火星における火成活動

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2013/1/9 北海道大学

背景

問題

Plate teconics の働かない系での物質循環は？

どのような化学進化が可能か？

物理的機構

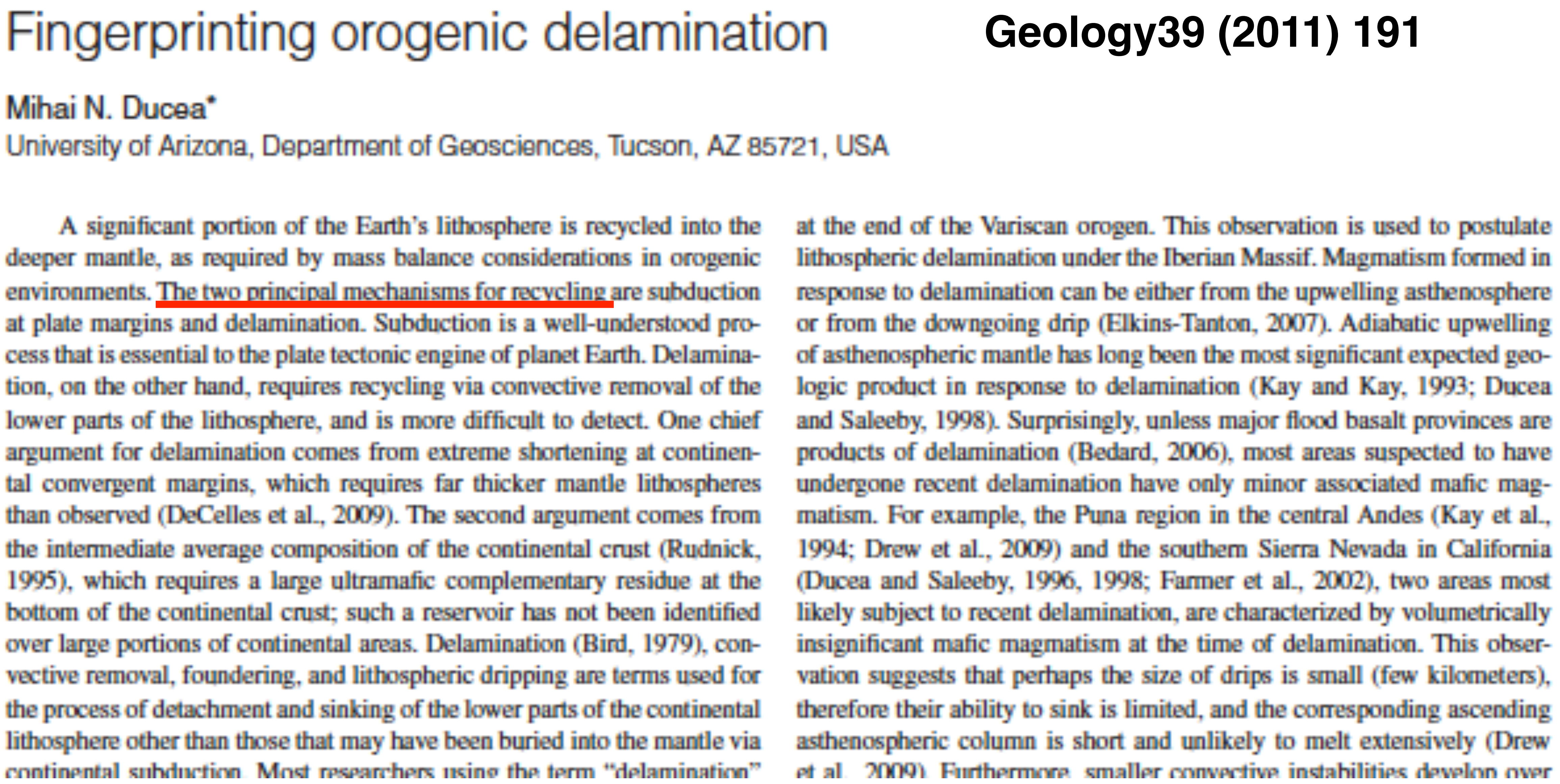
下部より：熱化学プルーム

上部より：リゾスフェア下部の熱対流

化学進化という観点からは？

地殻を巻き込んだリサイクリングは可能か？

Geology39 (2011) 191



Fingerprinting orogenic delamination

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A significant portion of the Earth's lithosphere is recycled into the deeper mantle, as required by mass balance considerations in orogenic environments. The two principal mechanisms for recycling are subduction at plate margins and delamination. Subduction is a well-understood process that is essential to the plate tectonic engine of planet Earth. Delamination, on the other hand, requires recycling via convective removal of the lower parts of the lithosphere, and is more difficult to detect. One chief argument for delamination comes from extreme shortening at continental convergent margins, which requires far thicker mantle lithospheres than observed (DeCelles et al., 2009). The second argument comes from the intermediate average composition of the continental crust (Rudnick, 1995), which requires a large ultramafic complementary residue at the bottom of the continental crust; such a reservoir has not been identified over large portions of continental areas. Delamination (Bird, 1979), convective removal, foundering, and lithospheric dripping are terms used for the process of detachment and sinking of the lower parts of the continental lithosphere other than those that may have been buried into the mantle via continental subduction. Most researchers using the term "delamination"

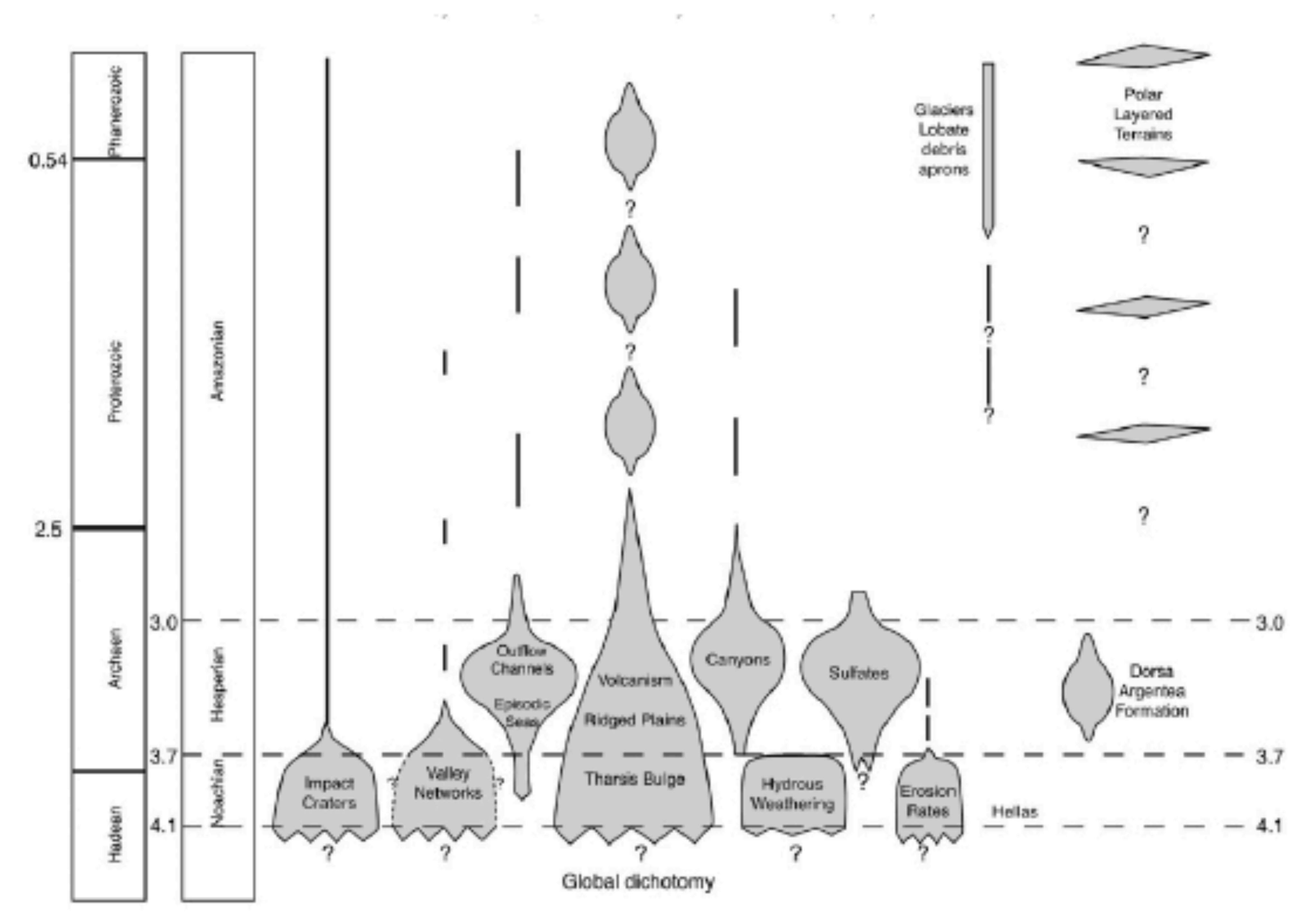
at the end of the Variscan orogen. This observation is used to postulate lithospheric delamination under the Iberian Massif. Magmatism formed in response to delamination can be either from the upwelling asthenosphere or from the downgoing drip (Elkins-Tanton, 2007). Adiabatic upwelling of asthenospheric mantle has long been the most significant expected geologic product in response to delamination (Kay and Kay, 1993; Ducea and Saleeby, 1998). Surprisingly, unless major flood basalt provinces are products of delamination (Bedard, 2006), most areas suspected to have undergone recent delamination have only minor associated mafic magmatism. For example, the Puna region in the central Andes (Kay et al., 1994; Drew et al., 2009) and the southern Sierra Nevada in California (Ducea and Saleeby, 1996, 1998; Farmer et al., 2002), two areas most likely subject to recent delamination, are characterized by volumetrically insignificant mafic magmatism at the time of delamination. This observation suggests that perhaps the size of drips is small (few kilometers), therefore their ability to sink is limited, and the corresponding ascending asthenospheric column is short and unlikely to melt extensively (Drew et al., 2009). Furthermore, smaller convective instabilities develop over

