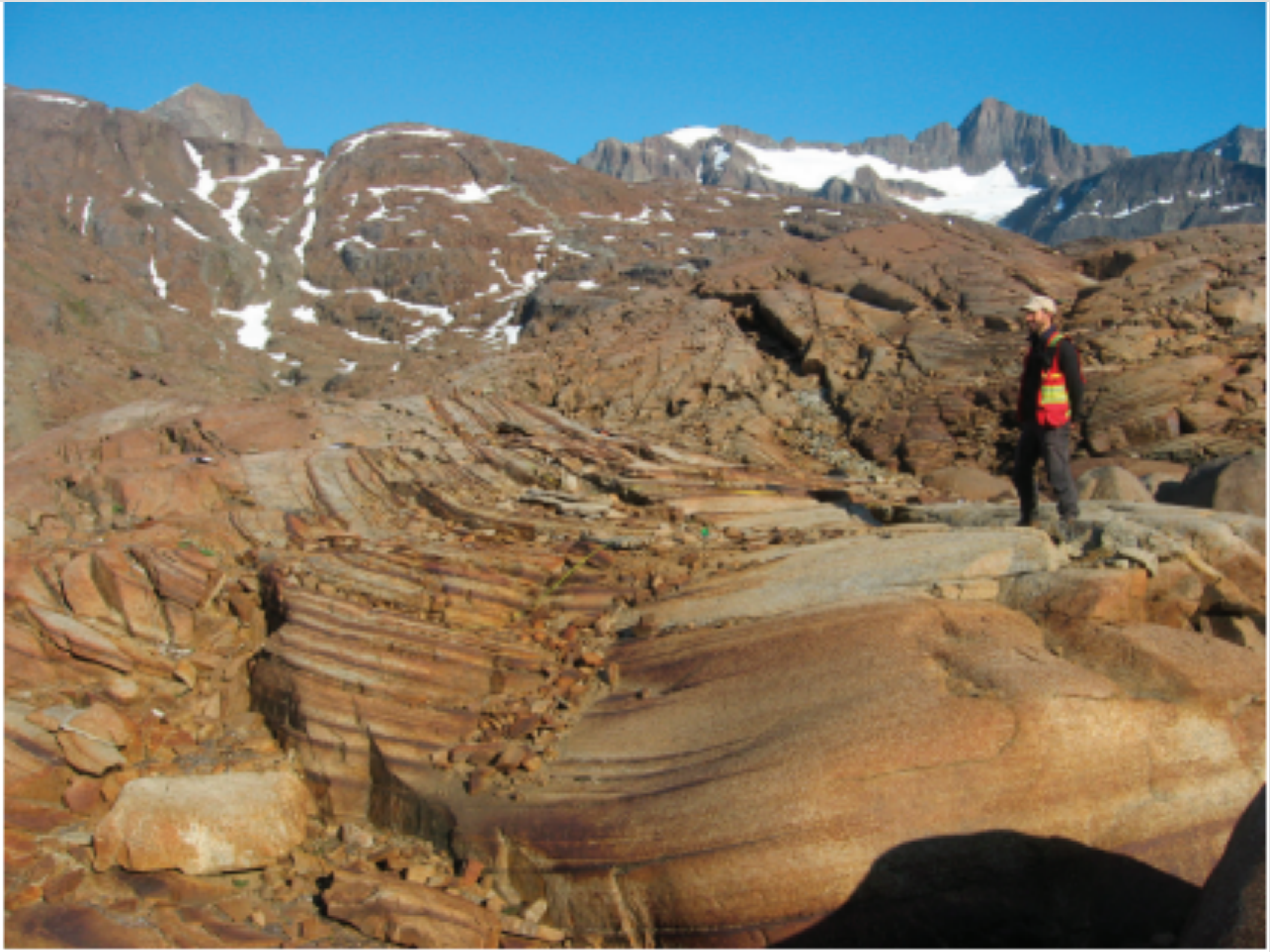
Layered series



☐	Ice
🟧	Holocene unconsolidated material
▨	Basistoppen sheet and feeder
UBZT	Plag + Ol
UBZα	Plag + Ol + Aug
UBZβ	Plag + Pig + Aug + Mt
UBZγ	Plag + Ol + Fe-Aug + Mt + Ap
UZc	Plag + Ol + Fe-Bust + Mt + Ap
UZb	Plag + Ol + Fe-Aug + Mt + Ap
UZa	Plag + Ol + Fe-Aug + Mt
MZ	Plag + Pig + Aug + Mt
LZc	Plag + Ol + Aug + Mt
LZb	Plag + Ol + Aug
LZa	Plag + Ol
HZ	Plag + Ol
🟪	Eocene volcanics
🟨	Cretaceous sediments
🟫	Archean gneisses

Eocene Skaergaard intrusion


Bowen's Reaction Series



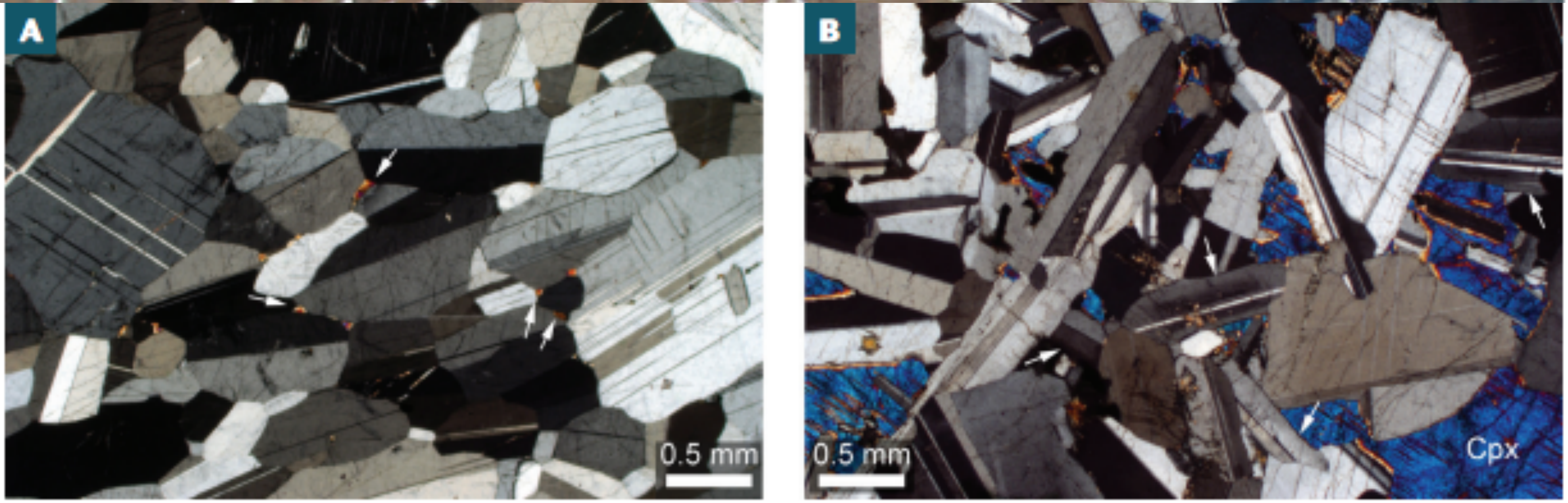
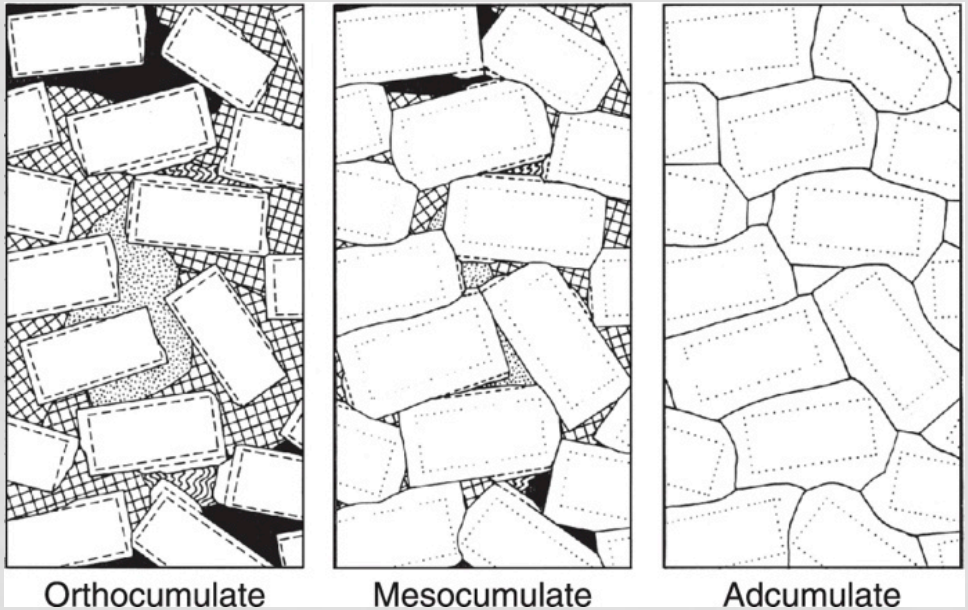
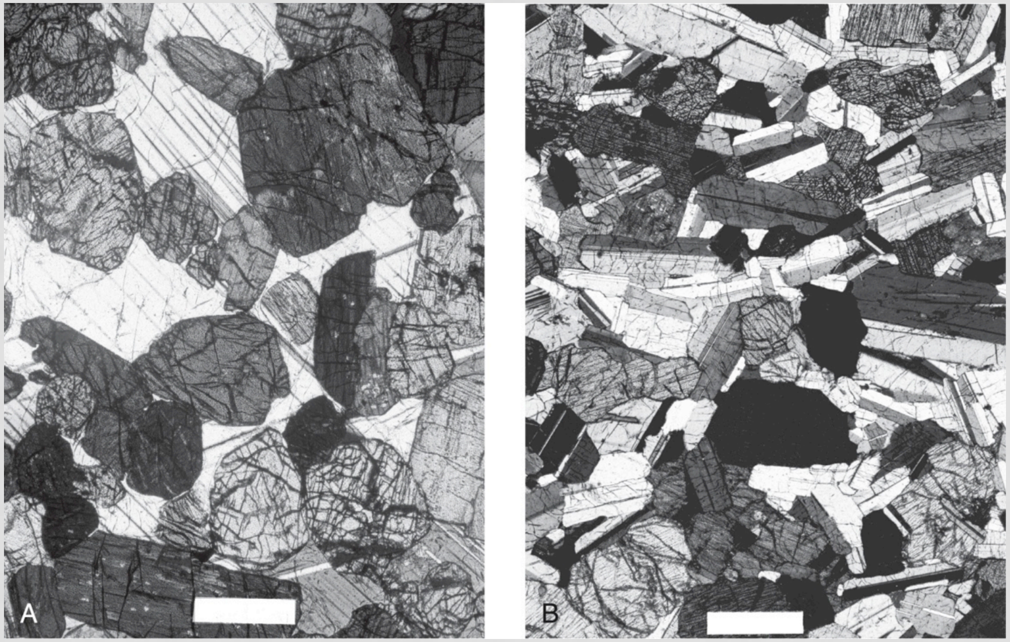
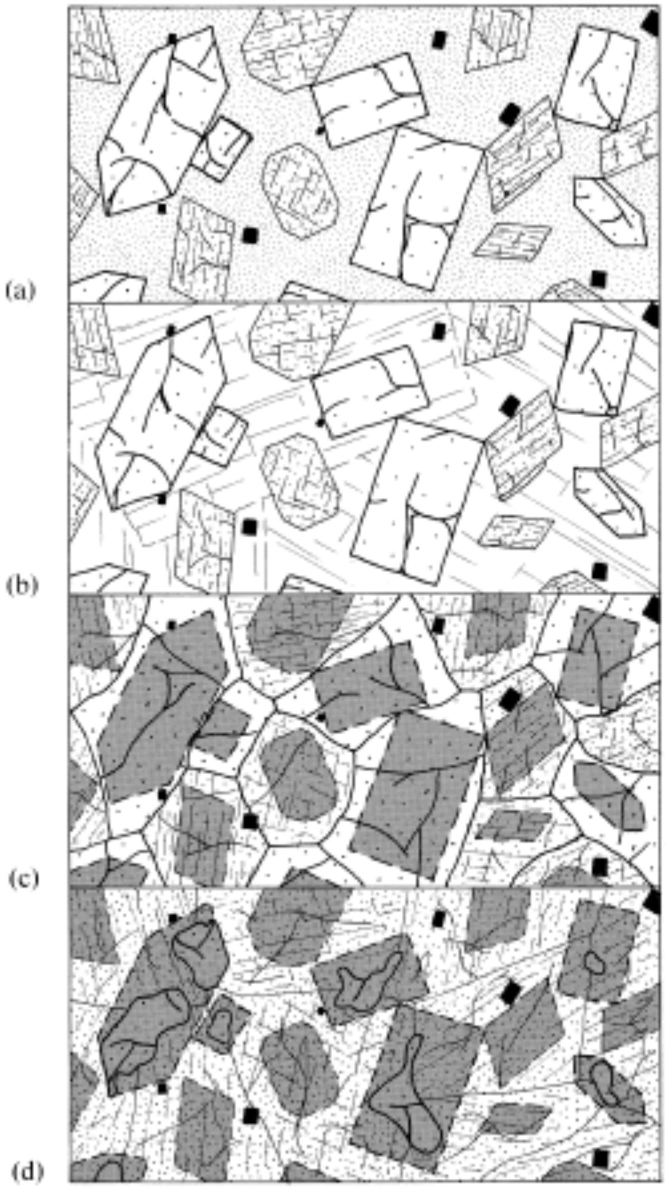


FIGURE 2 (**A**) A plagioclase adcumulate, formed of grains with a uniform composition grown from liquid derived from the overlying bulk magma. Clinopyroxene is the only other mineral in this rock, forming small isolated grains at grain boundaries (some are arrowed).

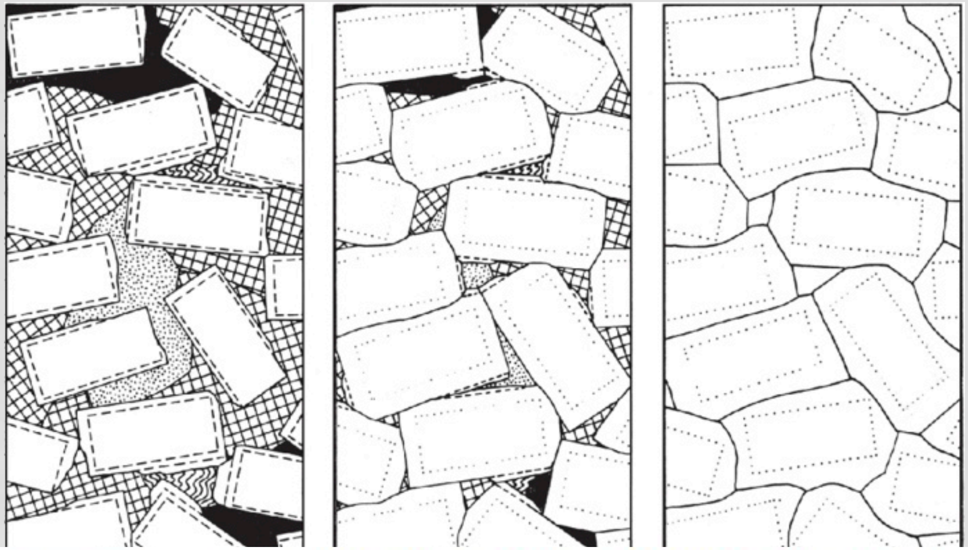
(**B**) An orthocumulate, formed of primary precipitate plagioclase grains cemented by abundant clinopyroxene (Cpx). In this rock, the plagioclase grains are compositionally normally zoned (some examples are arrowed) denoting growth from progressively fractionating liquid within the mushy layer. PHOTOS: MARIAN HOLNESS

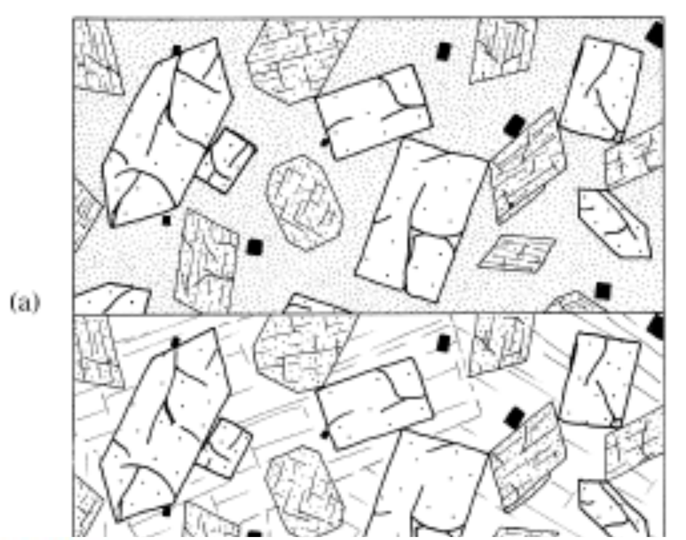






12.16 Evolution of **cumulus** fabric. The three **postcumulus** processes





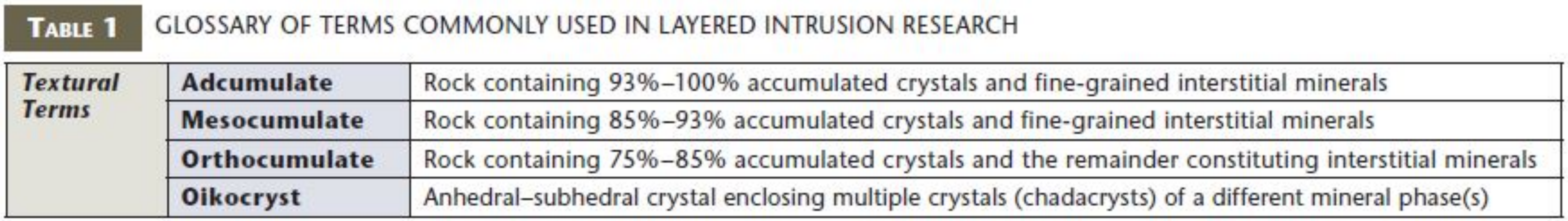
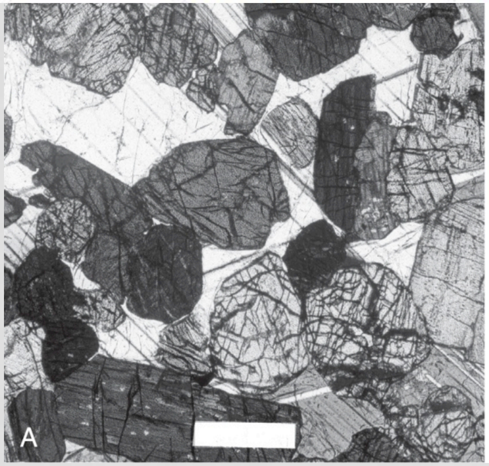
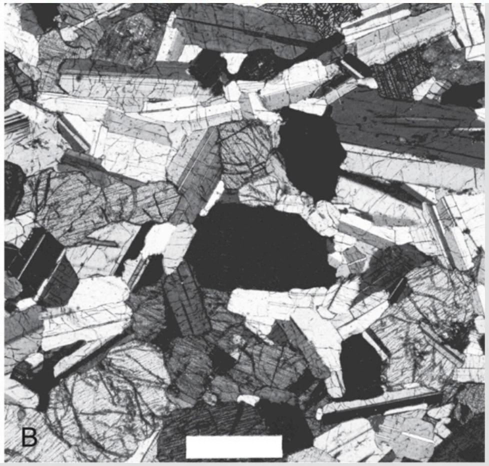
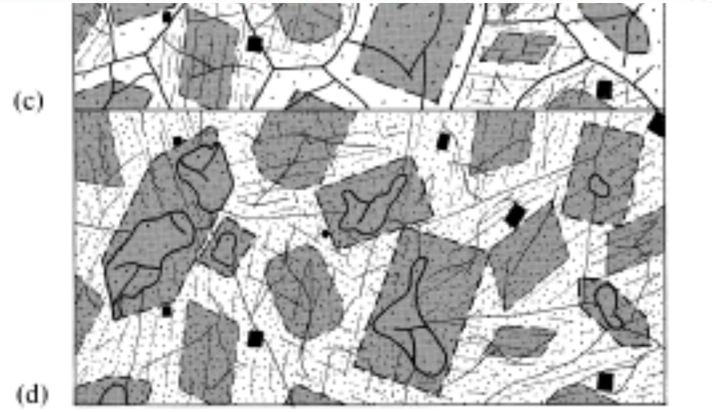