表層地殻のリサイクリング

1. Subduction by plate tectonics
2. Delamination of lower crust

Delamination Process の問題、難しさ:観測の問題、表層地形・地質に反映されない

?


Phanerozoic
0.54
Proterozoic
2.5
Archean
Hadean
Amazonian
Hesperian
Noachian
3.0
3.7
4.1
Impact Craters
Valley Networks
Outflow Channels
Episodic Seas
Volcanism
Ridged Plains
Tharsis Bulge
Canyons
Sulfates
Hydrous Weathering
Erosion Rates
Hellas
Global dichotomy
Glaciers Lobate debris aprons
Polar Layered Terrains
Dorsa Argentea Formation
?
3.0
3.7
4.1

最近の興味深い研究成果

- 活発な大気・固体表層間の物質交換
- 意外に「熱い」内部
  - Bills による潮汐散逸から見積もられた内部状態
- 最近まで起きている火山活動
  - 若い溶岩流の発見

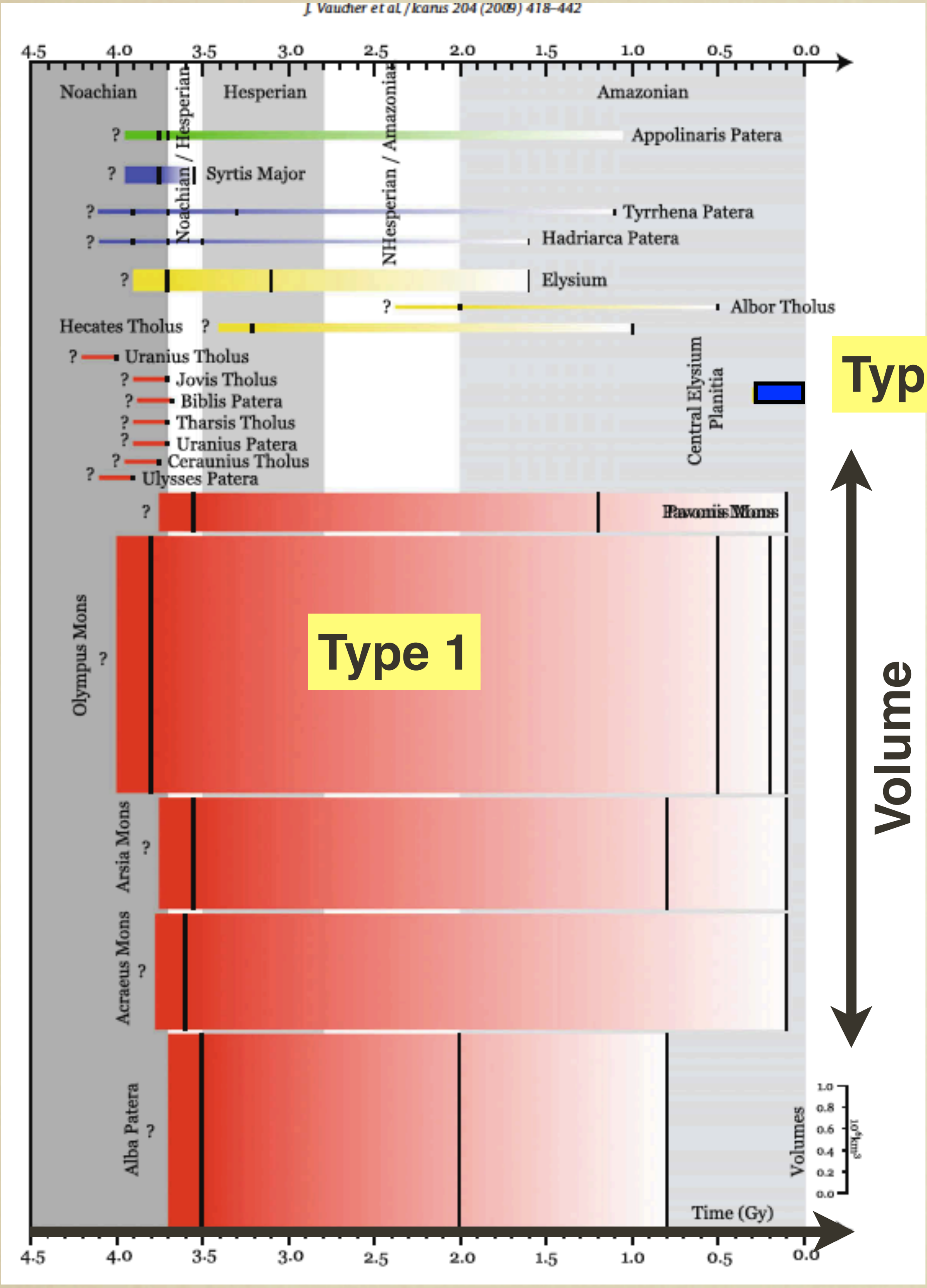
１：2種類の火成活動の存在

２： 火星地殻のBasalt-Eclogite転移(BET)の可能性

３：BETに起因する火成活動の可能性

４：地球における類似プロセスの例

Two styles of volcanism



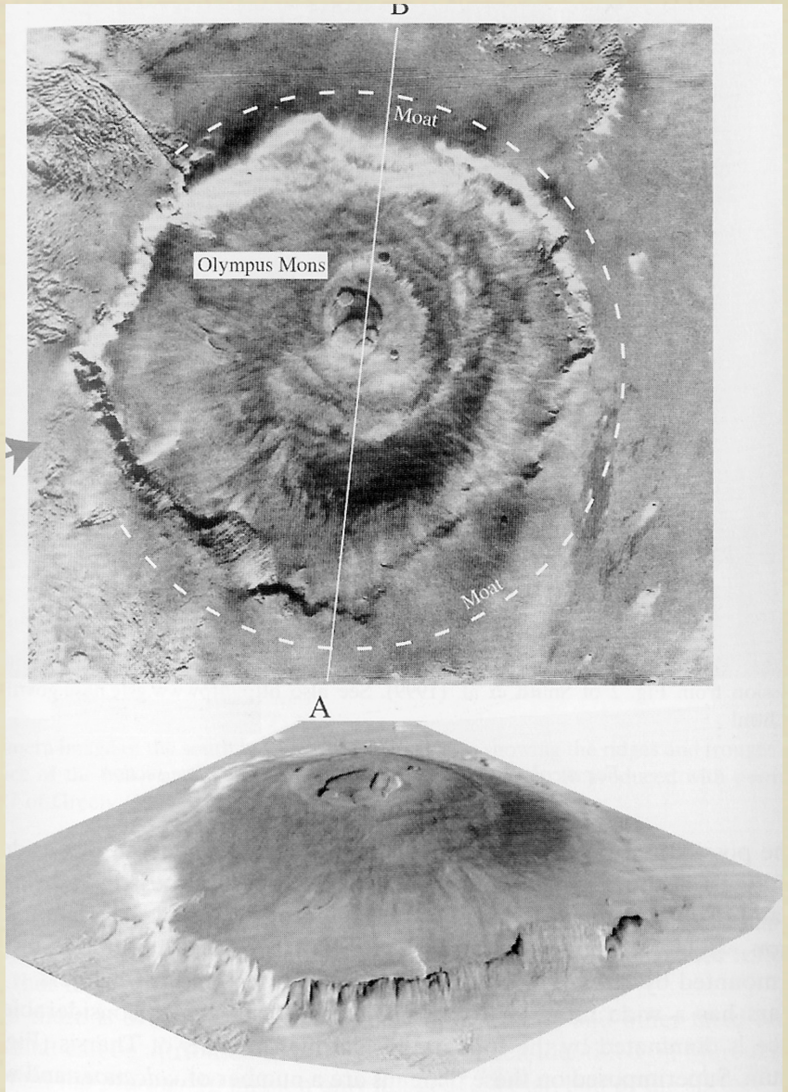
Type 1

Type 2

Volume

Vaucher et al, 2009

Type 1

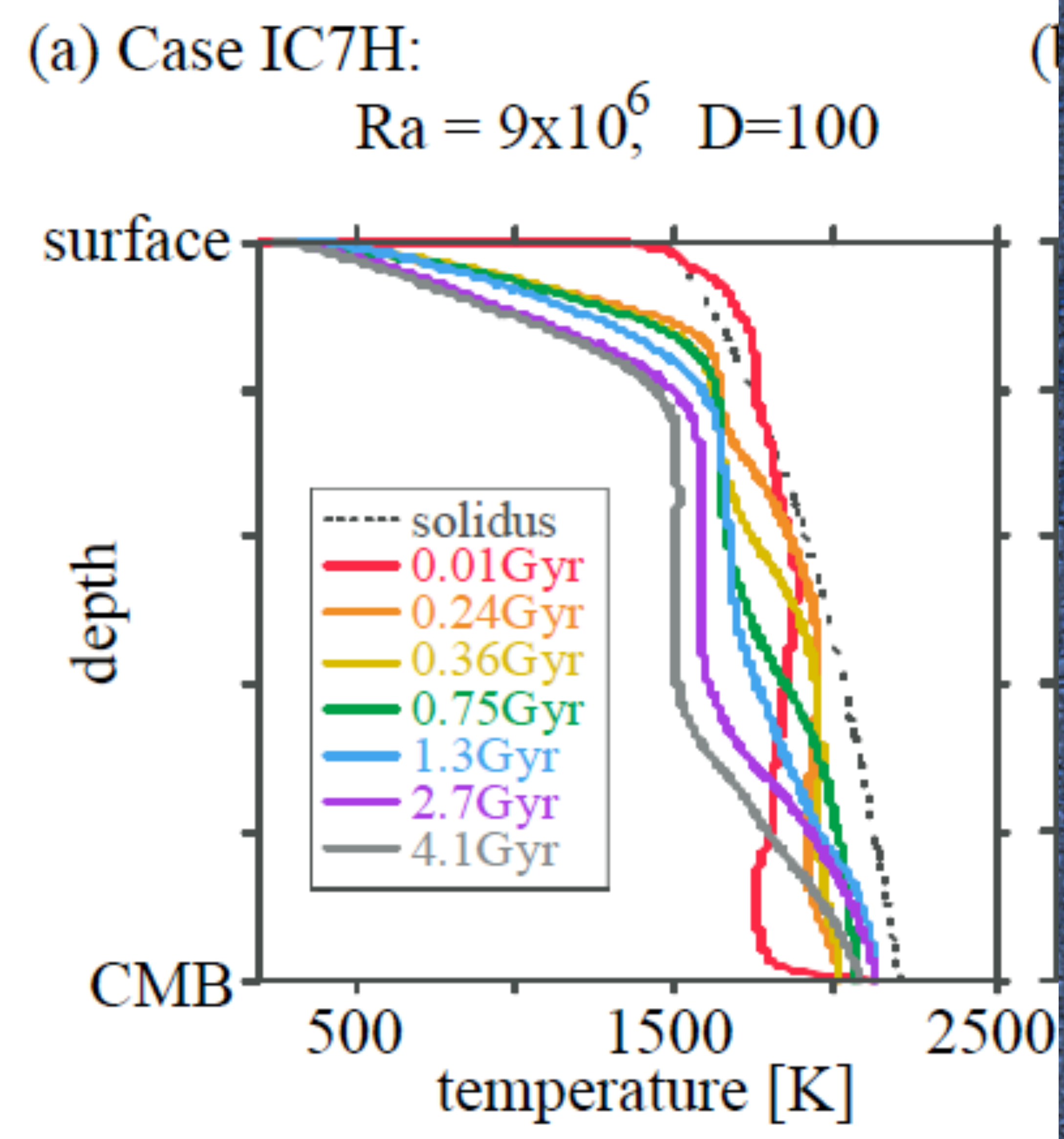


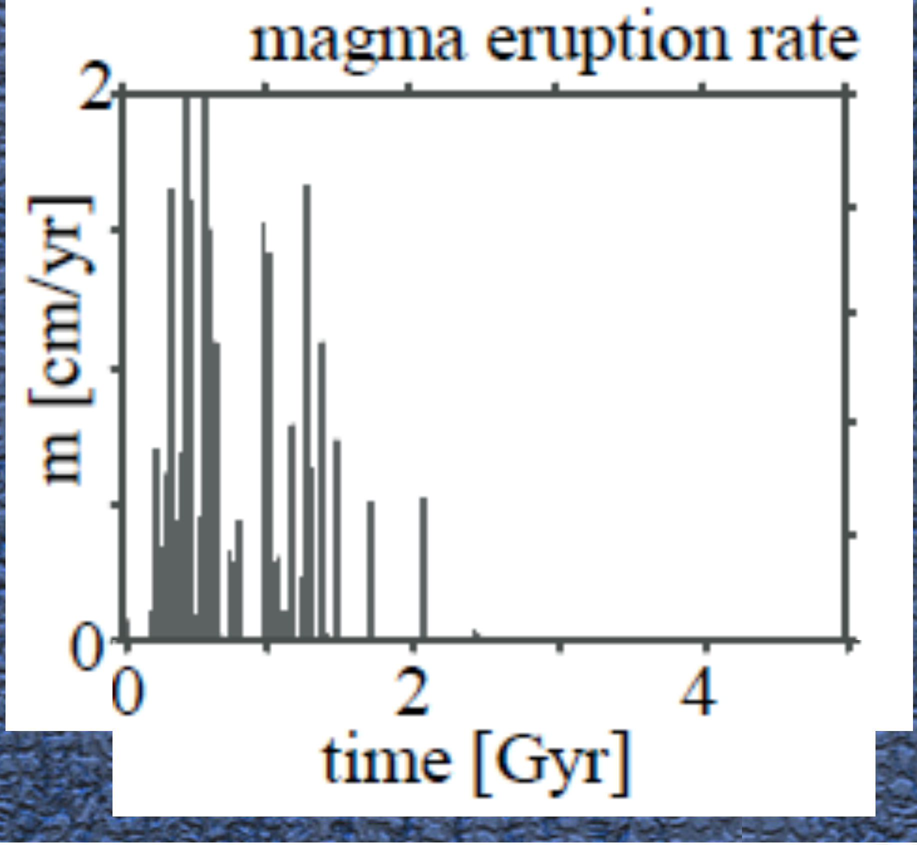
mera image of Olympus Mons in the Tharsis region of Mars. (a) plan view. (b) pe
m the west. Reproduced with permission from Fig. 7.11 of Greely (1994).

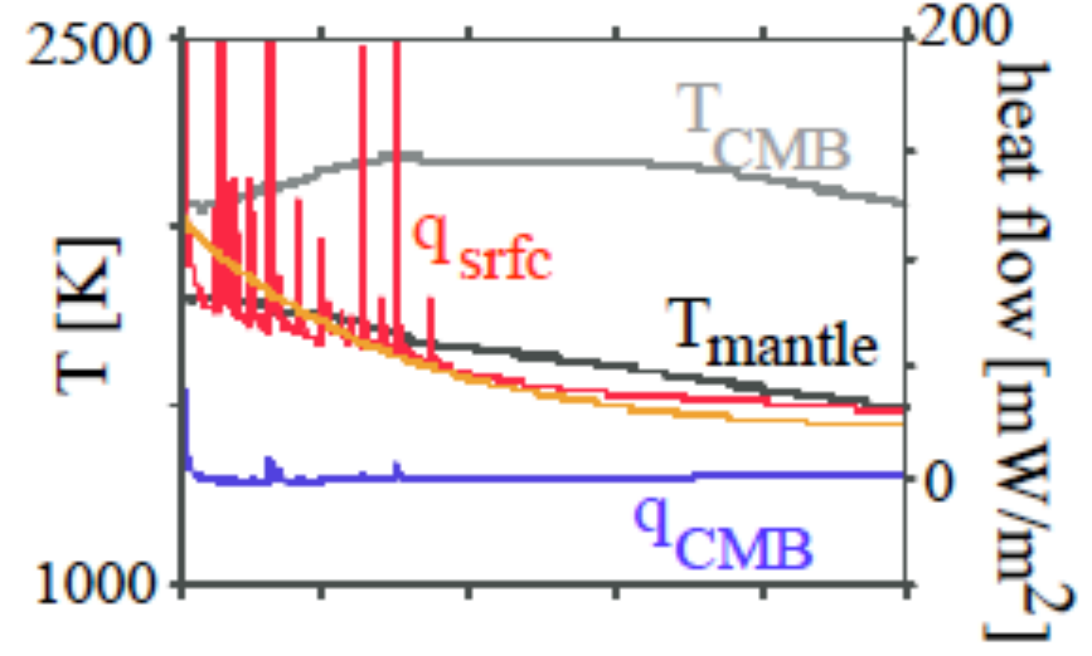
Huge edifice-building volcanism

Thermochemical evolution

(Ogawa & Yanagisawa 2011)







Type 1: Magma Type

1. Morphology of Volcanoes
2. Morphology of Lava Flows
3. Remote Sensing data

Cerberus Fossae & Athabasca

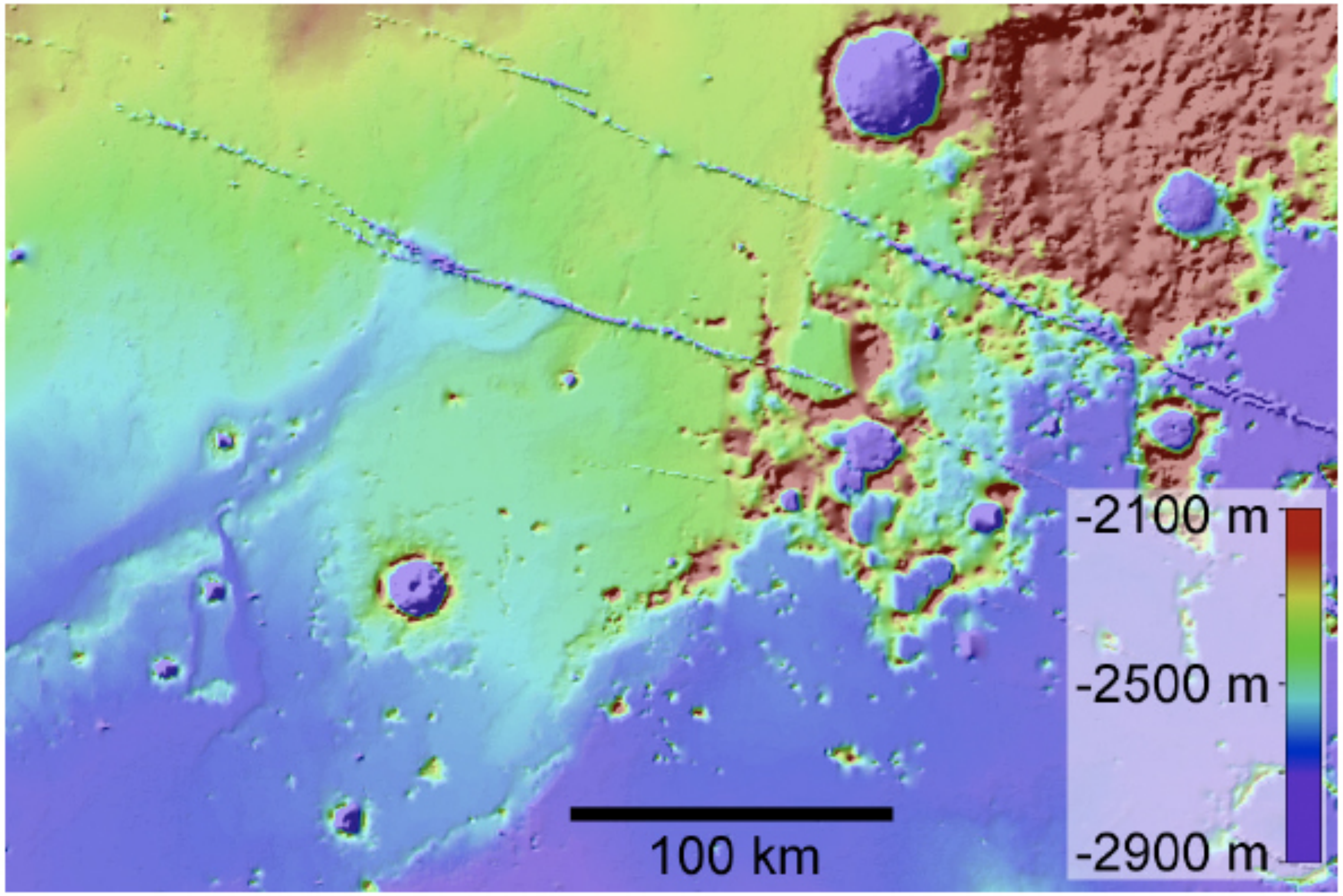
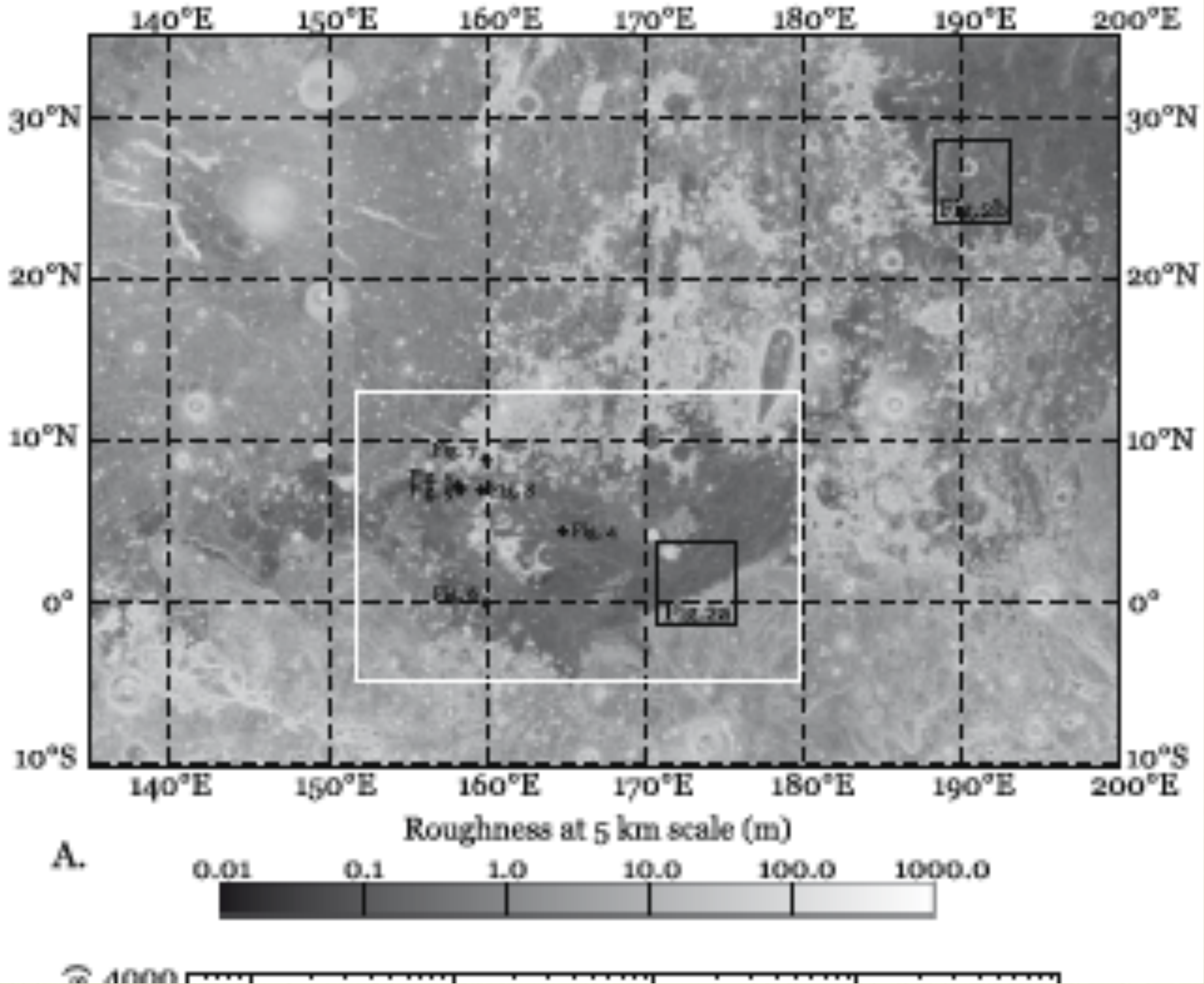
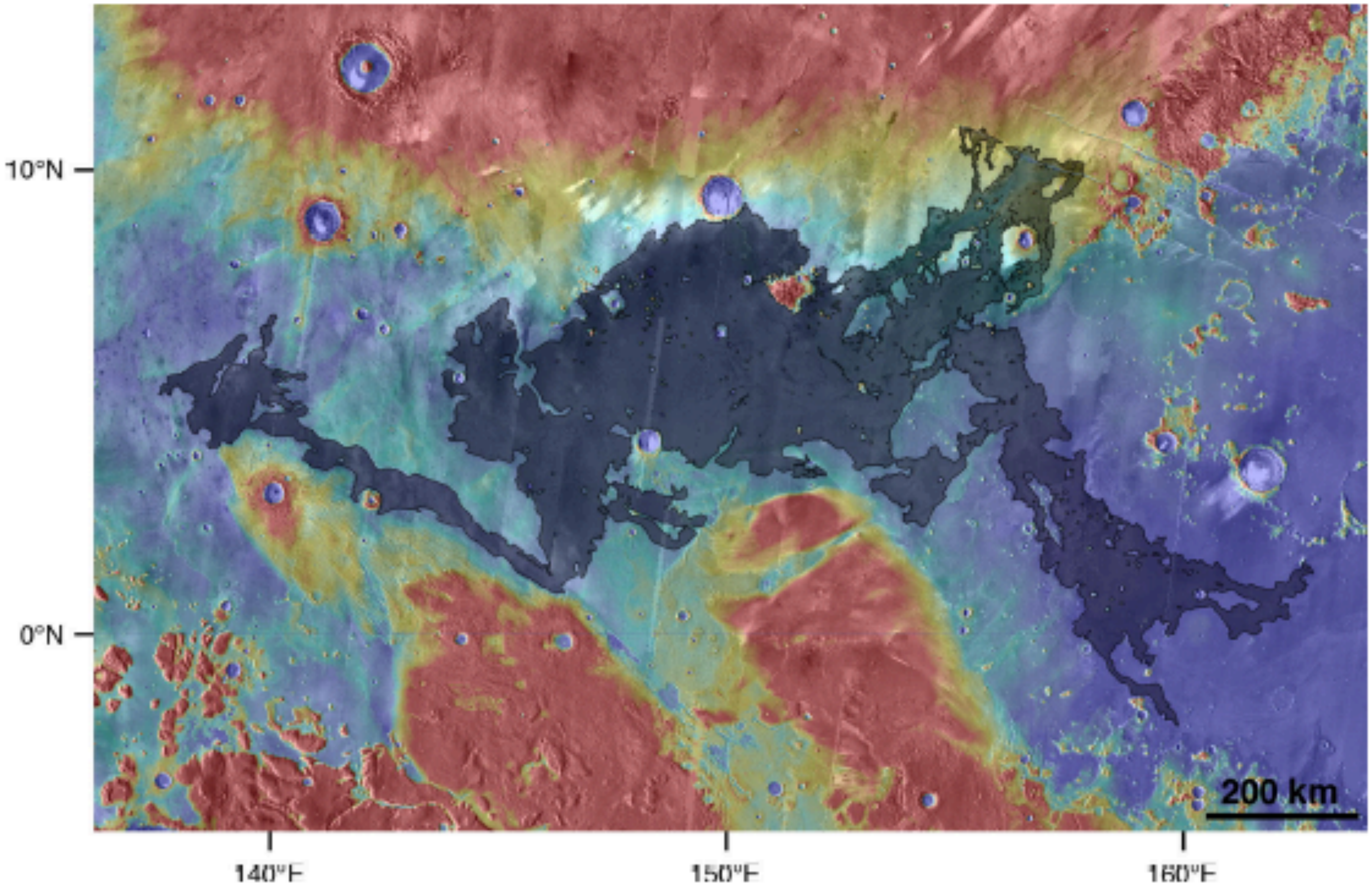