TABLE 1 GLOSSARY OF TERMS COMMONLY USED IN LAYERED INTRUSION RESEARCH

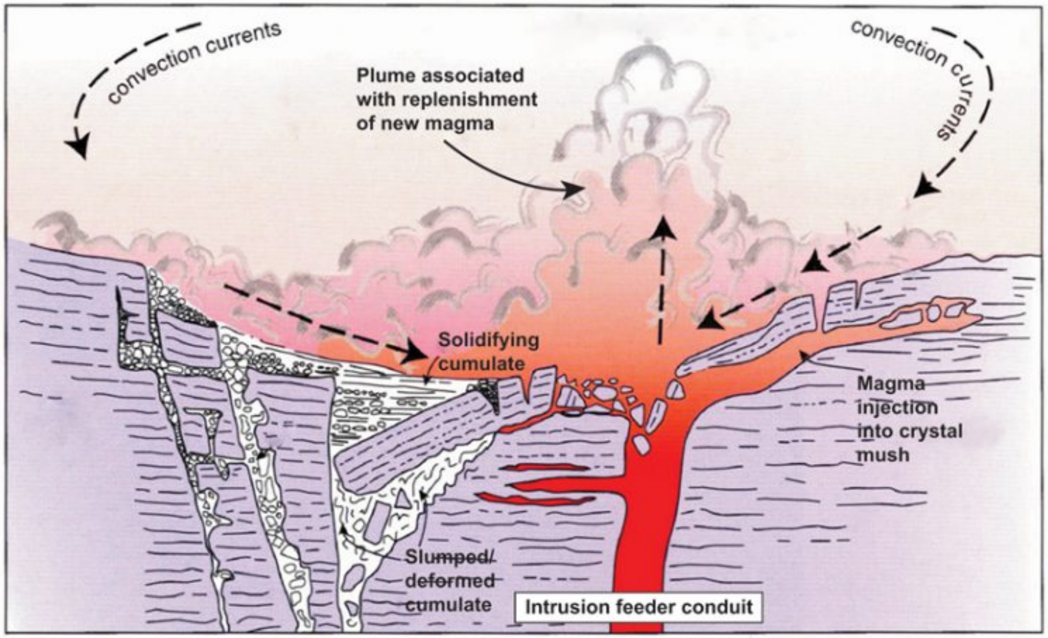
Textural Terms	**Adcumulate**	Rock containing 93%–100% accumulated crystals and fine-grained interstitial minerals
	Mesocumulate	Rock containing 85%–93% accumulated crystals and fine-grained interstitial minerals
	Orthocumulate	Rock containing 75%–85% accumulated crystals and the remainder constituting interstitial minerals
	Oikocryst	Anhedral–subhedral crystal enclosing multiple crystals (chadacrysts) of a different mineral phase(s)



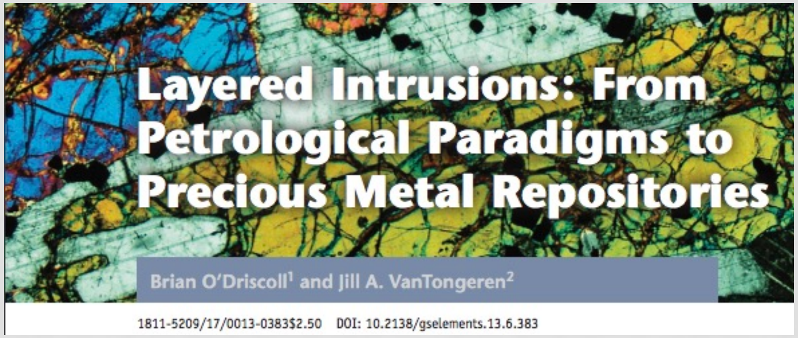




12.16 Evolution of **cumulus** fabric. The three **postcumulus** processes



- *Correntes de convecção*
- *Solidificação de cumulatos*
- *Plumas magmas de repreenchimento*



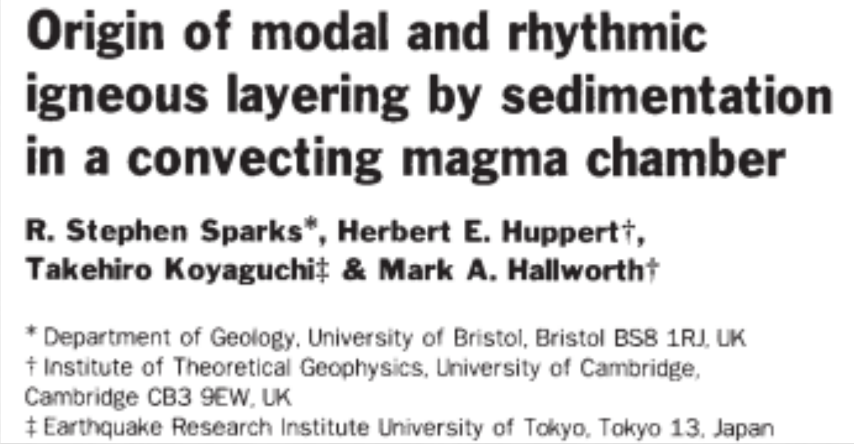
Layered Intrusions: From Petrological Paradigms to Precious Metal Repositories

Brian O'Driscoll[1] and Jill A. VanTongeren[2]

1811-5209/17/0013-0383$2.50 DOI: 10.2138/gselements.13.6.383

ROCHAS CUMULÁTICAS

- Como segregar o líquido: compactação *versus* convecção desencadeada por diferença de composição (vimos no vídeo)

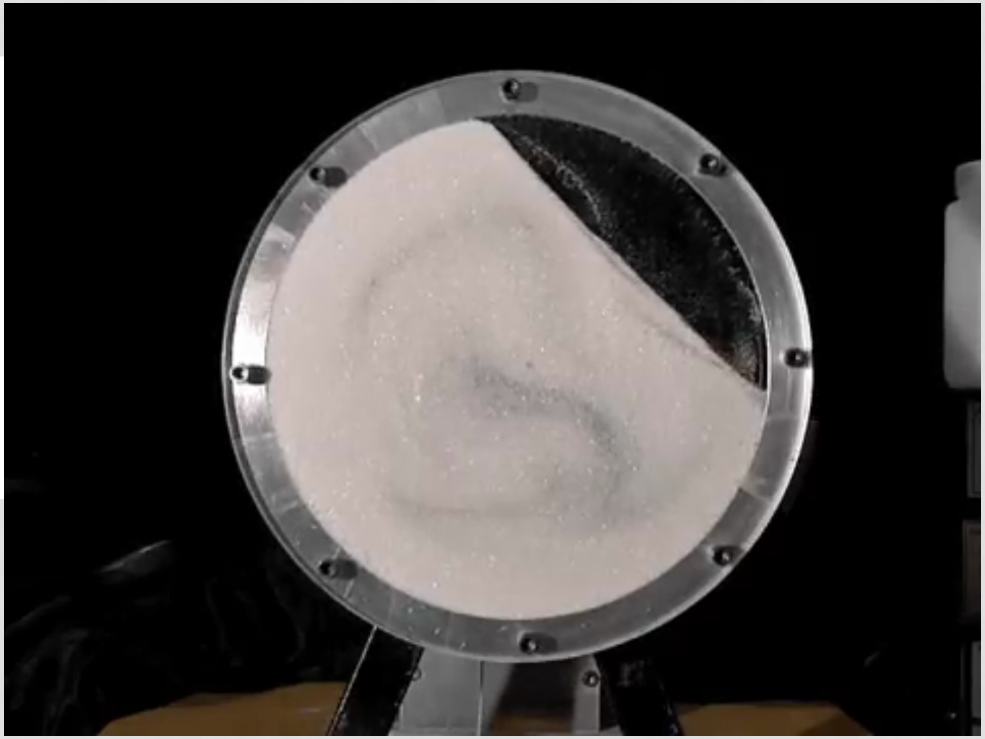


Origin of modal and rhythmic igneous layering by sedimentation in a convecting magma chamber

R. Stephen Sparks*, Herbert E. Huppert†, Takehiro Koyaguchi‡ & Mark A. Hallworth†

* Department of Geology, University of Bristol, Bristol BS8 1RJ, UK
† Institute of Theoretical Geophysics, University of Cambridge, Cambridge CB3 9EW, UK
‡ Earthquake Research Institute University of Tokyo, Tokyo 13, Japan

Nature, Janeiro (1993)



Dynamics of Magmatic Systems

Bruce D. Marsh*

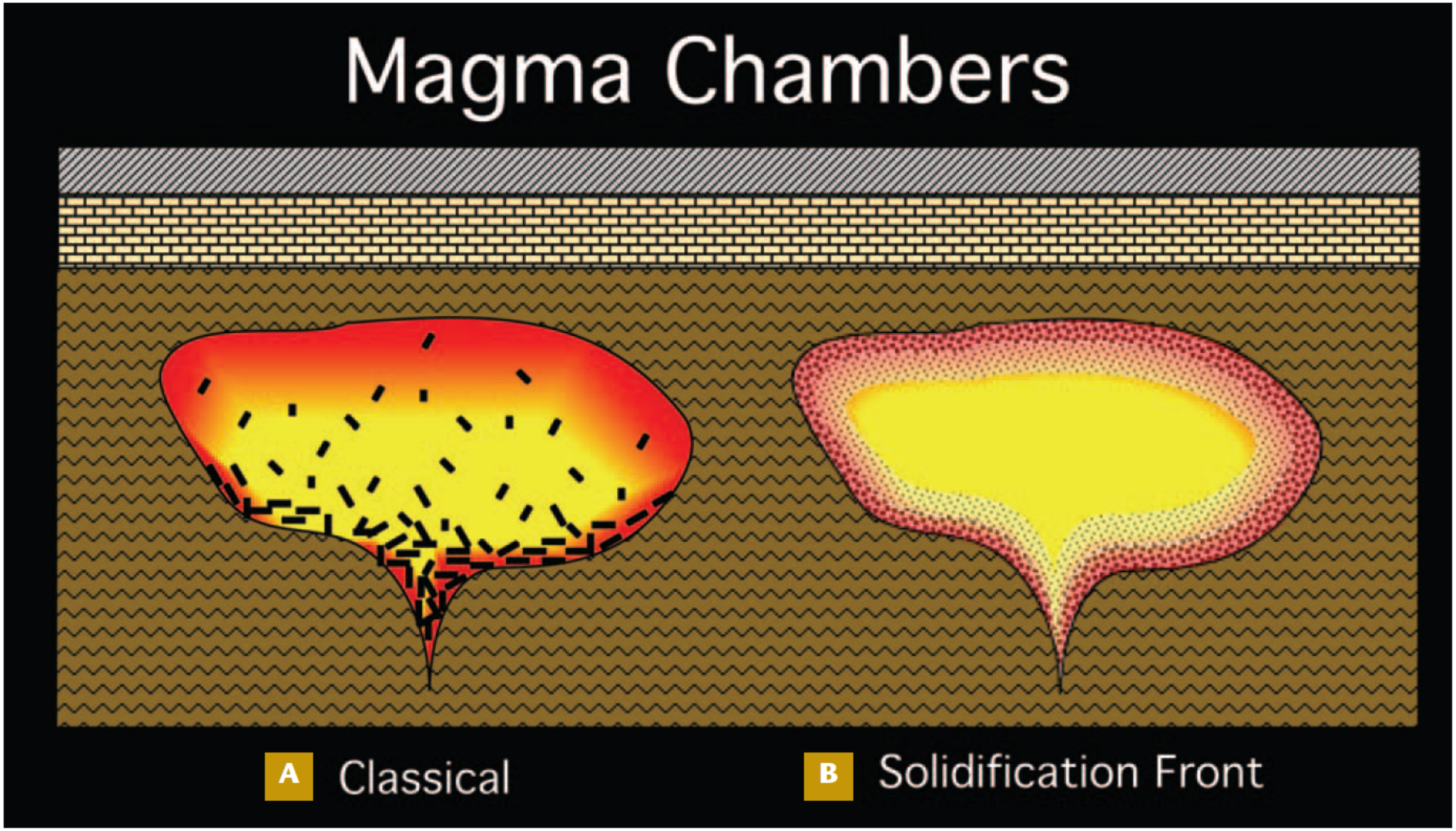
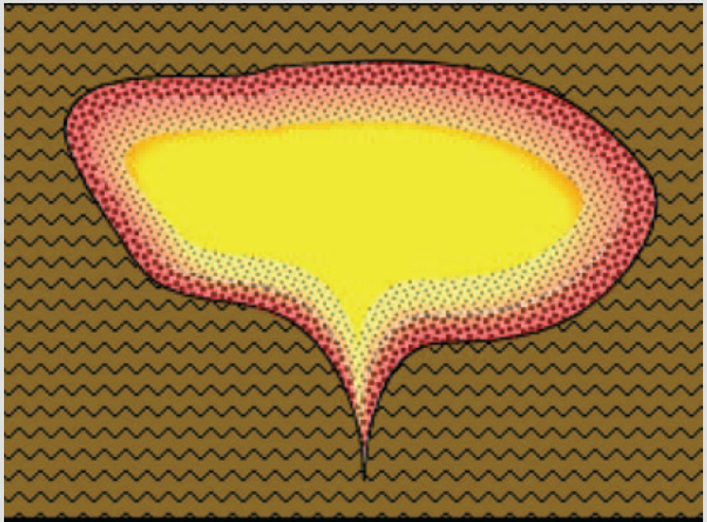


FIGURE 1 (**A**) The classical concept of a magma chamber where crystals nucleate, grow, and settle from the interior to chemically fractionate the residual melt. (**B**) The same magma chamber encased in marginal solidification fronts within which all crystallization occurs. The chemically fractionated residual melt is trapped within the front and is normally inaccessible to extraction and eruption.

Mecanismos de Fracionamento cristal-líquido

Dynamics of Magmatic Systems

Bruce D. Marsh*



B Solidification Front

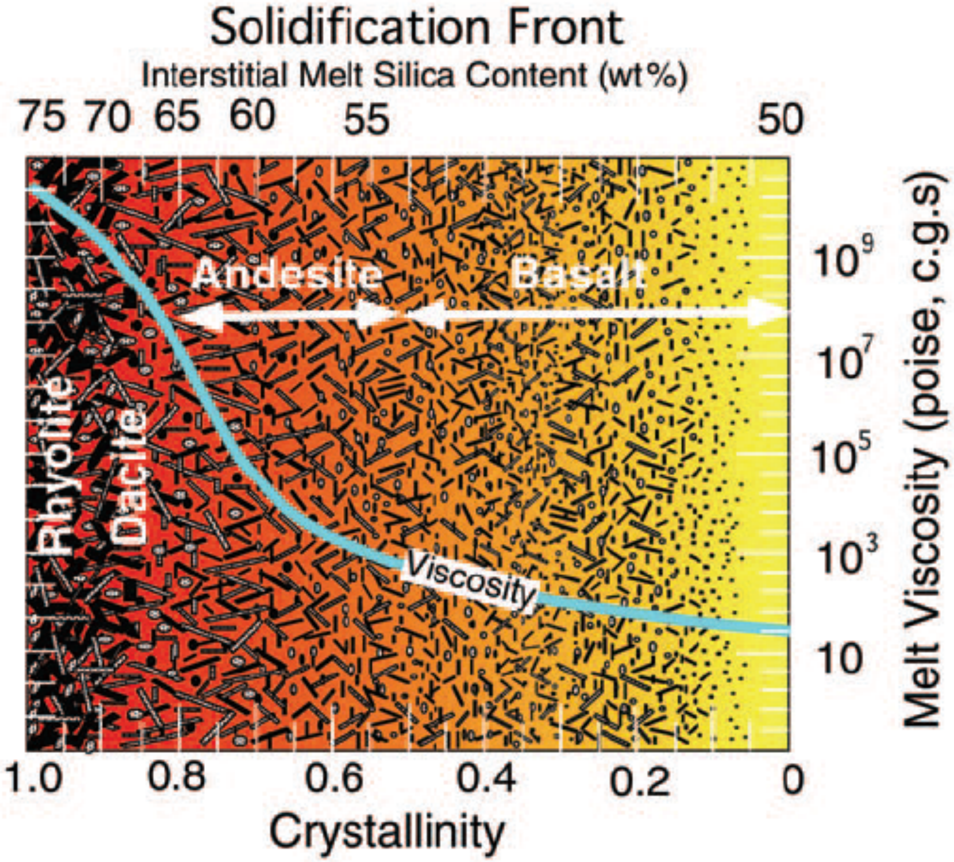
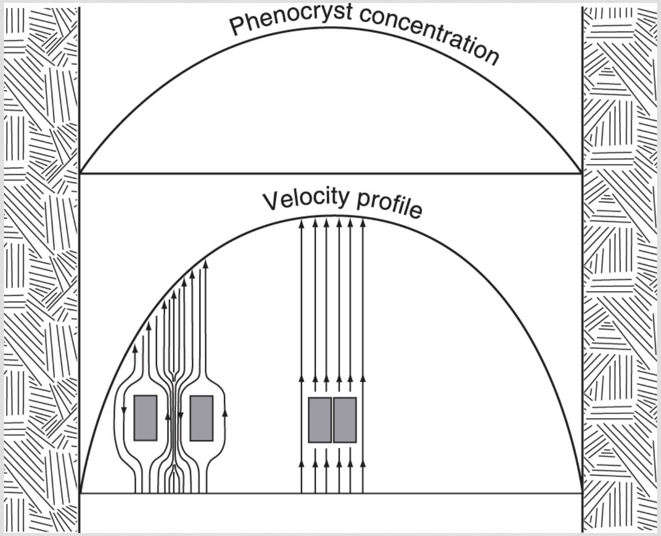
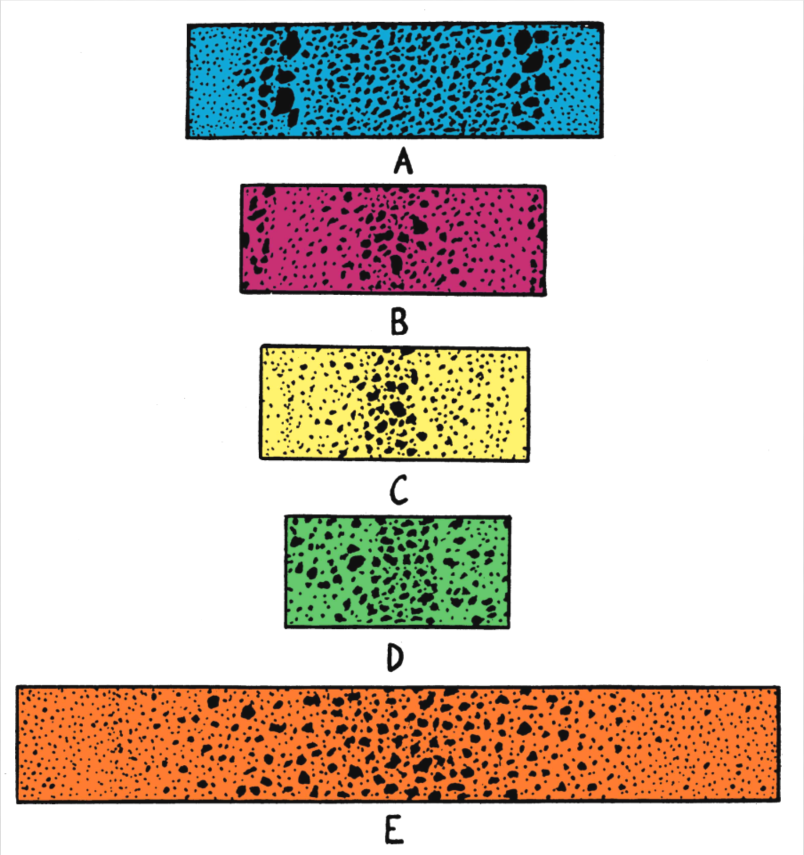


FIGURE 2 A basaltic solidification front depicting the change in composition and viscosity of the interstitial melt with position or crystallinity within the solidification front. The highly silicic melt resides within the strongest part of the front.