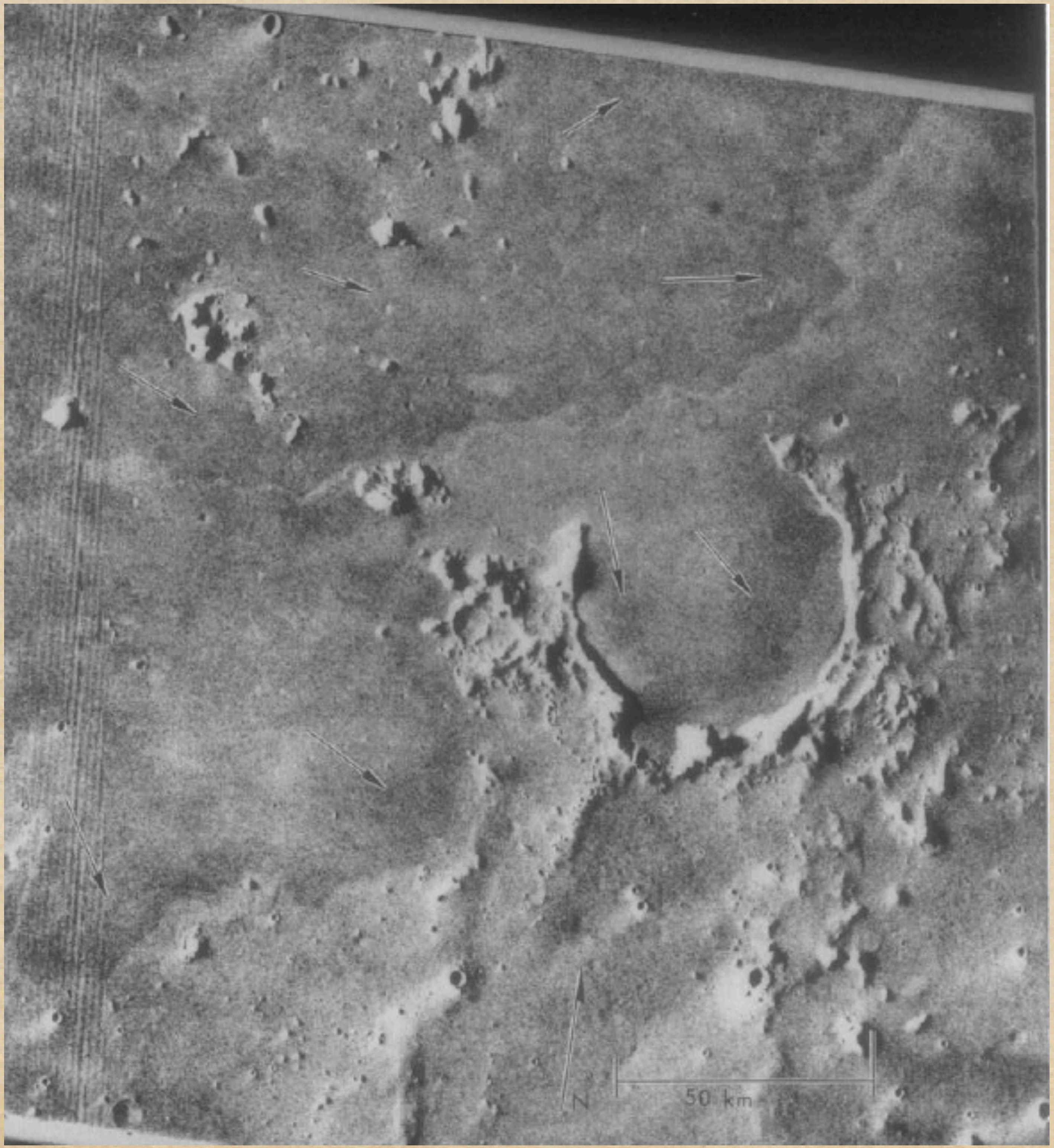
Figure 3. MOLA shaded relief topographic map of the source of Athabasca Valles at one of the Cerberus Fossae fissures (image centered at 9.2°N, 158.2°E).