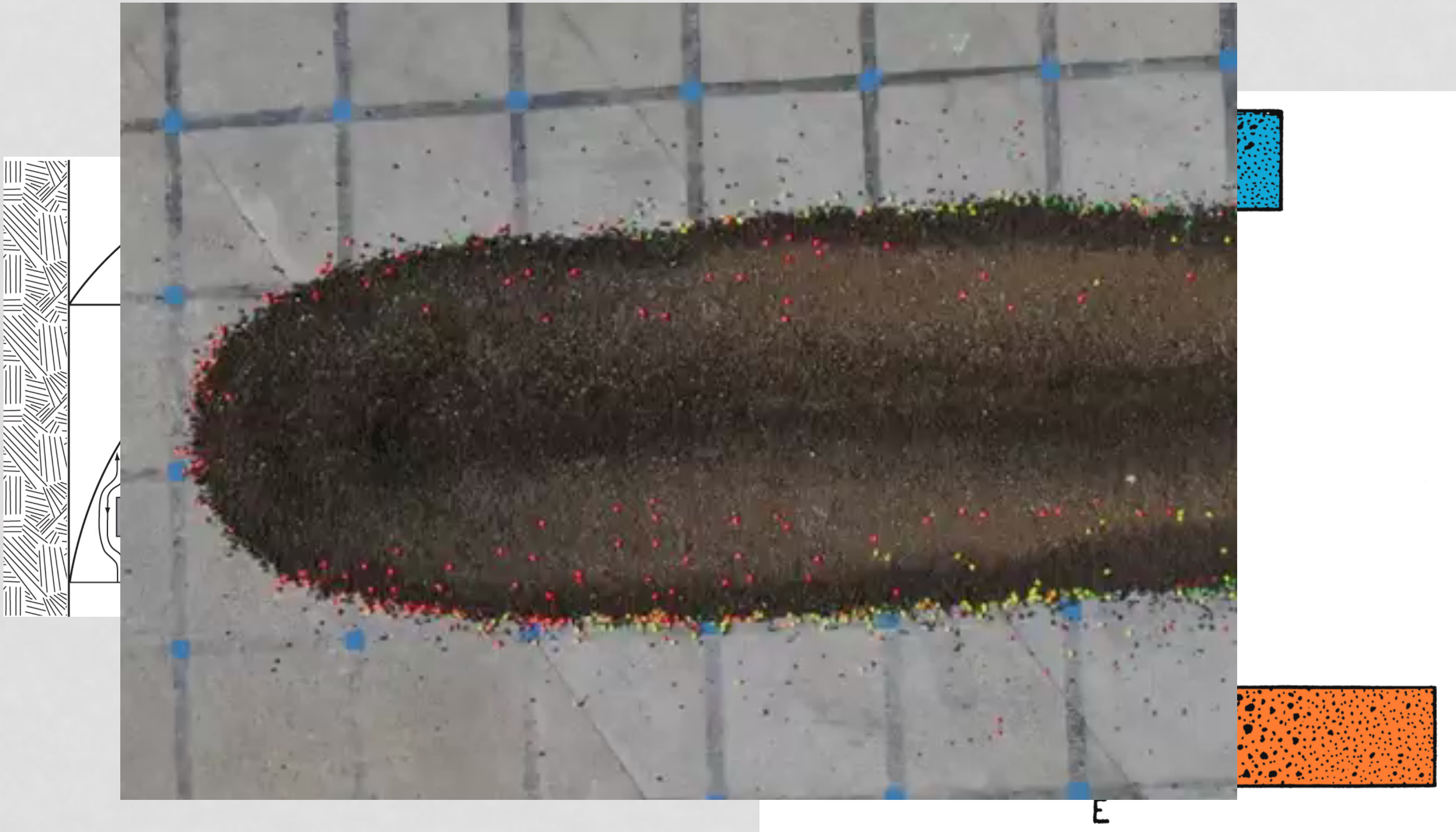
Mecanismos de Fracionamento cristal-líquido

SEGREGAÇÃO DE CRISTAIS POR FLUXO

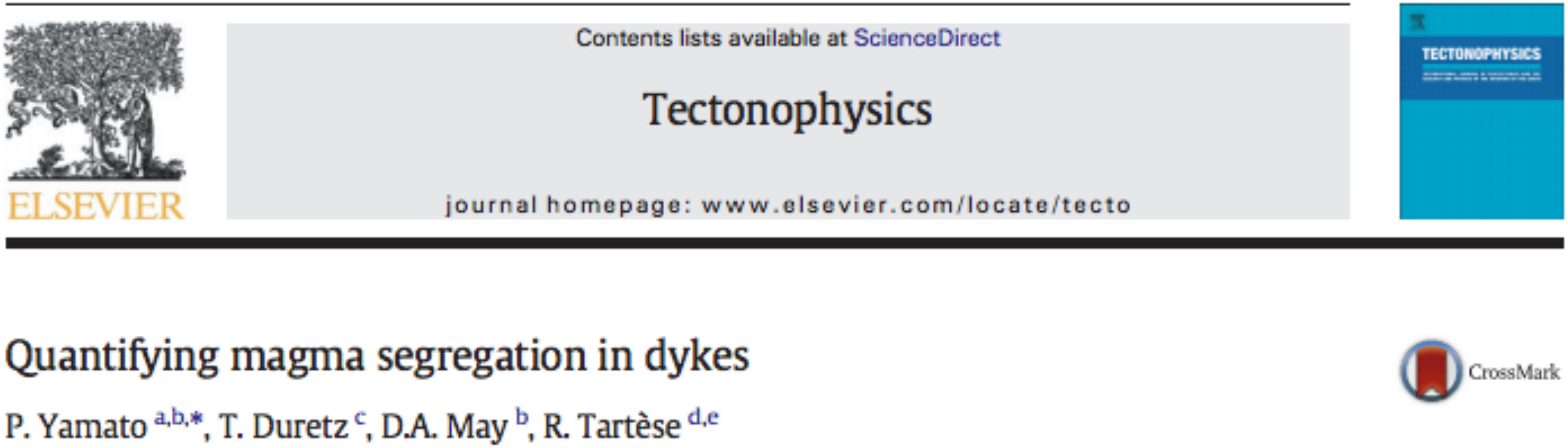




SEGREGAÇÃO DE CRISTAIS POR FLUXO



SEGREGAÇÃO POR FLUXO



Contents lists available at ScienceDirect

Tectonophysics

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

Quantifying magma segregation in dykes

P. Yamato [a,b,*], T. Duretz [c], D.A. May [b], R. Tartèse [d,e]

SEGREGAÇÃO POR FLUXO

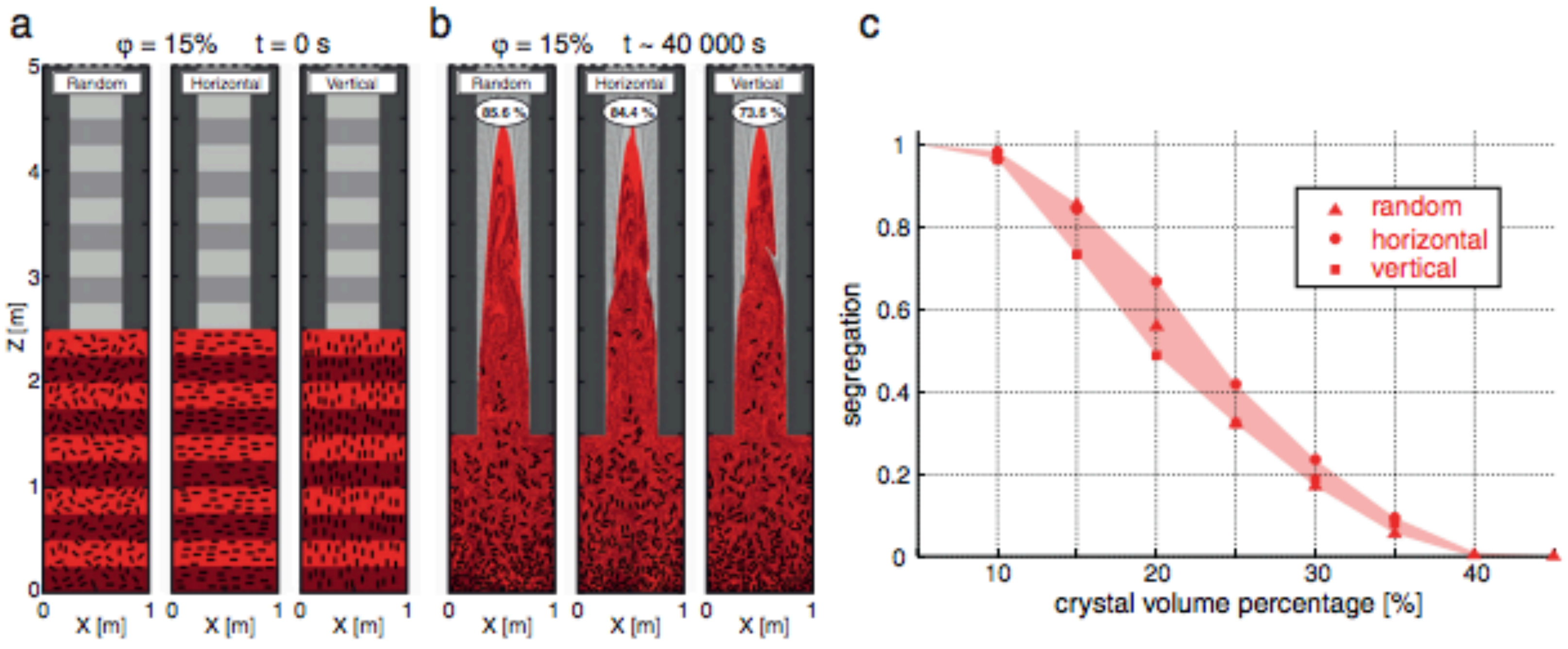


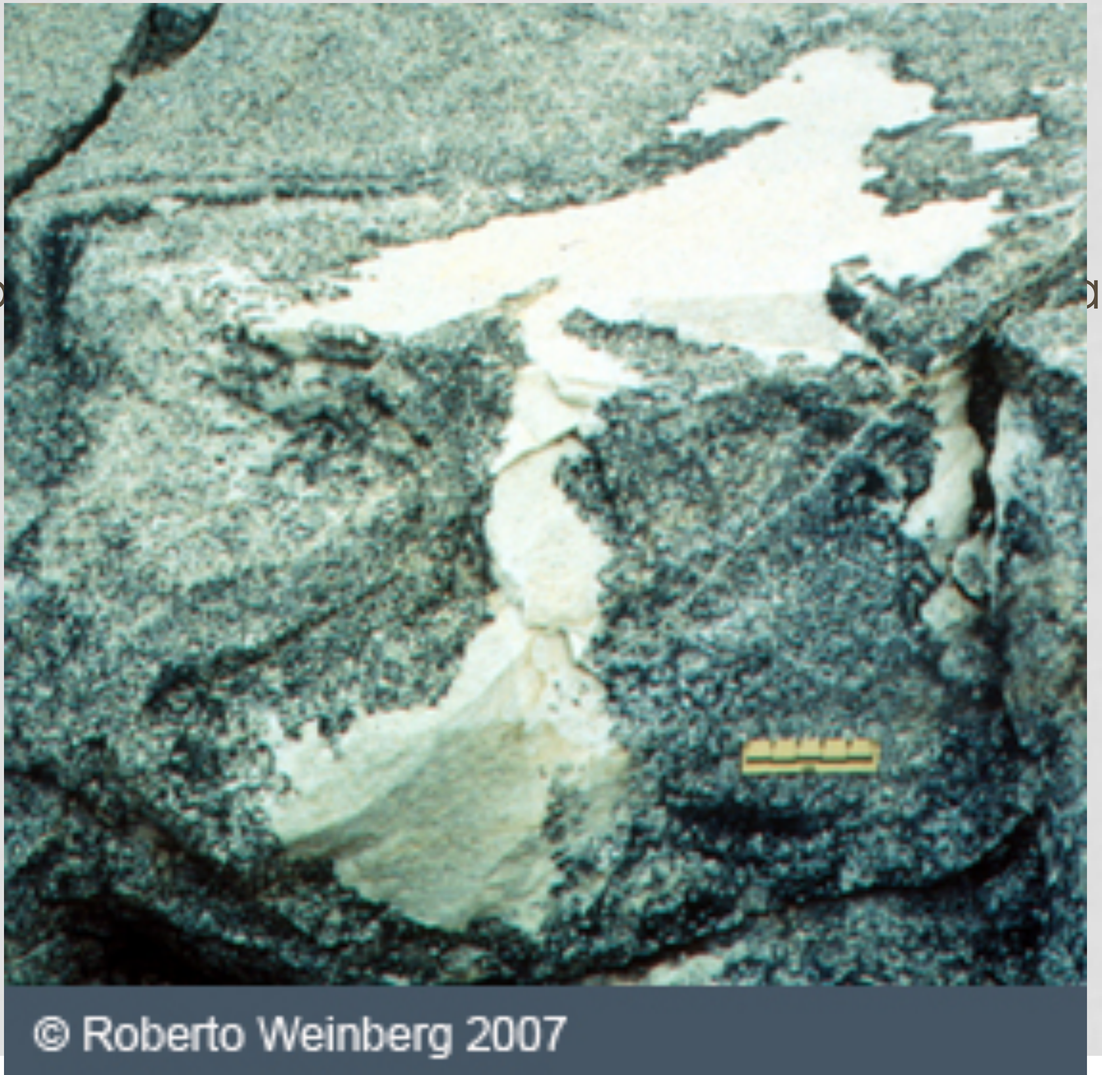
Fig. 3. Influence of the initial crystal arrangement. (a) Left: random arrangement (reference experiment), middle: horizontal arrangement, right: vertical arrangement. All other parameters are similar to those used in the reference simulation. (b) Results obtained after 40,000 s for these three numerical experiments. The amount of segregation is indicated in the white ellipse. (c) Values of segregation obtained in these three configurations for different initial crystal volume percentage. Red triangles, squares and dots correspond to the initial random arrangement experiments, the initial horizontal arrangement and the initial vertical arrangement, respectively. Red shaded area corresponds to the variability of the segregation that could be obtained by changing the initial arrangement of the crystals.

FILTER PRESSING

- Requer gradientes de pressão
  - Aberturas de fraturas
  - Efeitos de compactação
  - Sobrepressão por excesso de voláteis de magmas residuais

FILTER PRESSING

- Requer
  - Abertu
  - Efeitos
  - Sobrep as residuais



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DIFERENCIAÇÃO MAGMÁTICA

- Processos de **DIFERENCIAÇÃO**
  - Sistema Fechado
    a. **Fracionamento cristal-líquido**
    b. **Separação física de fundidos imiscíveis**
    c. Separação fundido-fluído

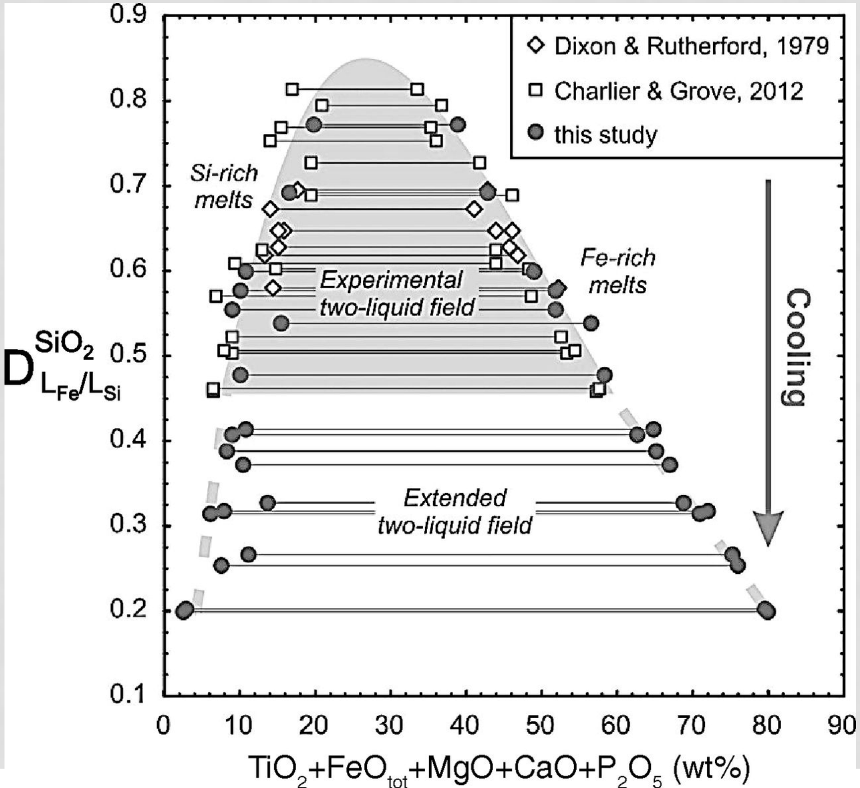
  - Sistema Aberto
    a. Assimilação de um contaminante inicialmente sólido
    b. "Mistura" entre dois ou mais magmas de composições similares
    c. "Mistura" entre dois ou mais magmas de composições contrastantes

IMISCIBILIDADE

- *Identificada pela primeira vez em basaltos lunares*
- *Tipos*
  - *Silicato-silicato*
  - *Silicato-óxido e silicato-fosfato*
  - *Silicato-carbonato*
  - *Silicato-sulfeto*

POR QUE?

- Acontece quando um magma atinge uma energia livre de Gibbs que é mais alta do que aquela dos melts provenientes da desmistura
- Mecanismo extremamente eficiente: a química dos magmas diverge significativamente



IMISCIBILIDADE SILICATO-SILICATO

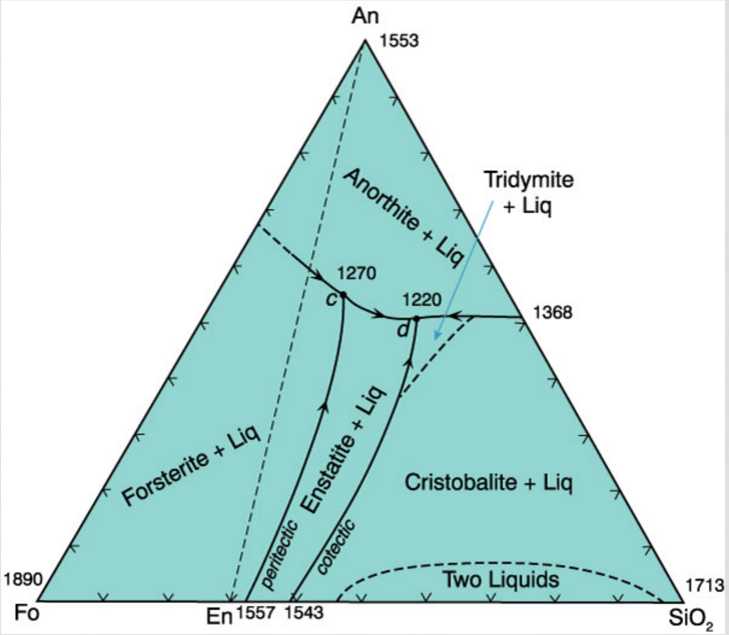


Figure 7-4. Diagrama T-X isobárico do sistema An-Fo-SiO_2 a 0.1 Mpa. Anderson (1915) e Irvine (1975)