J. Whitten et al./Icarus 204 (2009) 418–442

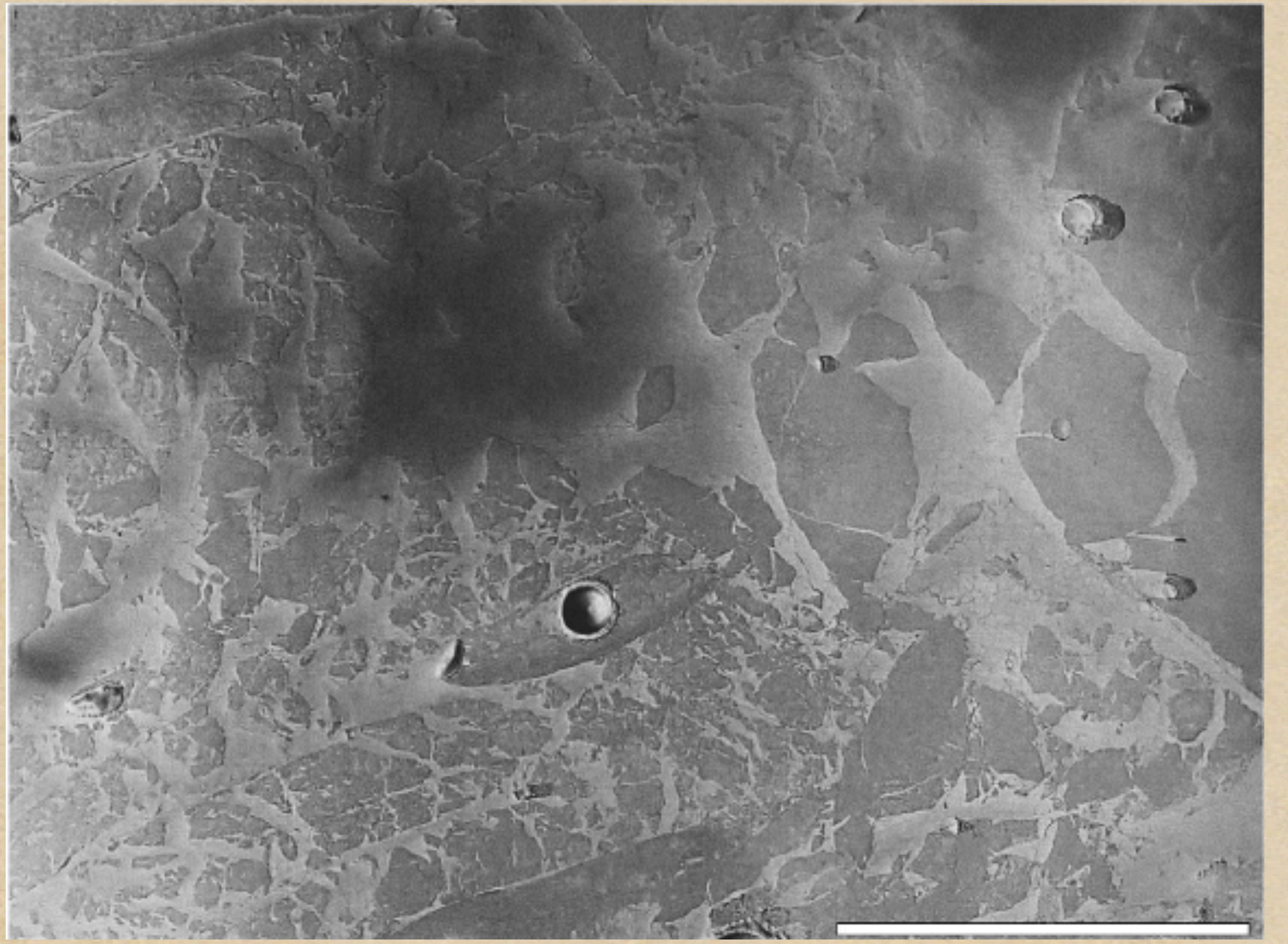



10°N
0°N
140°E
150°E
160°E
200 km

Plescia Icarus88,465 (1990)



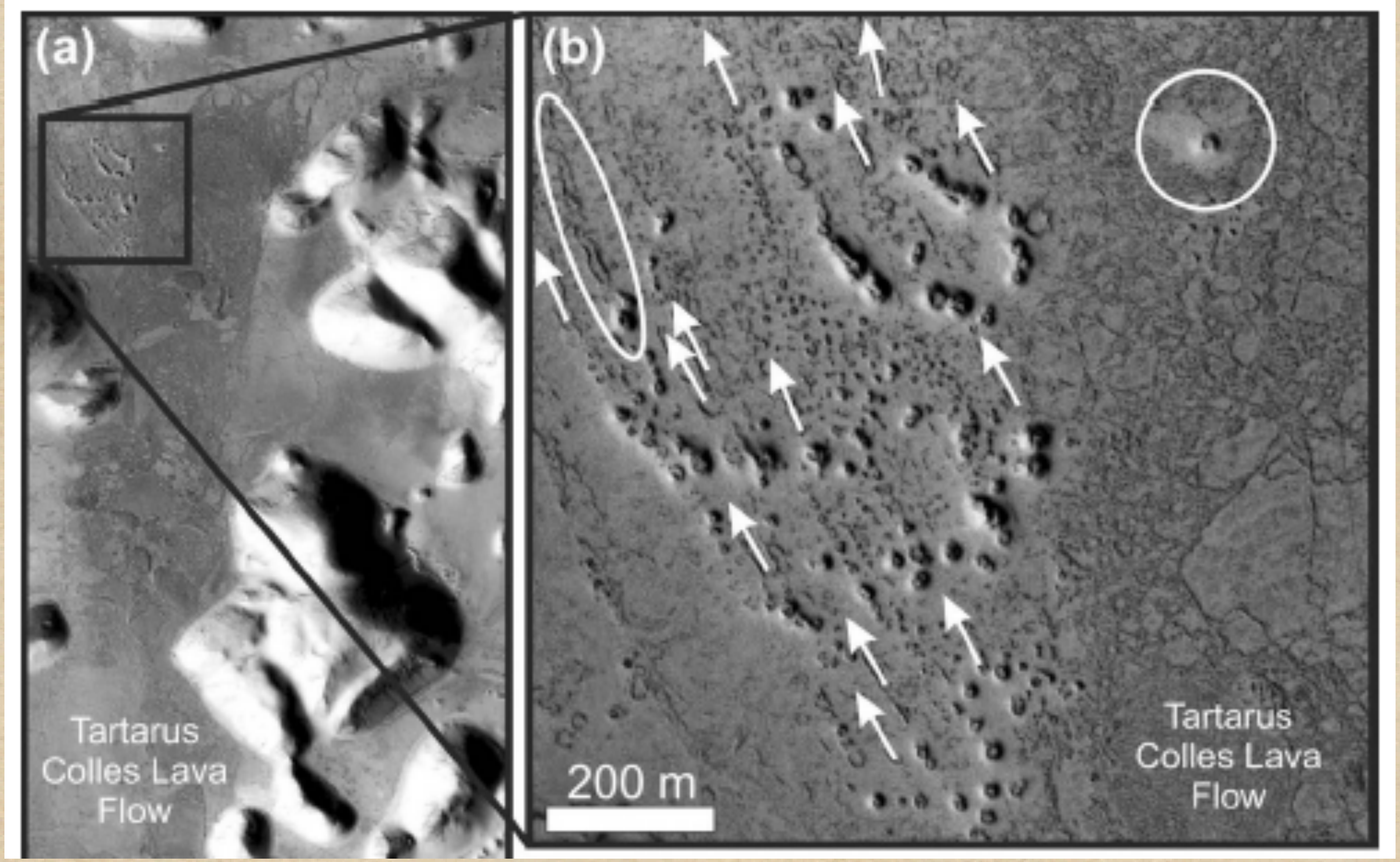
問題点：
噴出したのは溶岩か、水か？



Kossacki et al (2006)

small cones,

rootless cone?,pingo?,mud volcano?