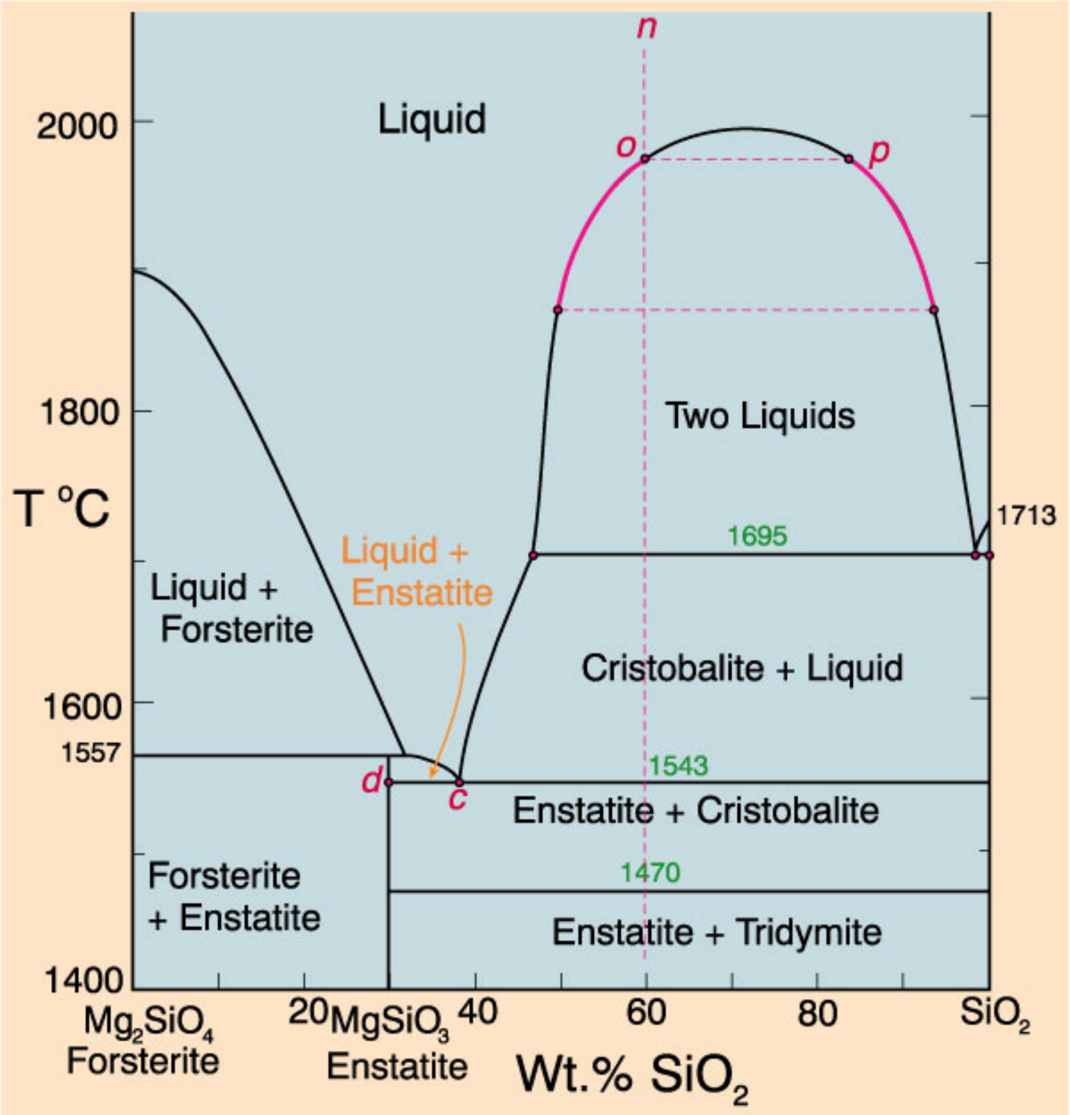


Figure 6-12. Diagrama T-X isobárico do sistema Fo-SiO2 a 0.1 Mpa. Bowen & Anderson (1914) e Grieg (1927)

IMISCIBILIDADE SILICATO SILICATO

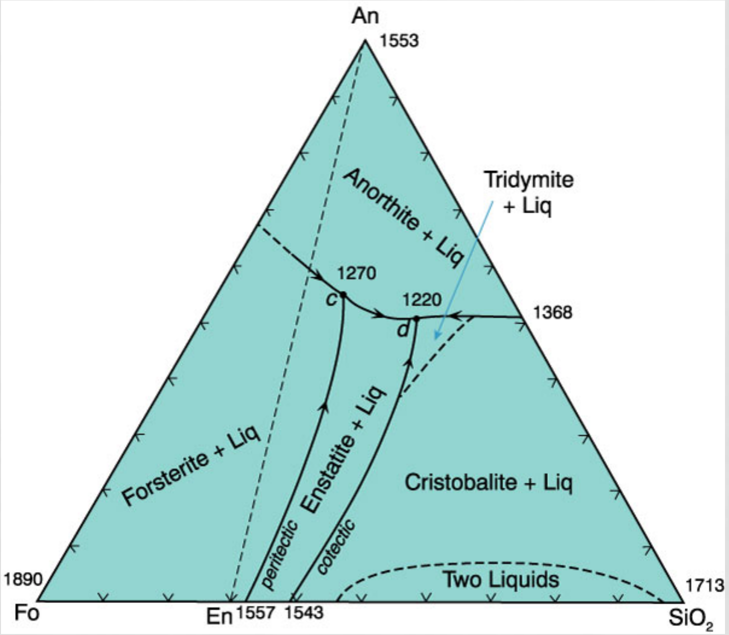


Figure 7-4. Diagrama T-X isobárico do sistema An-Fo-SiO$_2$ a 0.1 Mpa. Anderson (1915) e Irvine (1975)

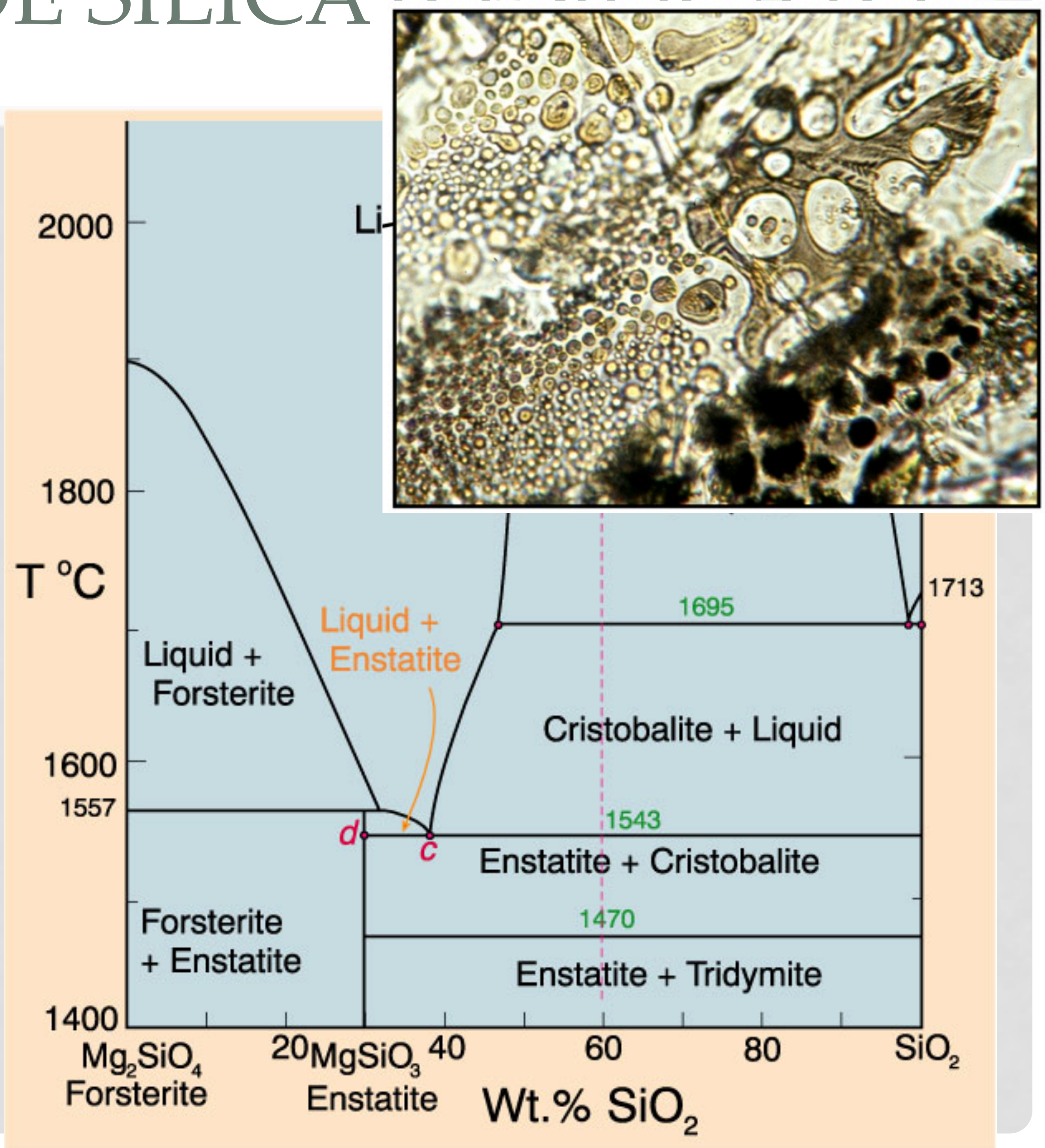
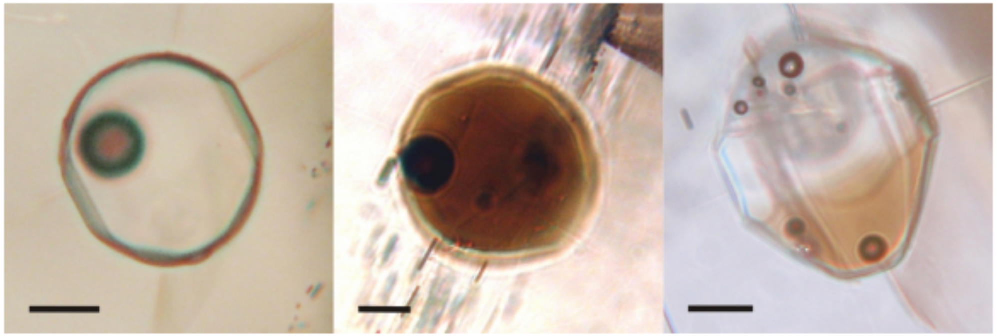
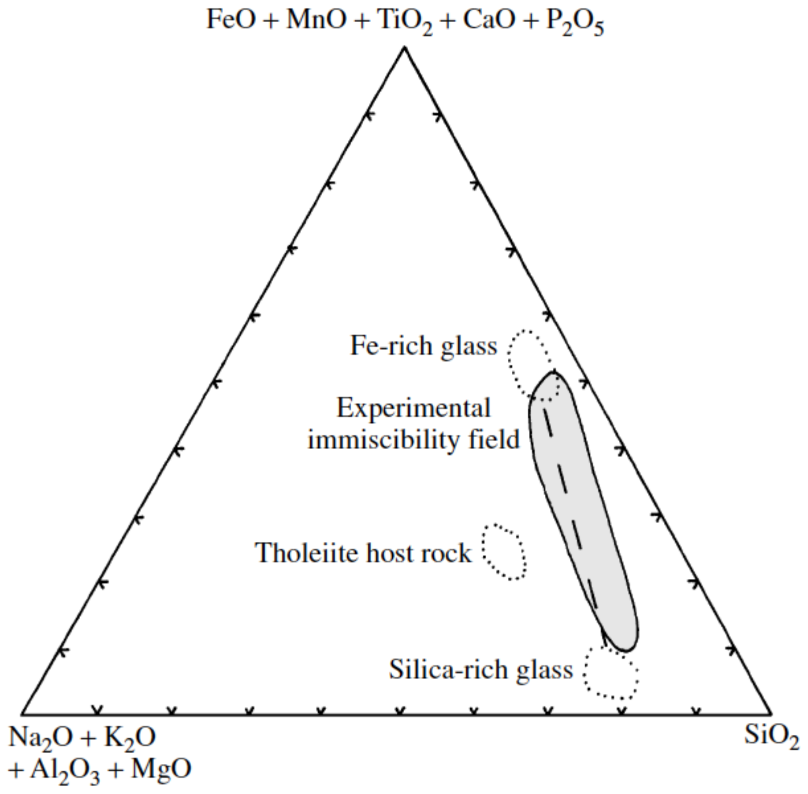


Figure 6-12. Diagrama T-X isobárico do sistema Fo-SiO2 a 0.1 Mpa. Bowen & Anderson (1914) e Grieg (1927)

SILICATO-SILICATO



Inclusões de líquidos imiscíveis ricos em Fe Si aprisionados me apatita, Sept Iles layered intrusion, Canada (Charlier et al, 2011)



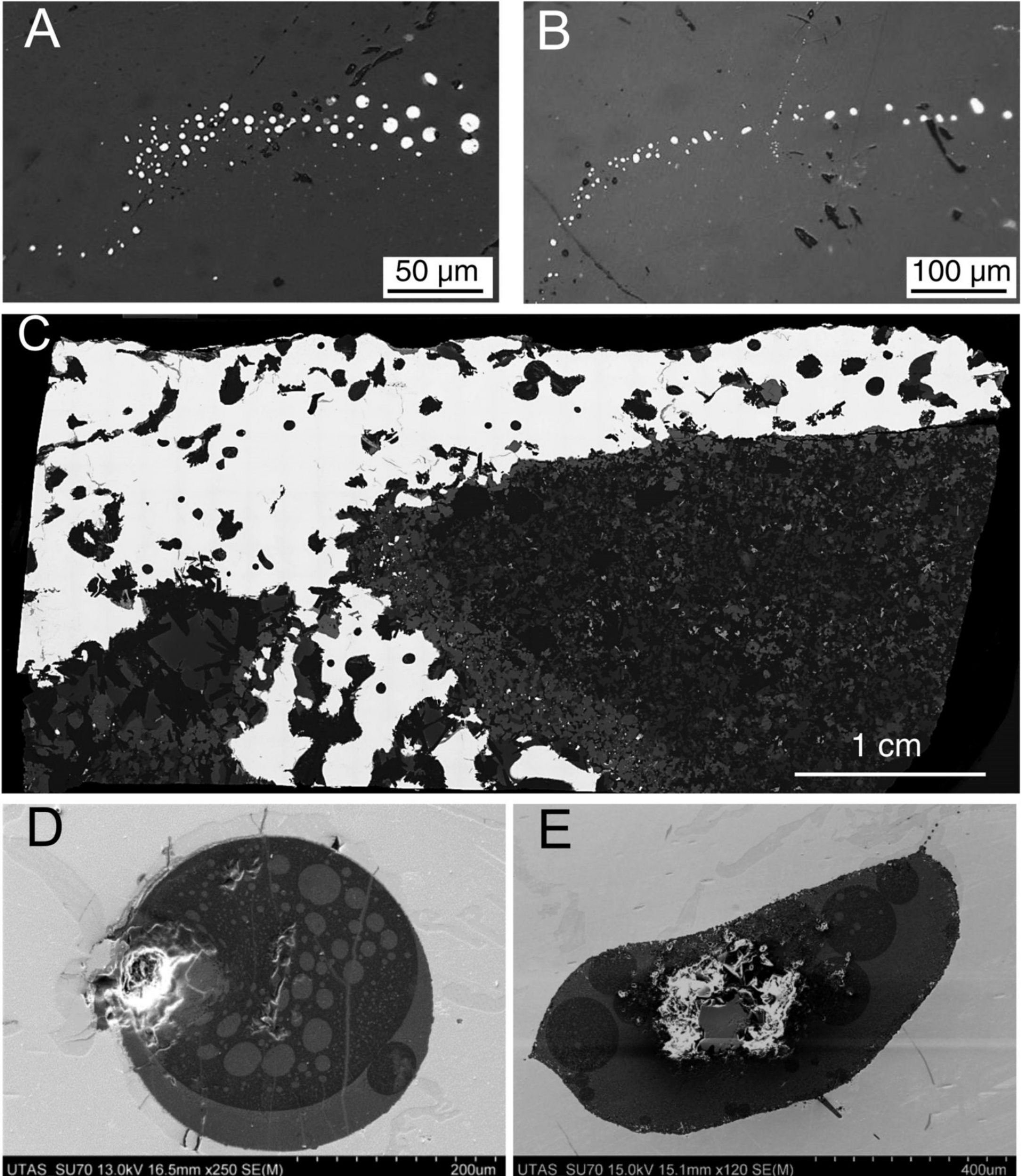
12.7 Compositions of immiscible melts in tholeiite basalt. Dotted lines enclose analyzed immiscible melts (now glasses, connected by dashed tie line) and host rock compositions. Shaded area is field of immiscible melts in model system $KAlSi_2O_6$-Fe_2SiO_4-SiO_2. (Redrawn from Philpotts, 1982.)

IMISCIBILIDADE SILICATO-METAL

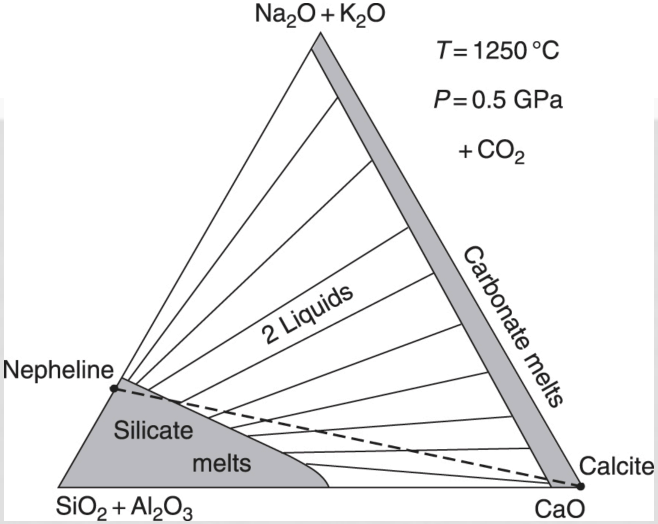
Geology. 2013;41(10):1091-1094. doi:10.1130/G34638.1

Native iron and iron-hosted melt pools in the Khungtukun intrusion (Siberia). A,B: Native Fe globules along fractures in plagioclase and clinopyroxene phenocrysts, respectively (reflected-light optical microscope). C: Back-scattered electron image of the polished fragment of gabbro with a large mass of native Fe (white), containing solidified melt pools (black). D,E: Secondary electron images of melt pools with two immiscible phases (L_{Fe}—bright; L_{Si}—dark) in native Fe with exsolved cohenite Fe_3C (slightly darker than Fe).

From: **Magma chamber–scale liquid immiscibility i the Siberian Traps represented by melt pools in native iron**



IMISCIBILIDADE SILICATO - CARBONATO



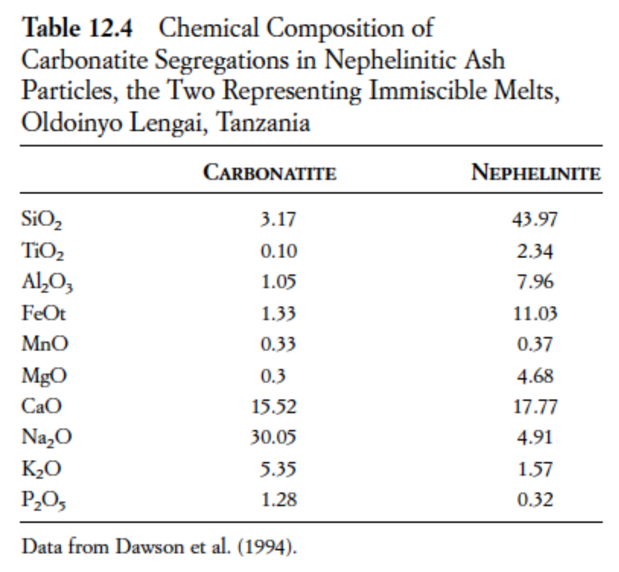
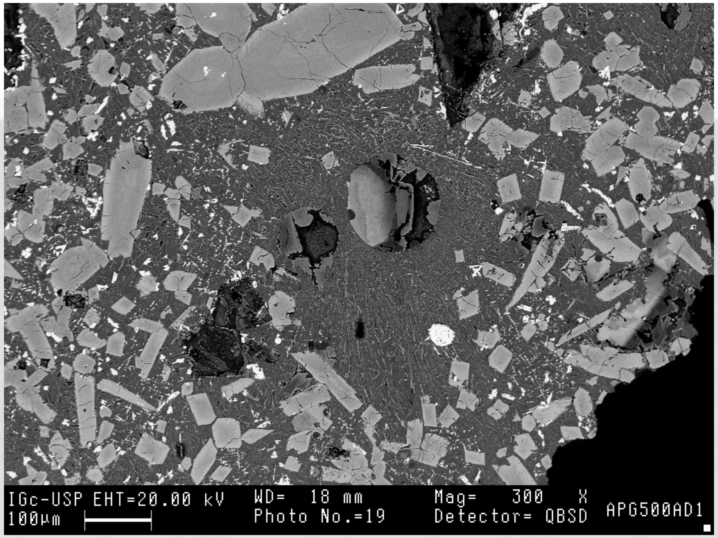
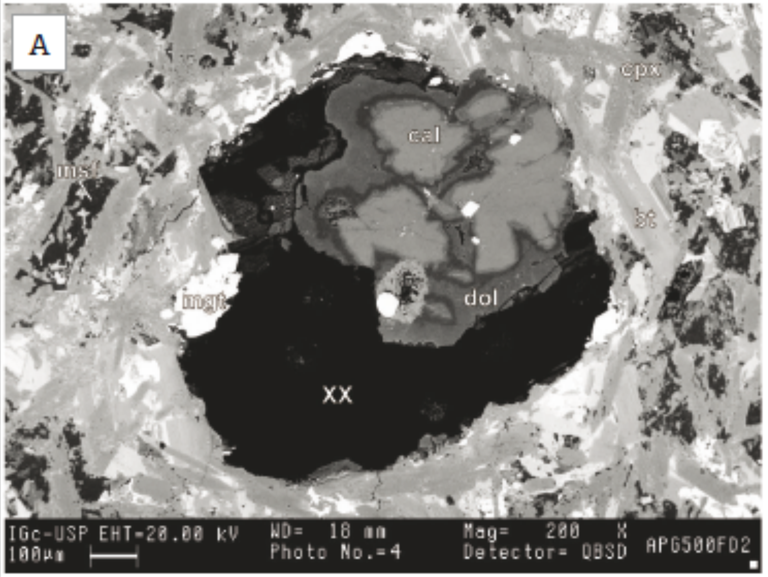


Table 12.4 Chemical Composition of Carbonatite Segregations in Nephelinitic Ash Particles, the Two Representing Immiscible Melts, Oldoinyo Lengai, Tanzania

	CARBONATITE	NEPHELINITE
SiO_2	3.17	43.97
TiO_2	0.10	2.34
Al_2O_3	1.05	7.96
FeOt	1.33	11.03
MnO	0.33	0.37
MgO	0.3	4.68
CaO	15.52	17.77
Na_2O	30.05	4.91
K_2O	5.35	1.57
P_2O_5	1.28	0.32

Data from Dawson et al. (1994).