Hamilton et al JGRE 115 (2010)

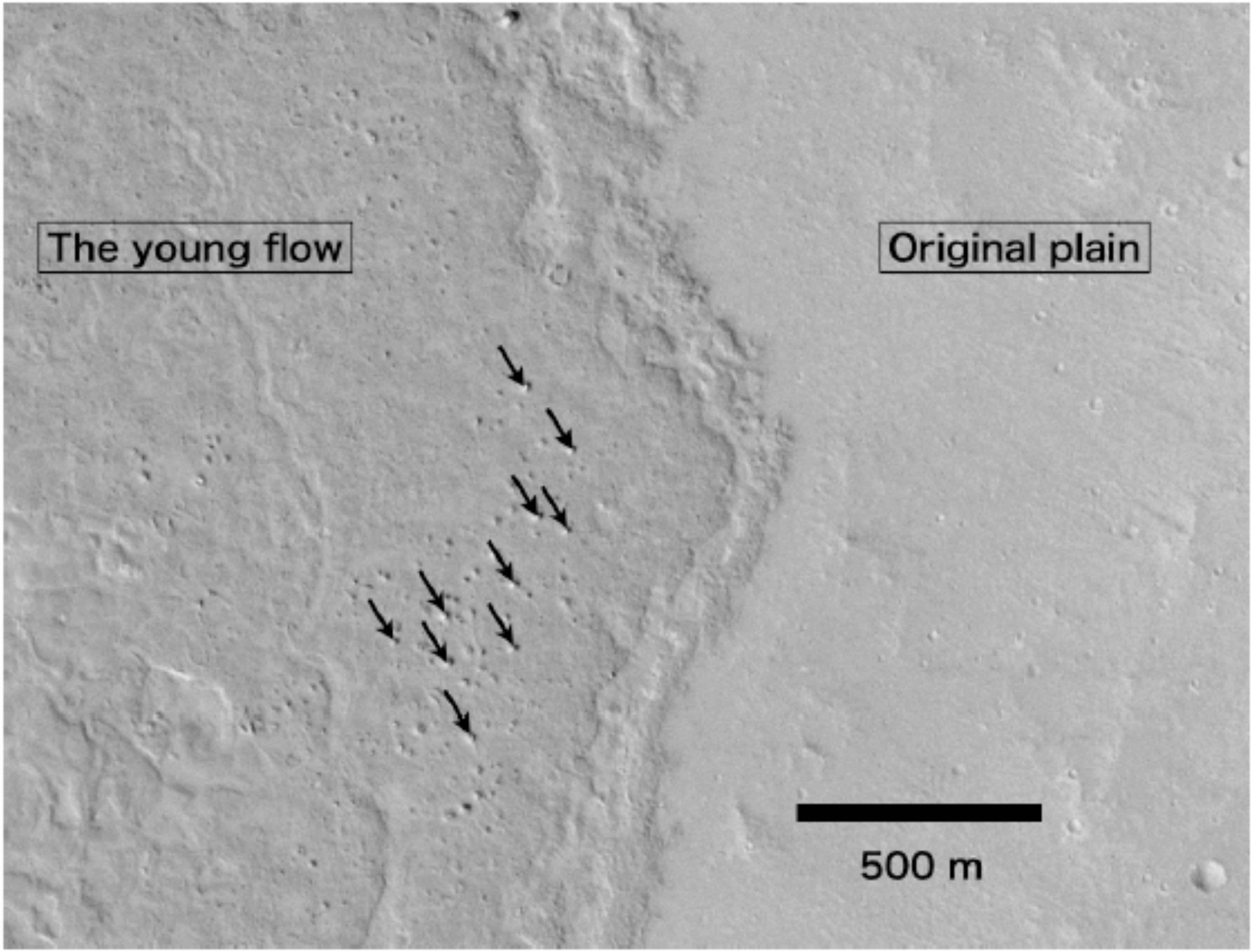
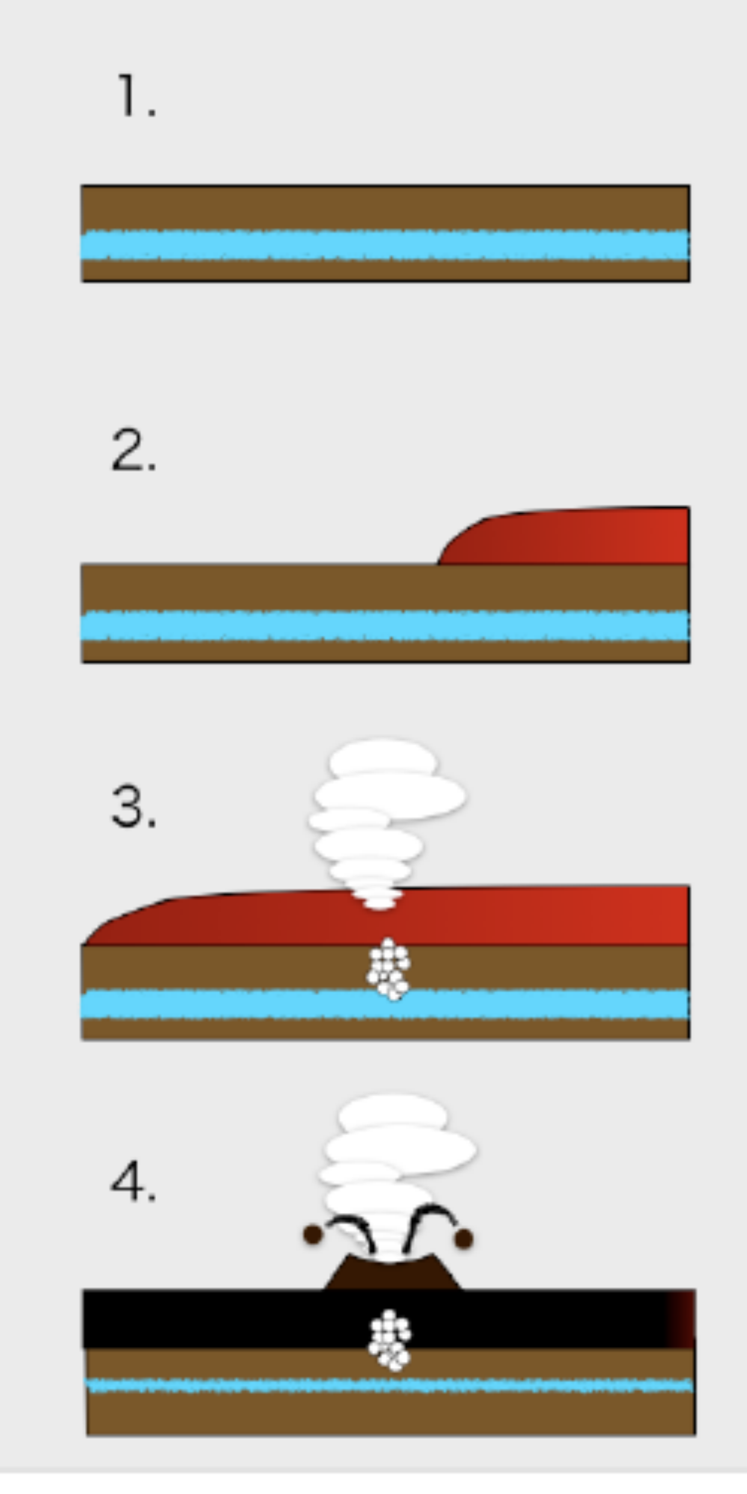
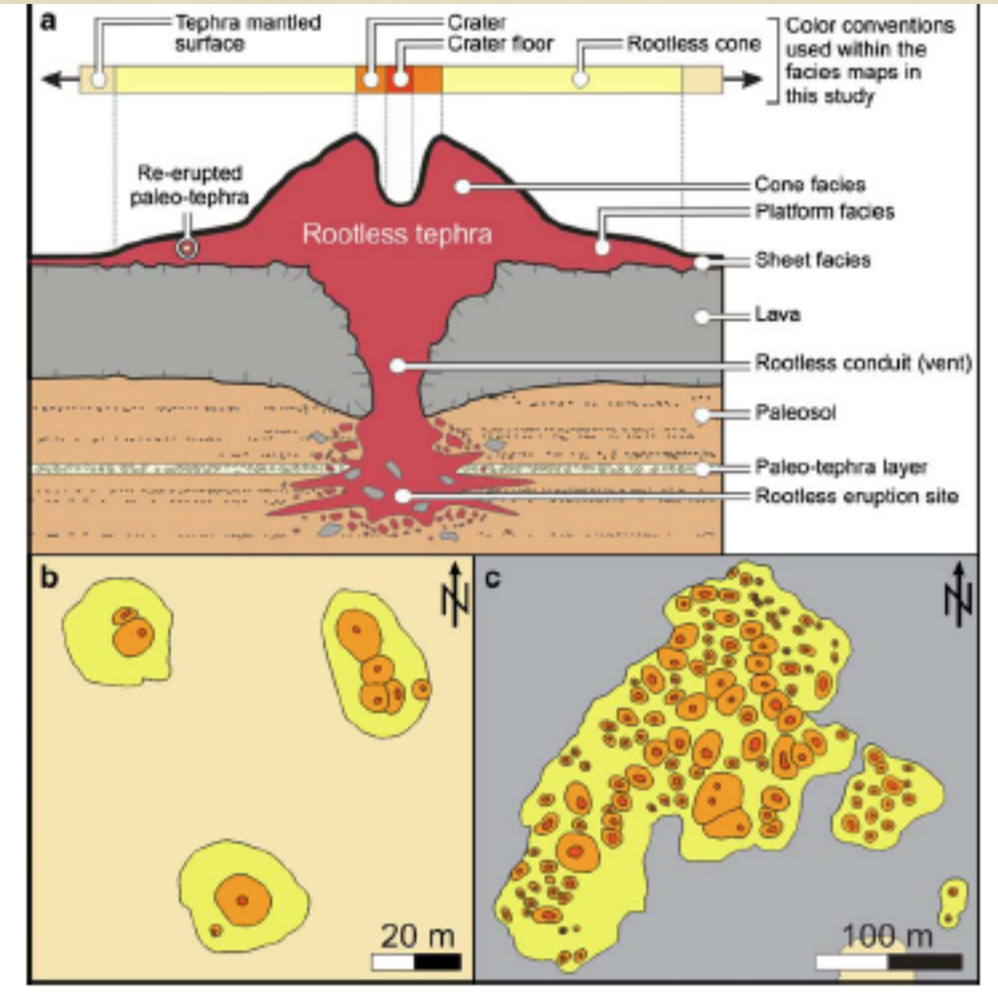