Separação Física de Fundidos Imiscíveis

DIFERENCIAÇÃO EM SISTEMA ABERTO

ASSIMILAÇÃO E MISTURA DE MAGMAS

ASSIMILAÇÃO

- Aspectos da disgestão de xenólitos
  - Transferência de calor para equilíbrio térmico
  - Transformações resultantes dessa transferência: difusão, fusão/dissolução

  - A primeira parte pode ser considerada puramente física
  - A segunda pode ser sumarizada como digestão química

DIFERENTES PROCESSOS DE ASSIMILAÇÃO

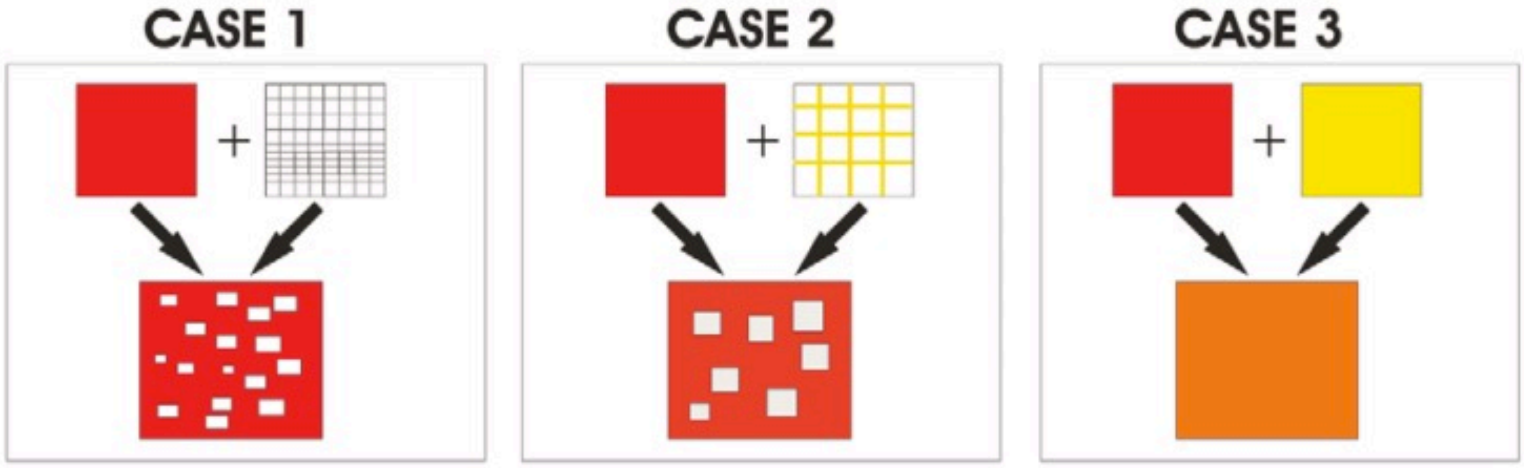
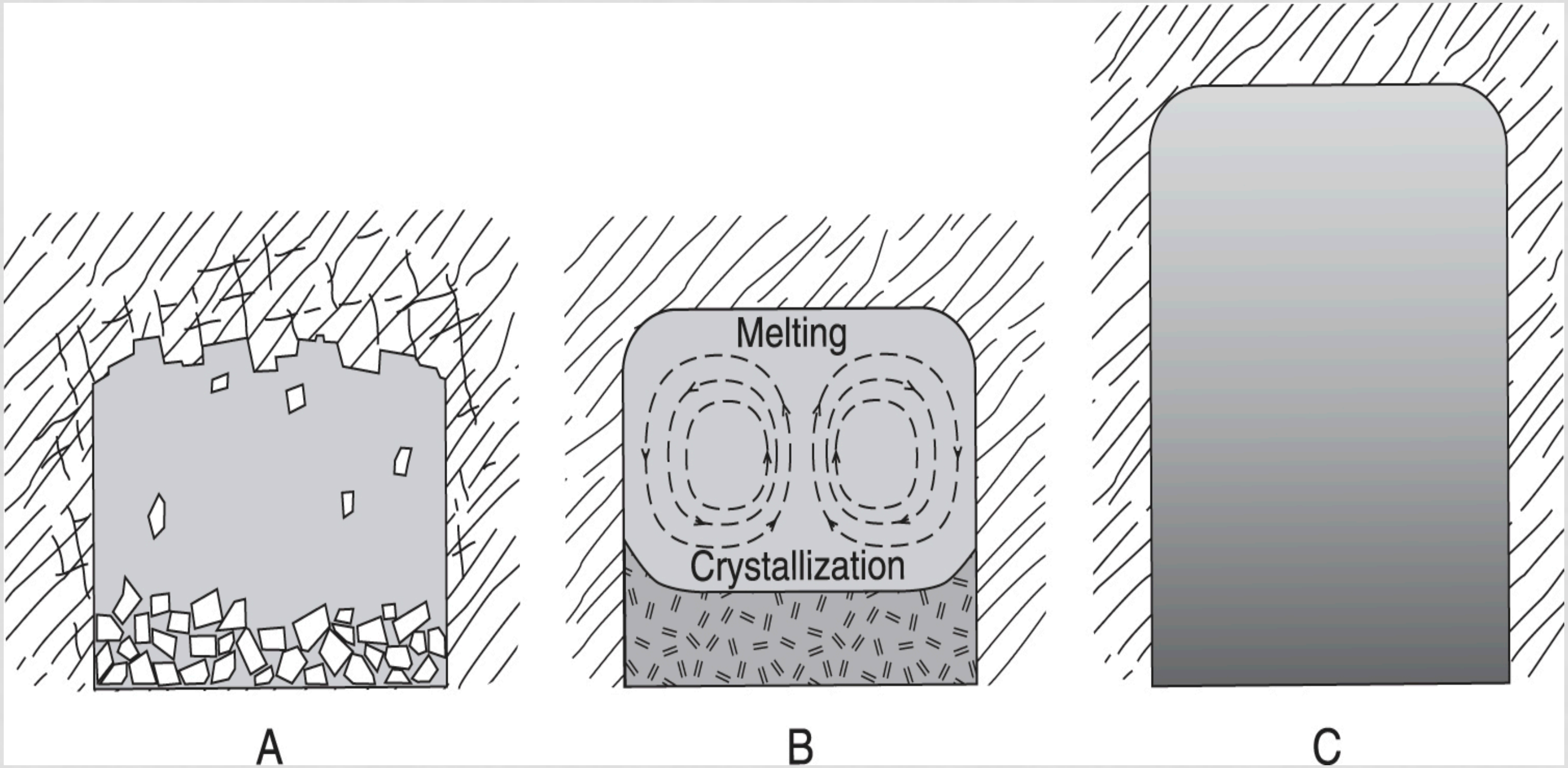


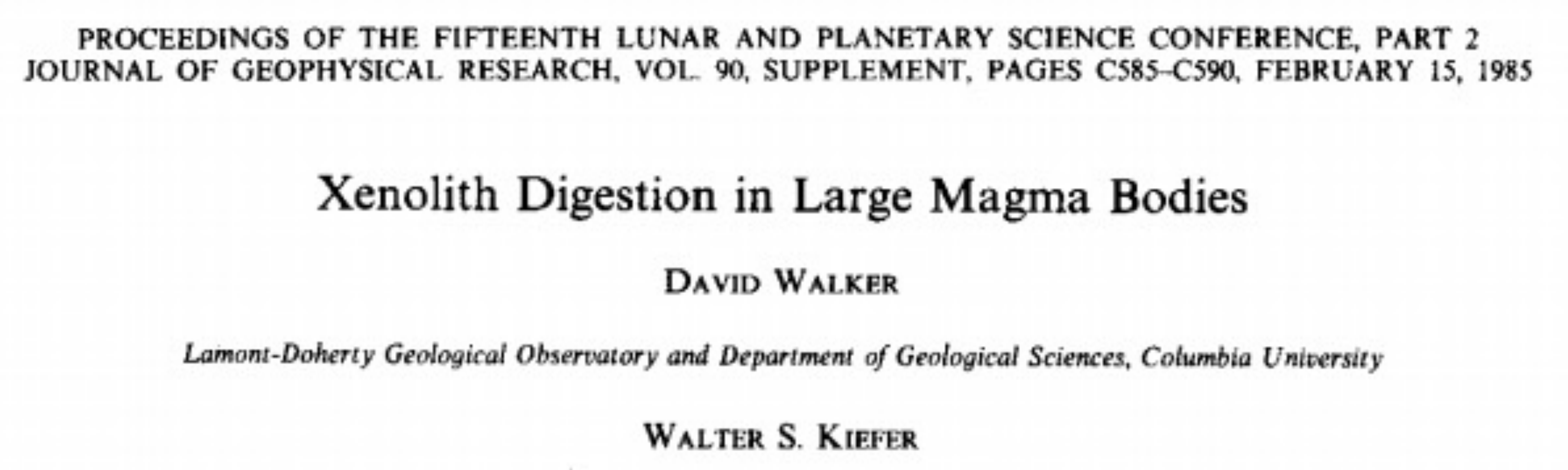
FIG. 6. Physical and chemical styles of assimilation. Case 1. Physical assimilation only. Purely mechanical disintegration of foreign material. Assimilation occurs entirely by physical processes to produce a statistically homogeneous distribution of the foreign solid material "strewn about" (Bowen 1922) in the granite host. There is a low cost in thermal energy to the host granitic magma (the only heat required is that to raise the temperature of the foreign material to the ambient temperature of the granitic magma). Case 2. Physical and chemical assimilation combined. Foreign material undergoes partial melting or partial dissolution and disintegrates. The two melts, or melt plus dissolved component, homogenize by diffusion or mixing, and the solids disperse to become statistically homogeneously distributed in the granitic magma host. There is a moderate cost in thermal energy for the granitic magma because of additional heat required for latent heat of fusion or dissolution. Case 3. Chemical assimilation only. Total melting or complete dissolution of foreign material followed by physical (mixing) or chemical (diffusion) to produce a homogeneous hybrid magma. There is a high cost in thermal energy for the granitic magma because of extensive additional heat for total fusion or dissolution.

ASSIMILAÇÃO



DIGESTÃO DE XENÓLITOS

- Fusão e incorporação do fundido



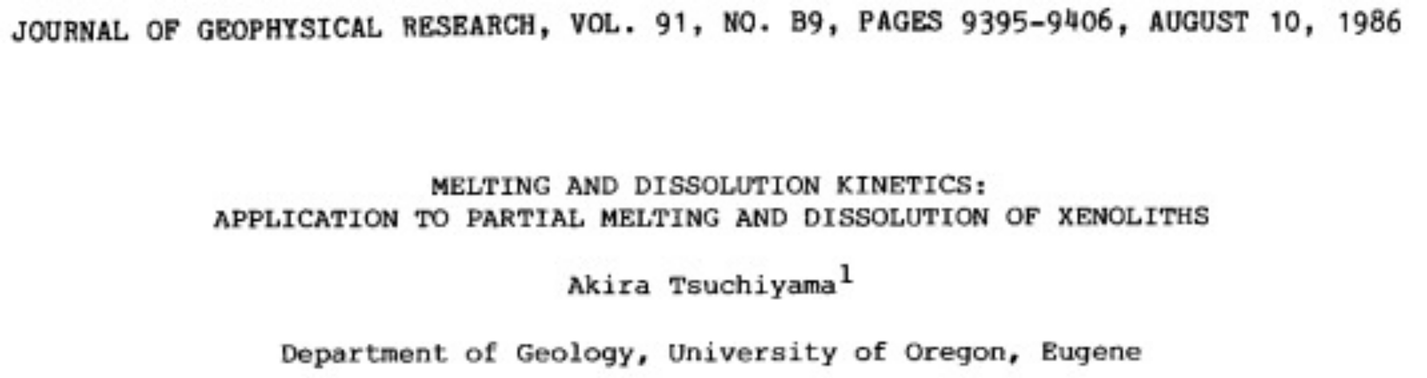
PROCEEDINGS OF THE FIFTEENTH LUNAR AND PLANETARY SCIENCE CONFERENCE, PART 2
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 90, SUPPLEMENT, PAGES C585–C590, FEBRUARY 15, 1985

Xenolith Digestion in Large Magma Bodies

DAVID WALKER

Lamont-Doherty Geological Observatory and Department of Geological Sciences, Columbia University

WALTER S. KIEFER



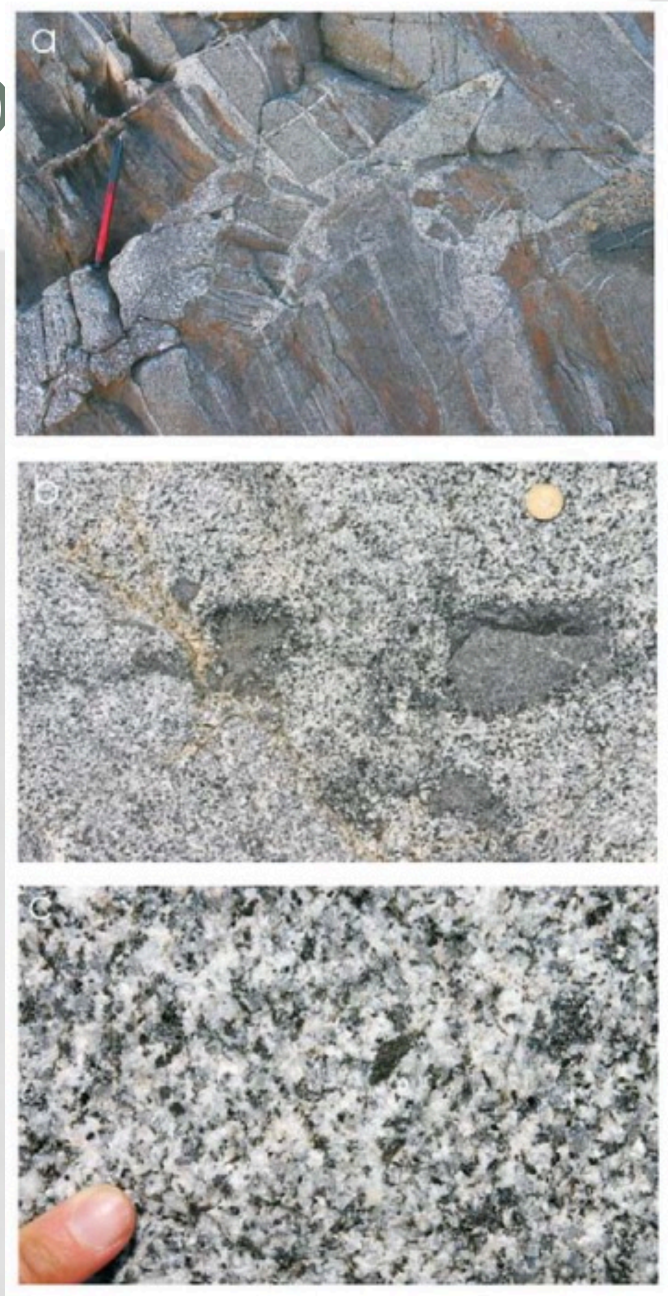
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 91, NO. B9, PAGES 9395-9406, AUGUST 10, 1986

MELTING AND DISSOLUTION KINETICS:
APPLICATION TO PARTIAL MELTING AND DISSOLUTION OF XENOLITHS

Akira Tsuchiyama[1]

Department of Geology, University of Oregon, Eugene

EVIDÊNCIAS DE CAMPO



CAMPO E QUÍMICA

- Química de cristais de biotita

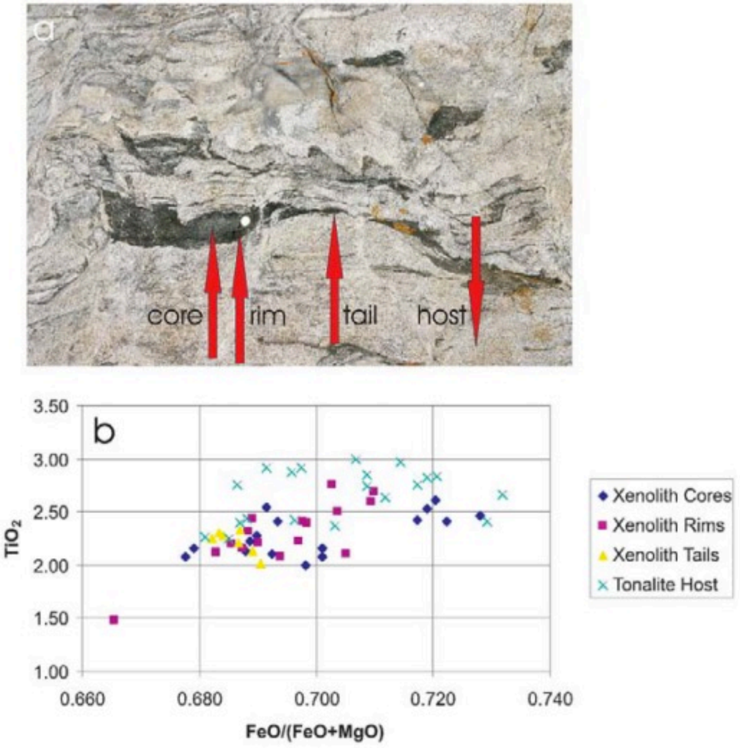


FIG. 3. Compositions of biotite grains in a contaminated tonalite. (a) Outcrop photograph of marginal tonalite in the Port Mouton Pluton (coin for scale). Country-rock xenoliths have become biotite-rich schlieren. Biotite samples selected for chemical analysis come from four locations: core, rim, and tail of xenolith, as well as from the tonalite remote from xenoliths. (b) Although xenolithic and magmatic biotite may have different concentrations of TiO_2, clear discrimination between xenolithic and "magmatic" populations is not possible. In particular, some of the texturally "magmatic" grains have a composition similar to that in the xenoliths. The chemical data are from McCuish (2001).

E QUANDO OS XENÓLITOS NÃO ESTÃO NOS PLÚTONS, MAS HÁ EVIDÊNCIAS DE CONTAMINAÇÃO?

VESICULAÇÃO E ASCENÇÃO

SCIENTIFIC REPORTS

OPEN

Erupted frothy xenoliths may explain lack of country-rock fragments in plutons

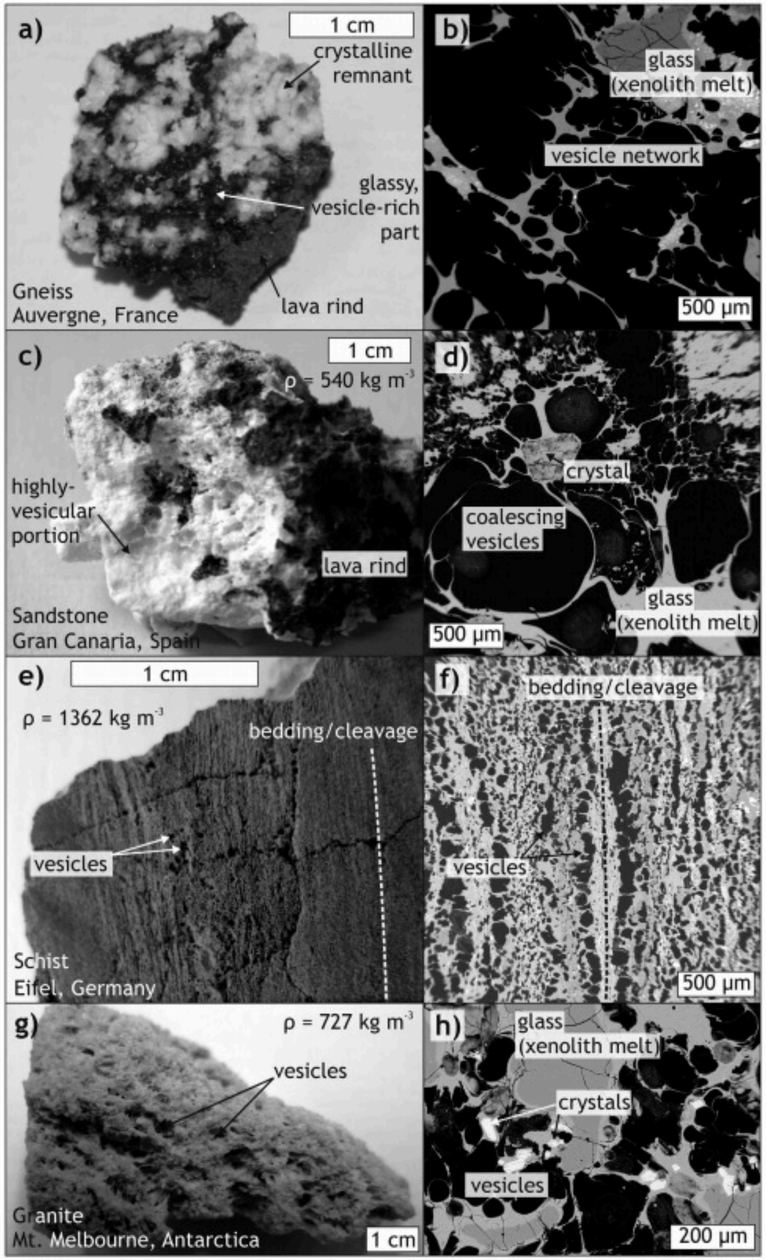
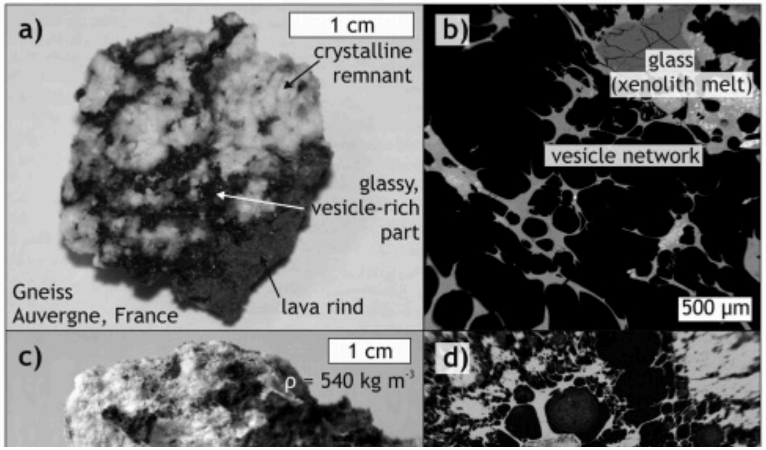
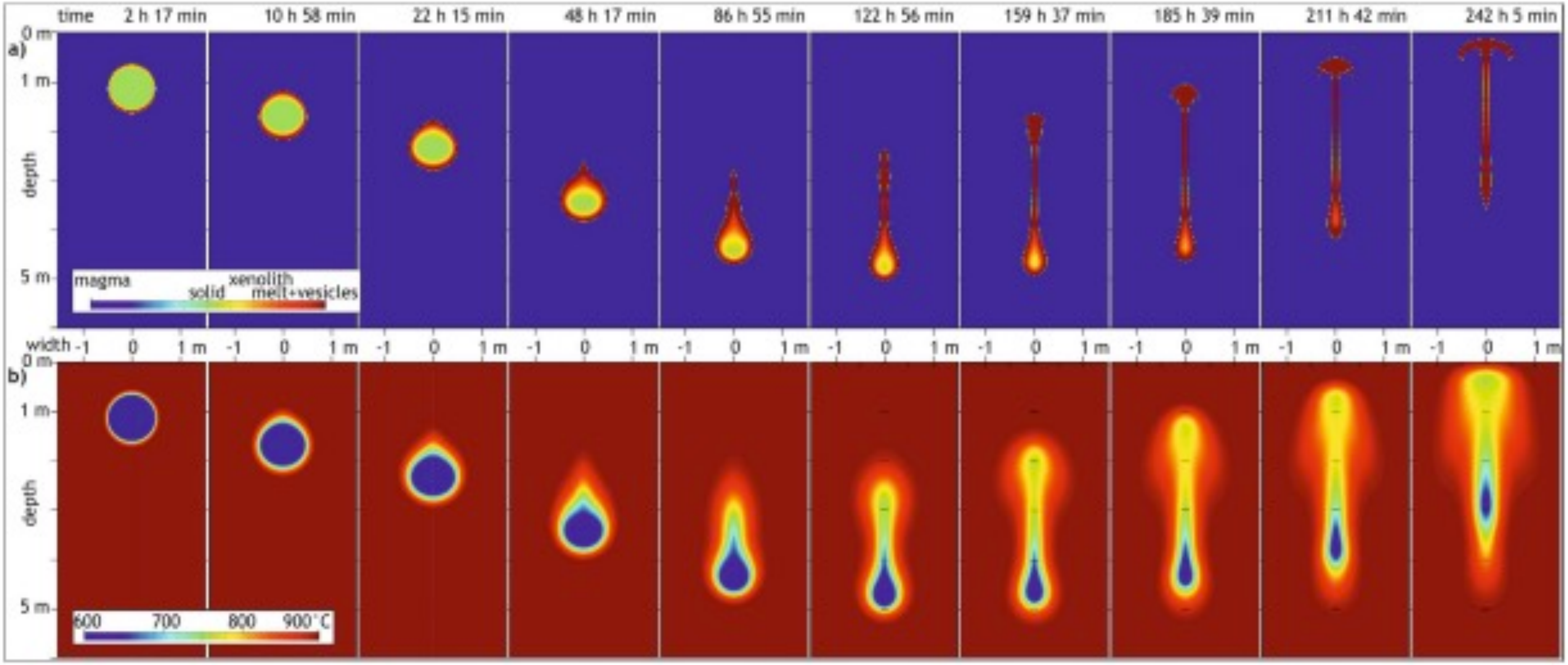


Figure 1. Appearance and structure of examples of frothy xenolith fragments. Densities have been determined using the Archimedes method after Kueppers *et al.*[57]. Errors are estimated to be approximately 5%. Left column: sample photographs. Right column: Scanning Electron Microscope (SEM) images. **(a,b)** Partially melted and vesiculated gneiss fragment enclosed in phonolitic lava from the Auvergne, France. **(c,d)** Vesicular marine arkose enclosed in basaltic scoria from Gran Canaria, Canary Islands, Spain[34]. **(e,f)** Vesiculated schist from the Eifel, Germany. Vesicles form preferentially along the bedding/cleavage planes. **(g,h)** Frothy former granite erupted from Mt. Melbourne, Antarctica.

VESICULAÇÃO E ASCENÇÃO

SCIENTIFIC REPORTS





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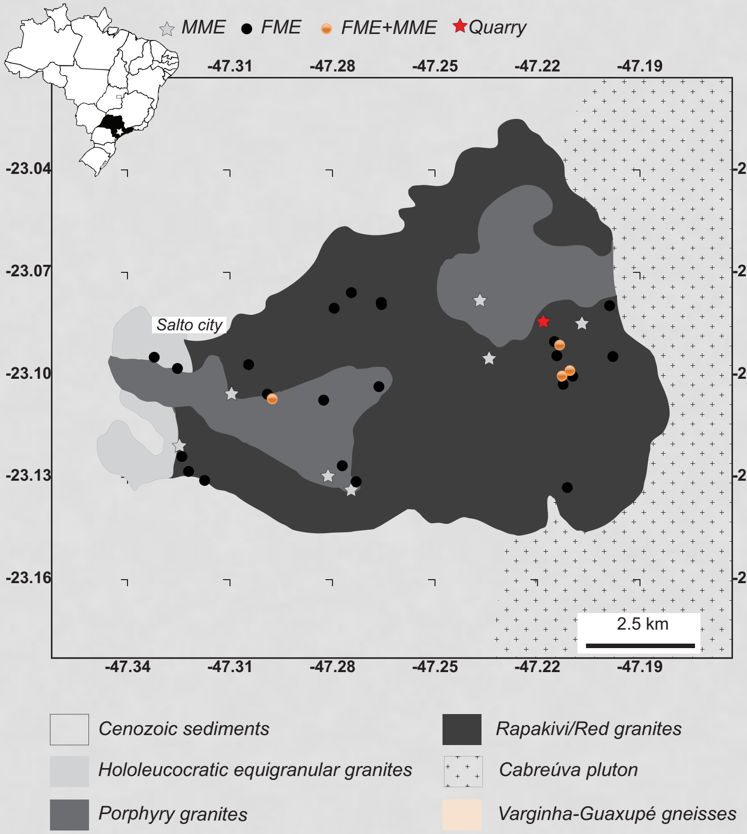
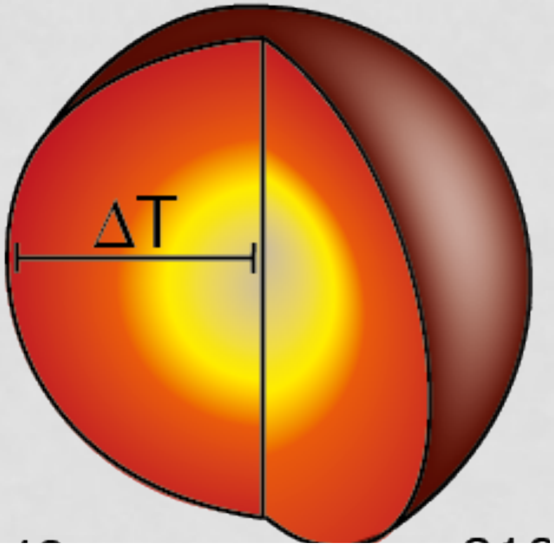
ASSIMILAÇÃO

- Incorporação das rochas encaixantes
- Assimilação via fusão é limitada. Por quê?



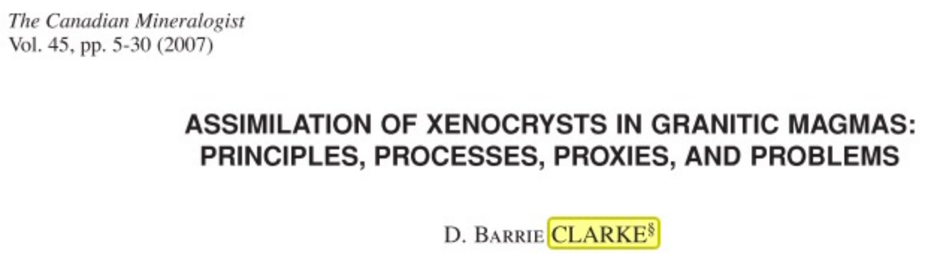


$$Resfriamento = \frac{raio^2}{difusividade\ térmica}$$

Difusividade = 5×10^{-7} m^2/s

ASSIMILAÇÃO: XENOCRISTAIS

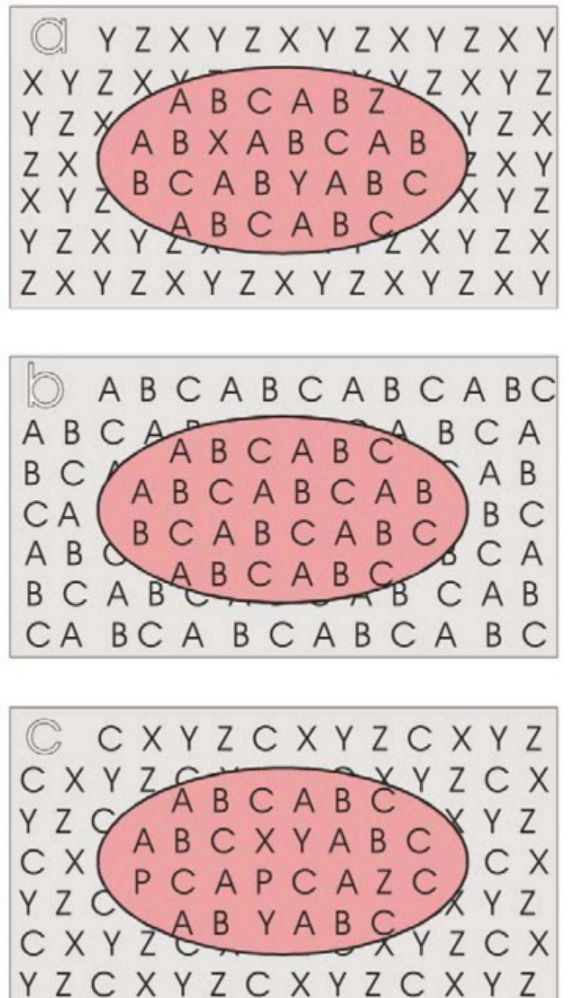
- Desagregação mecânica, depois digestão



The Canadian Mineralogist
Vol. 45, pp. 5-30 (2007)

ASSIMILATION OF XENOCRYSTS IN GRANITIC MAGMAS: PRINCIPLES, PROCESSES, PROXIES, AND PROBLEMS

D. BARRIE **CLARKE**[§]



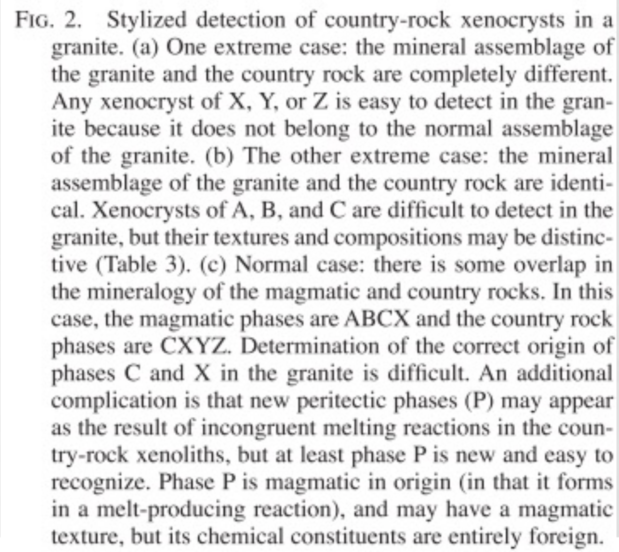


FIG. 2. Stylized detection of country-rock xenocrysts in a granite. (a) One extreme case: the mineral assemblage of the granite and the country rock are completely different. Any xenocryst of X, Y, or Z is easy to detect in the granite because it does not belong to the normal assemblage of the granite. (b) The other extreme case: the mineral assemblage of the granite and the country rock are identical. Xenocrysts of A, B, and C are difficult to detect in the granite, but their textures and compositions may be distinctive (Table 3). (c) Normal case: there is some overlap in the mineralogy of the magmatic and country rocks. In this case, the magmatic phases are ABCX and the country rock phases are CXYZ. Determination of the correct origin of phases C and X in the granite is difficult. An additional complication is that new peritectic phases (P) may appear as the result of incongruent melting reactions in the country-rock xenoliths, but at least phase P is new and easy to recognize. Phase P is magmatic in origin (in that it forms in a melt-producing reaction), and may have a magmatic texture, but its chemical constituents are entirely foreign.

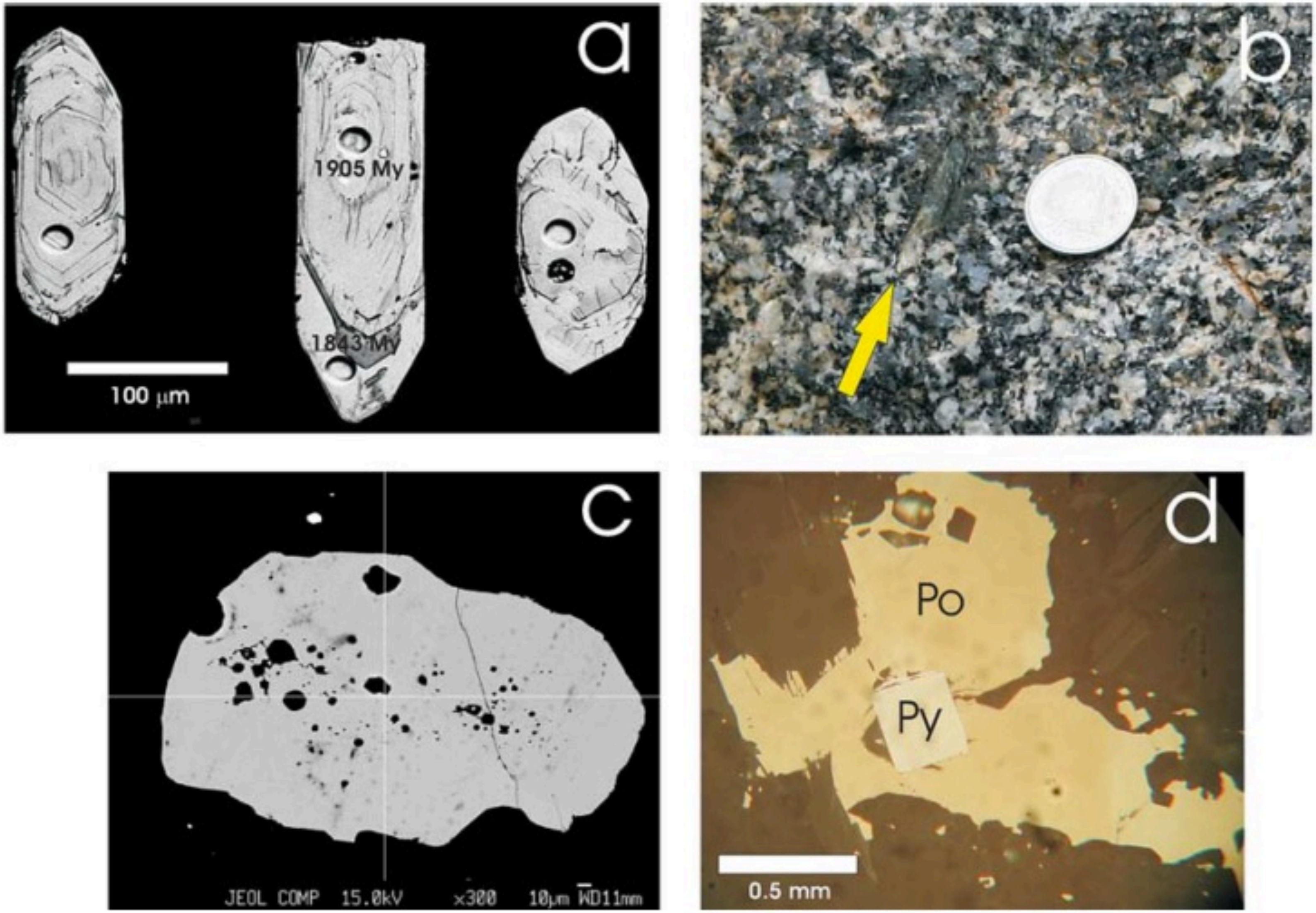


FIG. 1. Examples of xenocrysts in granitic rocks. (a) Crystals of zircon are among the most readily identifiable xenocrysts in granitic rocks because of their distinctive U/Pb age signatures. These grains occur in peraluminous granites from the Rottenstone Domain, Trans-Hudson Orogen (after Clarke *et al*. 2005b, Fig. 7f) and have a xenocrystic core with SHRIMP ages of *ca*. 1905 m.y. and a magmatic rim with ages of *ca*. 1843 m.y. (b) Large isolated crystal of xenocrystic andalusite in the contact of the South Mountain Batholith (photo by Saskia Erdmann). (c) Xenocrystic ilmenite (sample A11–2286) from the South Mountain Batholith showing the same texture as ilmenite from the country rock (photo by Sarah Carruzzo). (d) Irregularly shaped bleb of sulfide from the marginal granodiorite of the South Mountain Batholith. Although technically not a xeno*cryst*, it represents foreign material incorporated in the granitic magma (photo by Hugh Samson).

- C

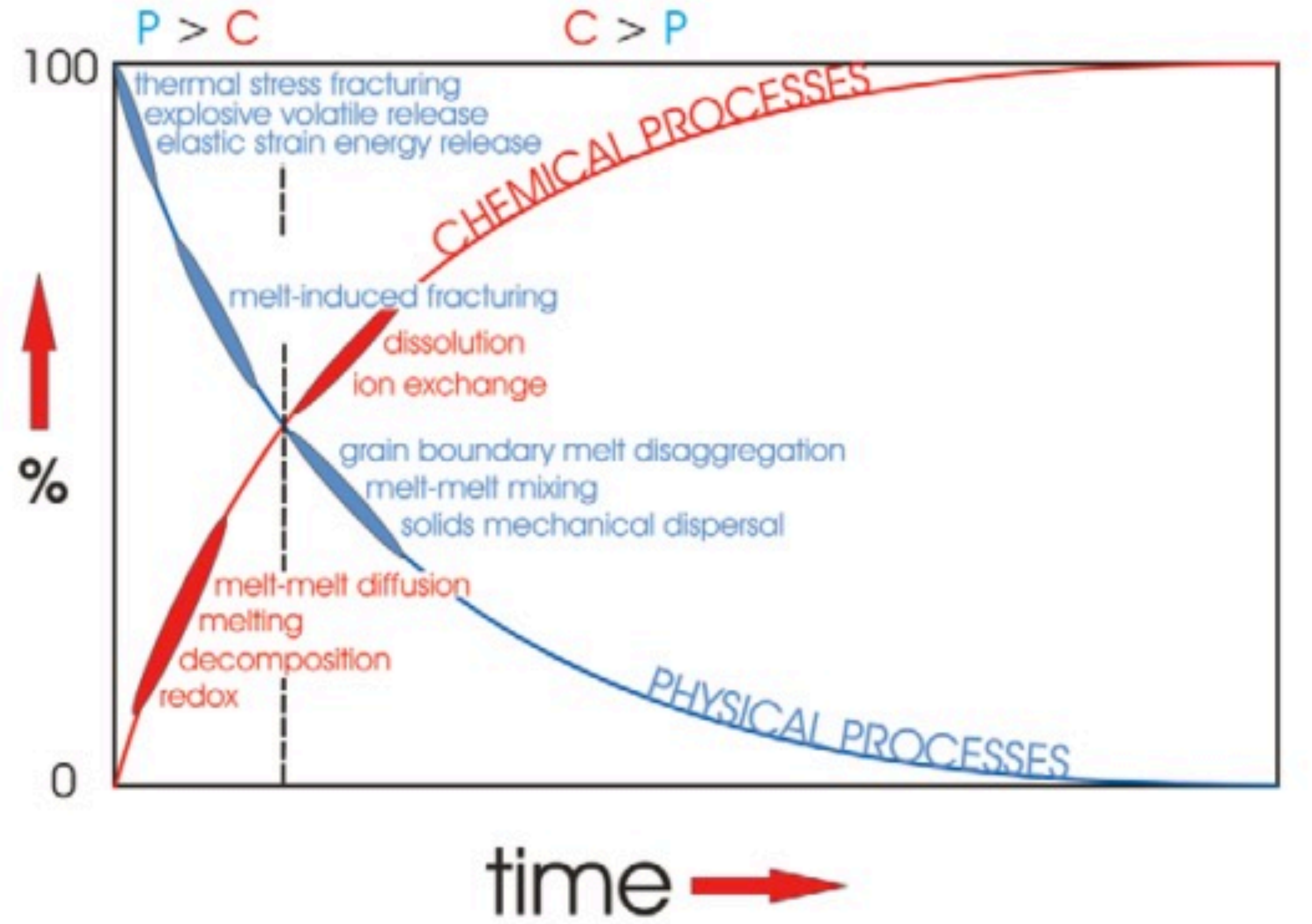


FIG. 11. Sequence and relative importance of processes of assimilation of xenocrysts as a function of time in a granitic magma. A purely qualitative estimate of the relative importance of physical (P) and chemical (C) processes in the assimilation of country-rock xenoliths in a granitic magma as a function of time. With increasing time, physical processes decrease, and chemical processes increase, in relative importance.

) Outcrop photograph
ountry-rock xenoliths
or chemical analysis
l as from the tonalite
otite may have differ-
thic and "magmatic"
agmatic" grains have
a are from McCuish
(2001).

MISTURA DE MAGMAS

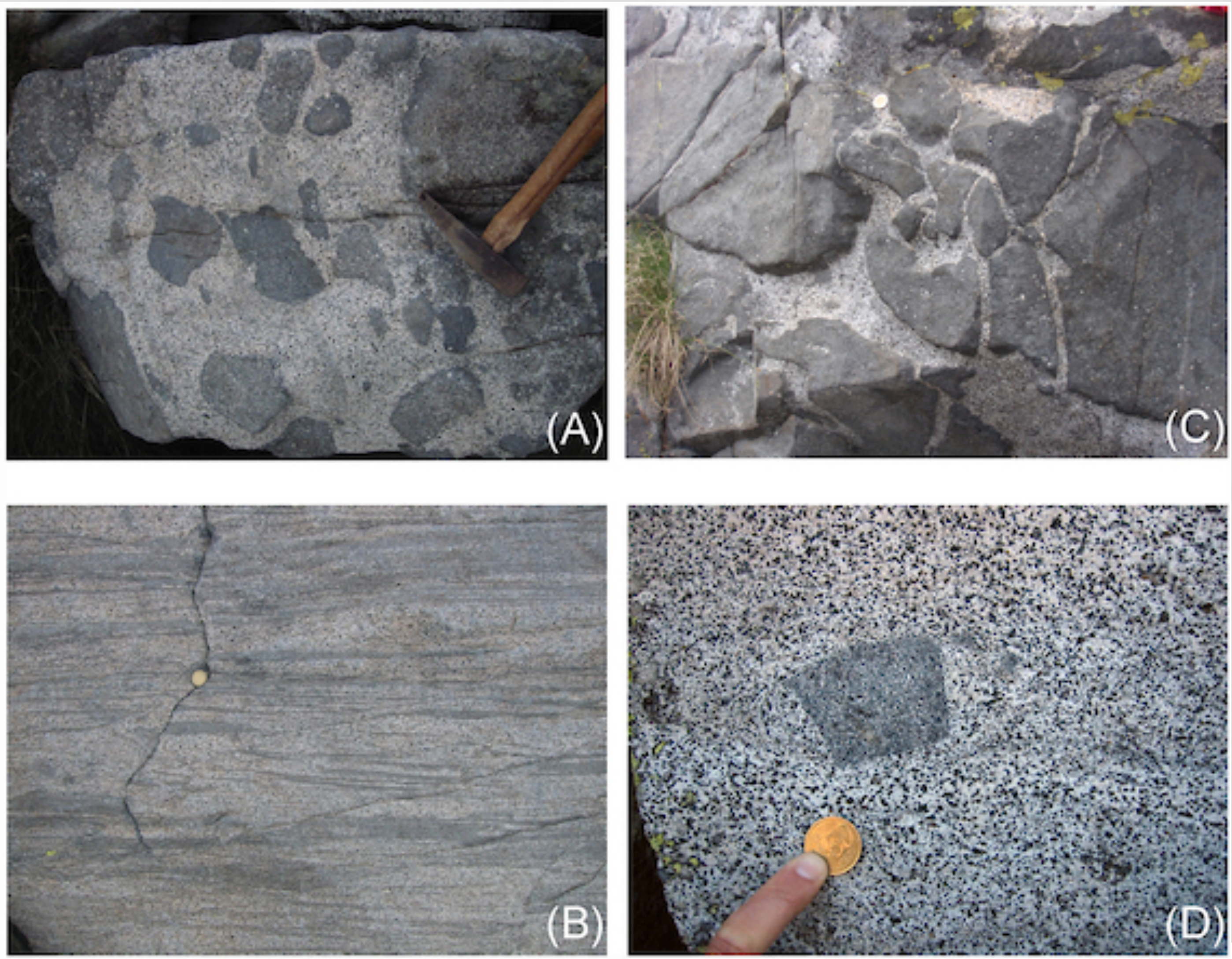
TERMINOLOGIA

- Mingling e mixing
- Enclave Agregados minerais que não se cristalizaram do magma em que aparecem. Termo é principalmente descritivo, (Ron H. Vernon – *A practical guide to microstructure*)

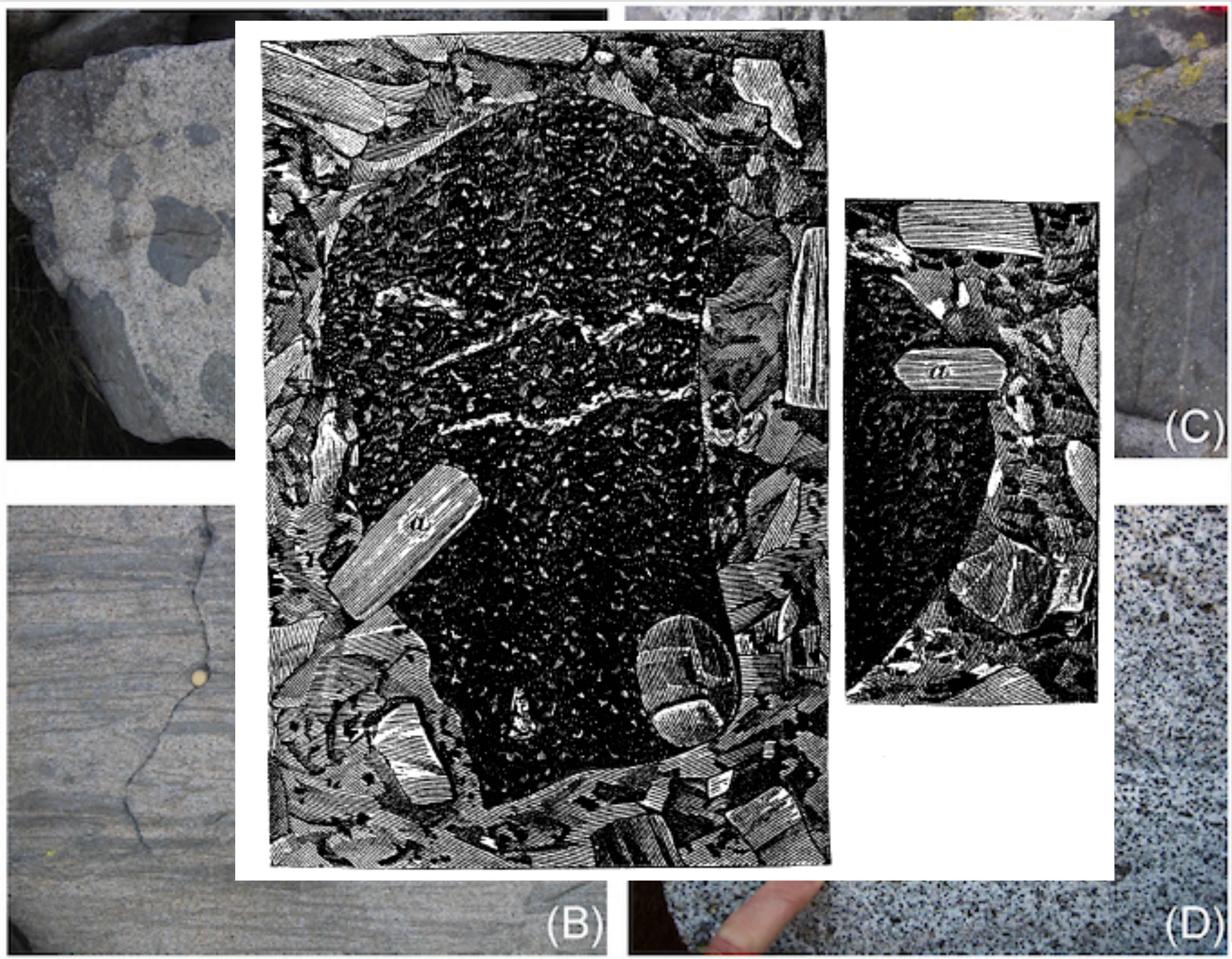
TIPOS DE ENCLAVE

- Xenólitos
- Autólitos
- Restitos
- ***Enclaves microgranulares (félsicos e máficos)***
- **Ante/xenocristais**

EVIDÊNCIAS DE CAMPO E PETROGRAFIA

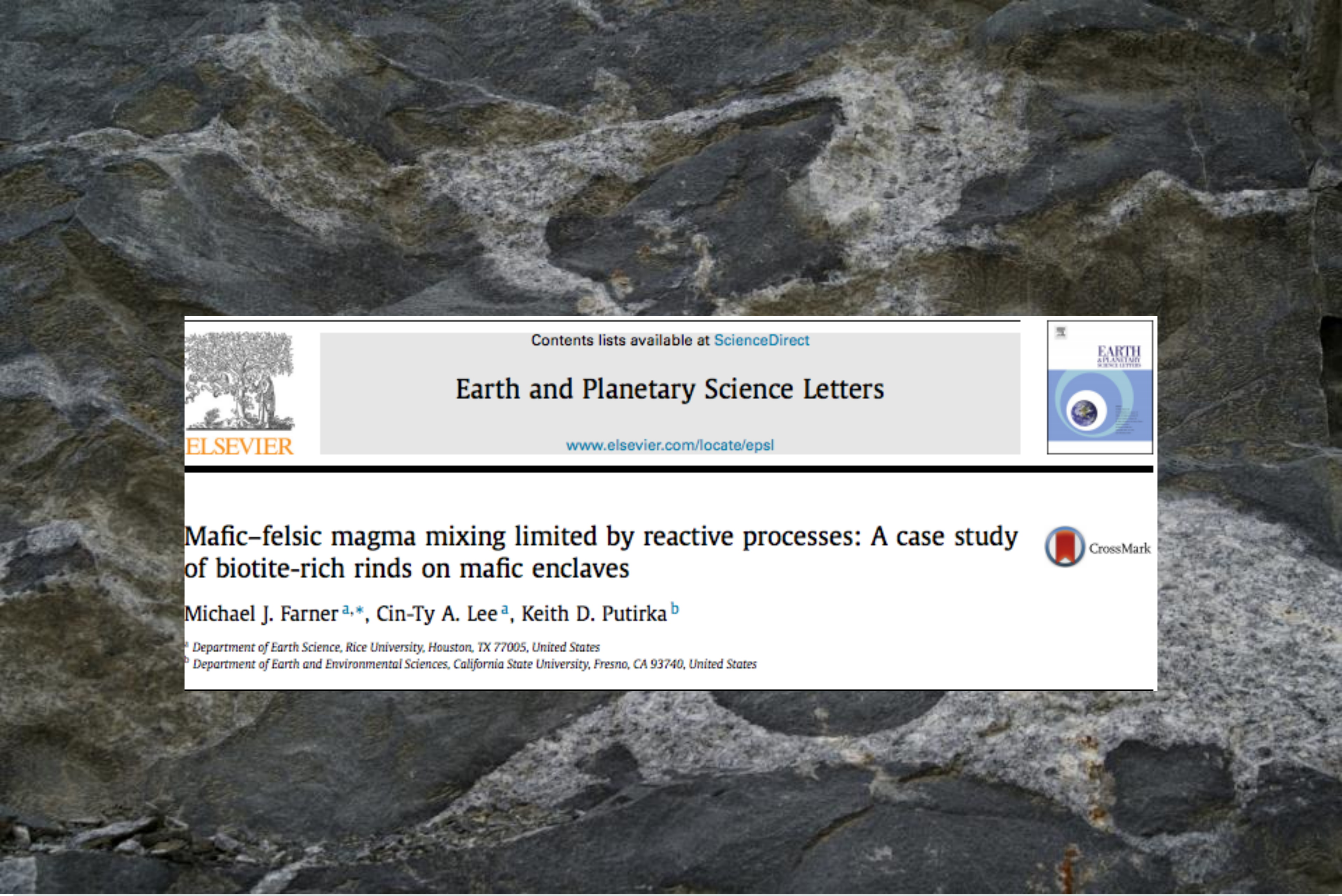


EVIDÊNCIAS DE CAMPO E PETROGRAFIA



EVIDÊNCIAS DE CAMPO

Roadside wonders of route 287
Blog
https://blogs.agu.org/mountainbeltway/2011/09/28/roadside-wonders-of-route-287/



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Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Mafic–felsic magma mixing limited by reactive processes: A case study of biotite-rich rinds on mafic enclaves

Michael J. Farner[a,*], Cin-Ty A. Lee[a], Keith D. Putirka[b]

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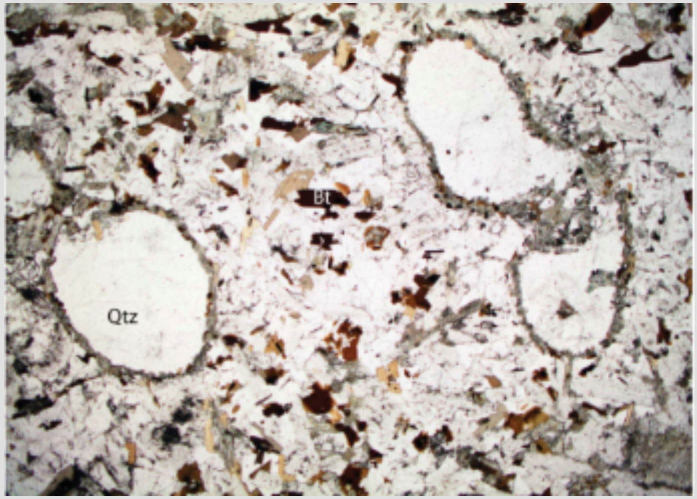
[b] Department of Earth and Environmental Sciences, California State University, Fresno, CA 93740, United States

Tynong, Asutralia
http://users.monash.edu.au/~weinberg/Pages/Tynong_mingling/50pct/DSC07669.JPG

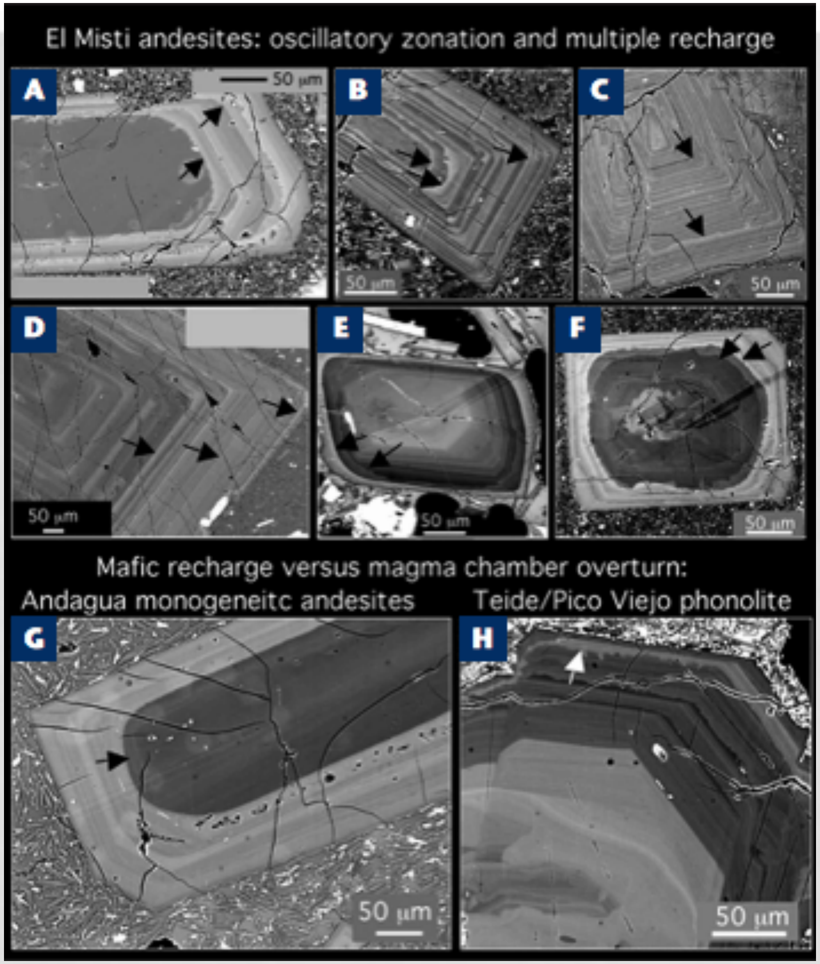
EVIDÊNCIAS PETROGRÁFICAS DA MISTURA DE MAGMAS

- Desequilíbrio químico



Base da foto 3.4 mm

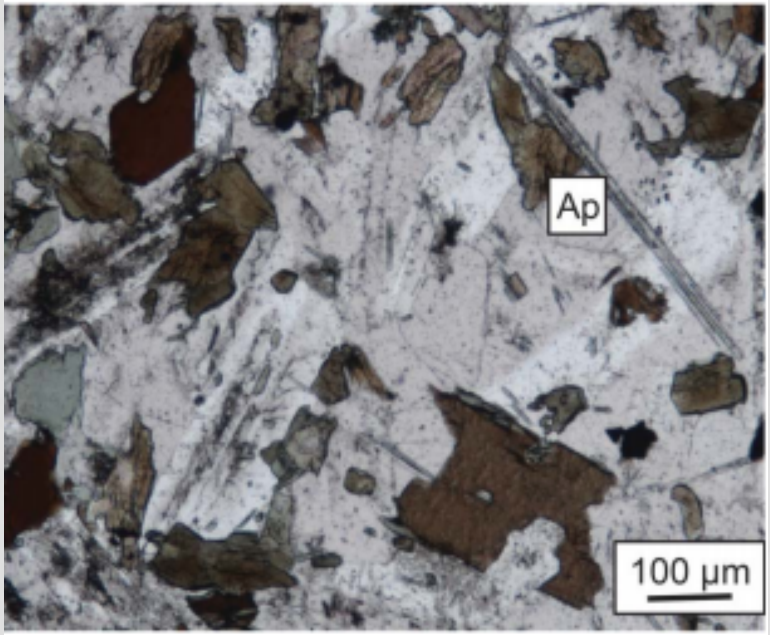
Vernon (2014)
Australian Journal of Earth Sciences



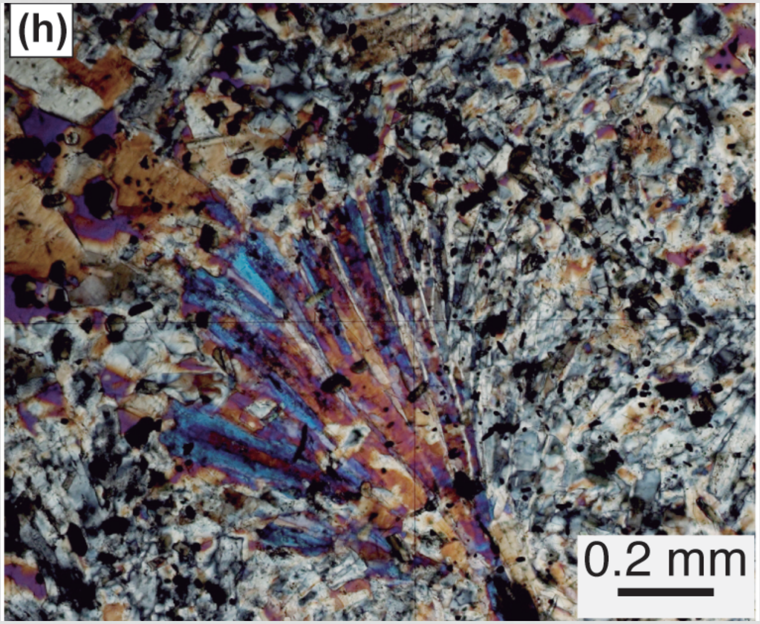
Ginibre et al (2007)
Elements v.3, 261-266

EVIDÊNCIAS PETROGRÁFICAS DA MISTURA DE MAGMAS

- Resfriamento rápido

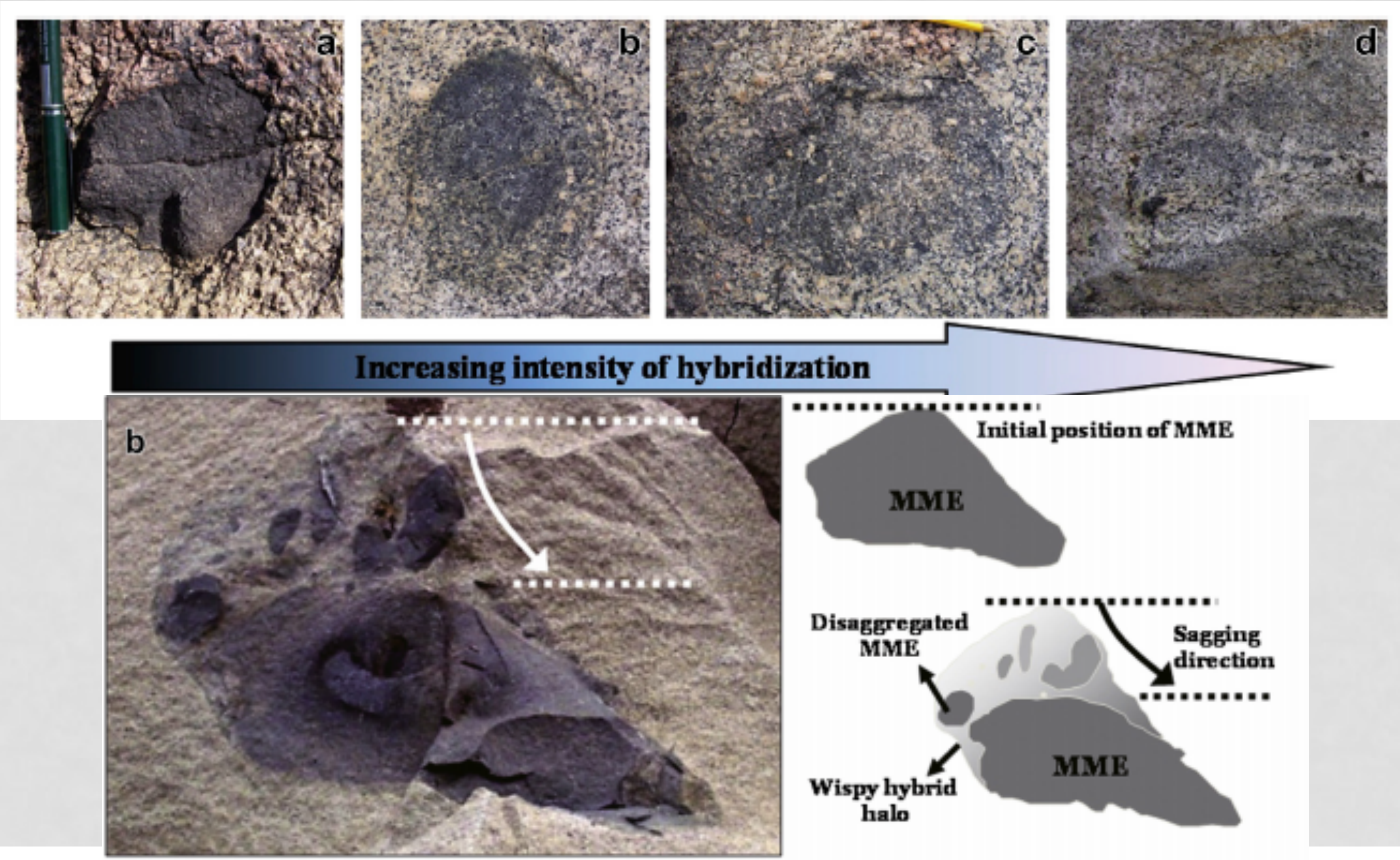


Vernon (2014)
Australian Journal of Earth Sciences

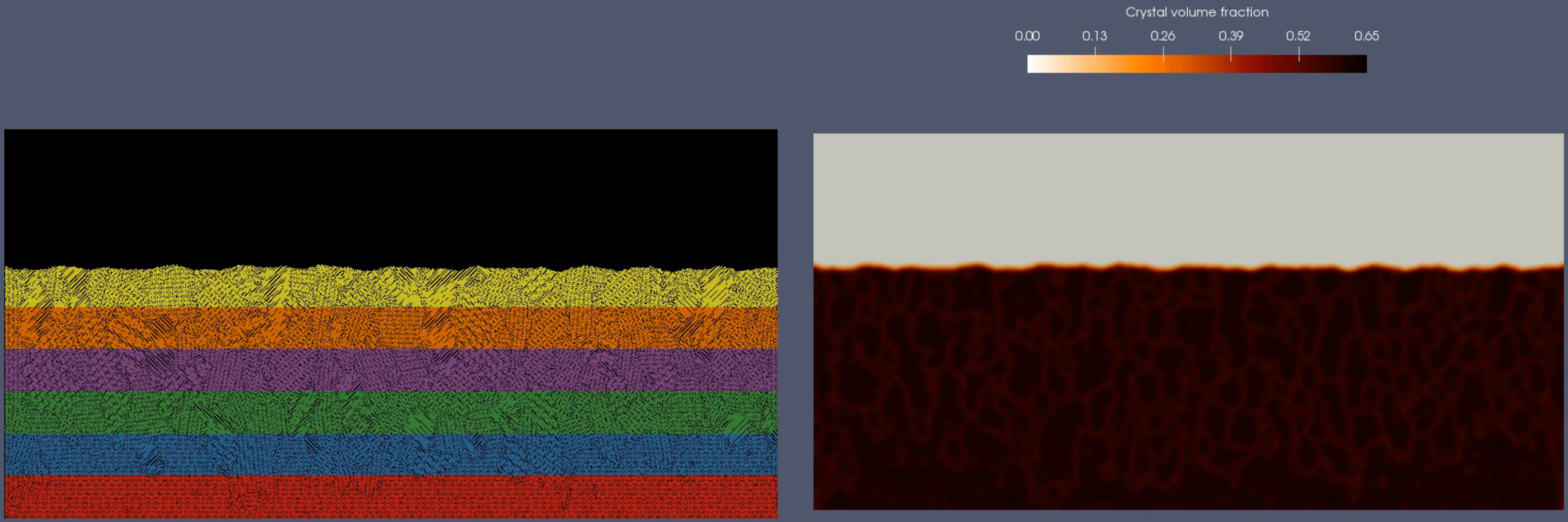


Alves et al (2015)
Lithos 239, 33-44

A IMPORTÂNCIA DA MISTURA NA DIVERSIDADE COMPOSICIONAL DE MAGMAS

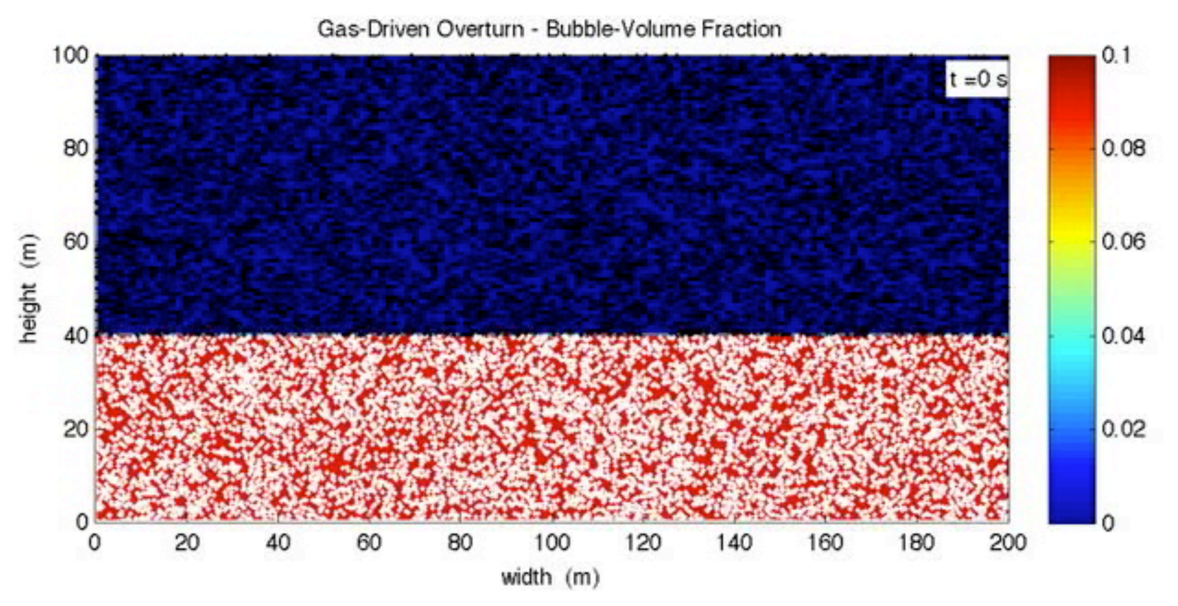


MAGMAS HÍBRIDOS

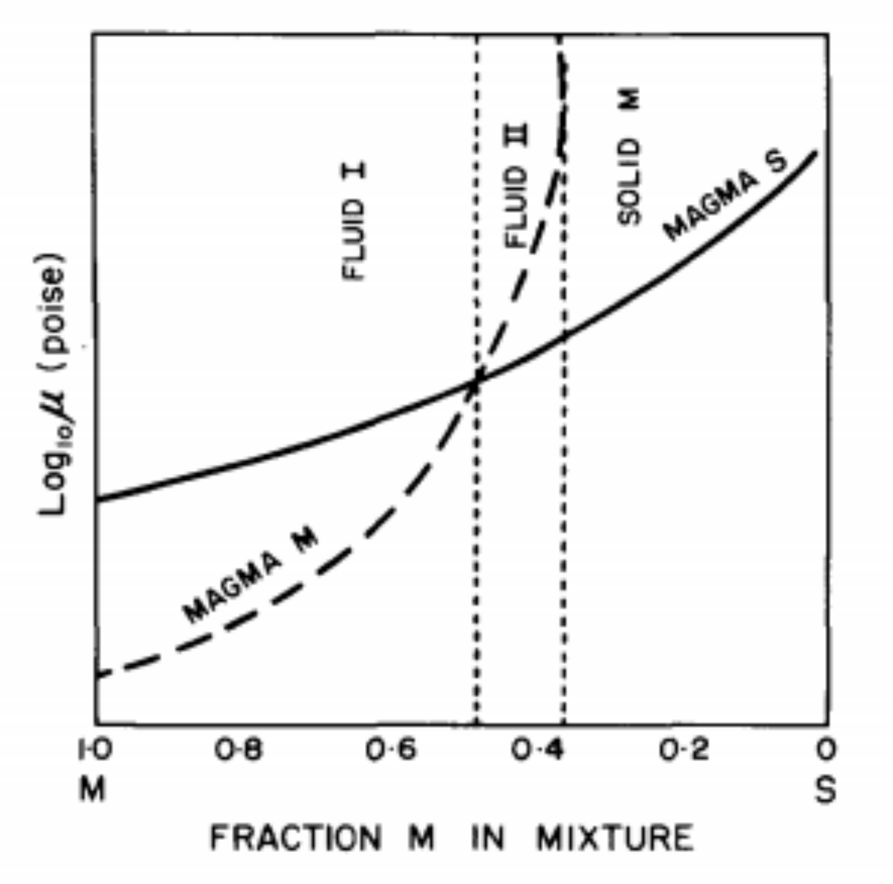


- Schleicher and Bergantz (2017) Jpet, 58(6): 1-14

HÍBRIDOS SEM MUSH



ATENÇÃO!



Log₁₀μ (poise)
FLUID I
FLUID II
SOLID M
MAGMA S
MAGMA M
1·0
0·8
0·6
0·4
0·2
0
M
S
FRACTION M IN MIXTURE

IMPLICAÇÕES DA MISTURA DE MAGMAS PARA A PETROLOGIA MODERNA

- Desencadeamento de erupções
- A ideia é antiga, data da década de 70
- Dois mecanismos distintos *ponding* + sobrepressão *versus* **hibridização**
- Erupção do Eyjafjallajökull (carinhosamente E15) possibilitou a observação in loco do **processo** pela primeira vez

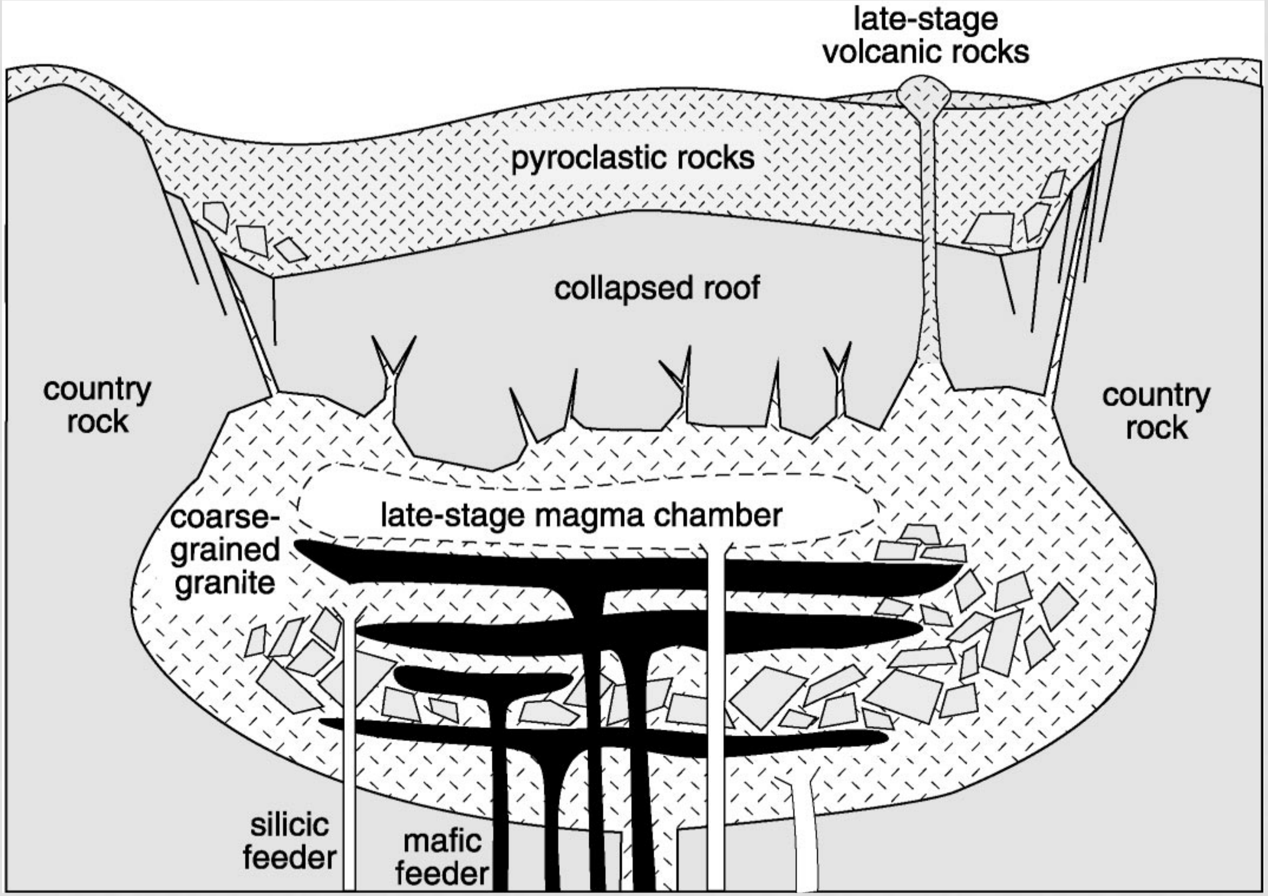
Solid Earth, 2, 271–281, 2011
www.solid-earth.net/2/271/2011/
doi:10.5194/se-2-271-2011

Solid Earth

Remobilization of silicic intrusion by mafic magmas during the 2010 Eyjafjallajökull eruption

O. Sigmarsson[1,2], I. Vlastelic[1], R. Andreasen[3], I. Bindeman[4], J.-L. Devidal[1], S. Moune[1], J. K. Keiding[5], G. Larsen[2], A. Höskuldsson[2], and Th. Thordarson[6]

QUAL PROCESSO É RESPONSÁVEL POR UMA DADA OCORRÊNCIA?



NOTA DE CAUTELA SOBRE QUÍMICA DE ROCHA TOTAL

- Cristalização fracionada e mistura resultam em padrões semelhantes