Figure 42: Single Cone Structure in boundary area of the young flow and original plain. Black arrow shows SCS (Image ID: ESP_012419_1865).

*Rootless Cone*の存在：溶岩流である証拠





Iceland Laki

*Rootless Cone*の存在：溶岩流である証拠

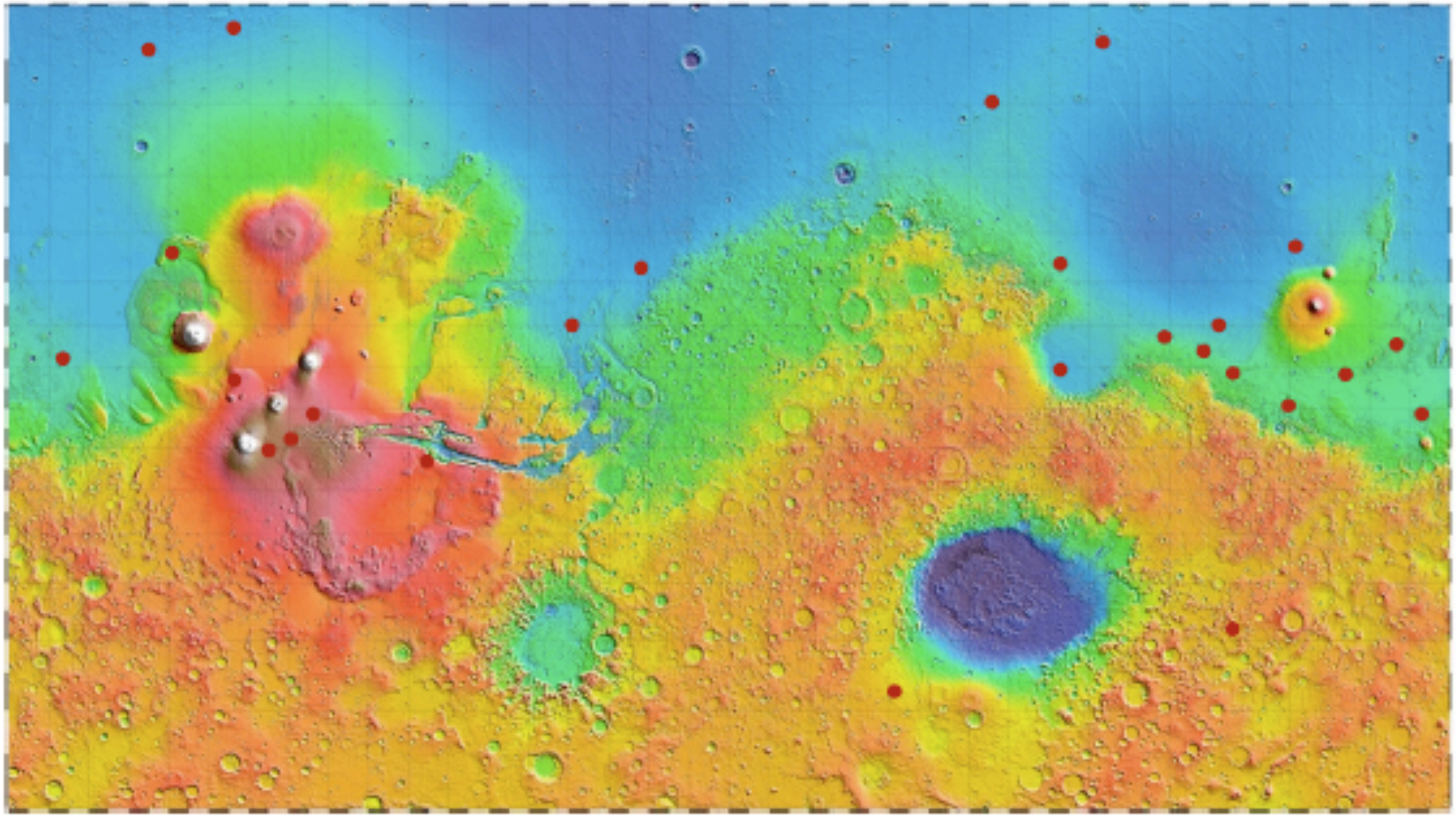


Figure 6: Distribution of cones on Mars. Red dots show location of cone region [refer Burr et al., 2009a, Fagents et al., 2007, Skinner and Mazzini, 2009].

Type 1:巨大火山体の形成活動

1.固定したマグマ源

2.長時間継続したマグマ生成

Hot Spot magmatism
との類似

マントル深部起源の熱組成プルーム

Decline of activity by secular cooling
Ogawa & Yanagisawa JGRE 2011

Type 2:小規模溶岩原の活動

1.dichotomy 境界周辺に散在

2.一回性の活動

?

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?

BETによるDelamination駆動火成活動

火星の地殻のBasalt-Eclogite転移の可能性

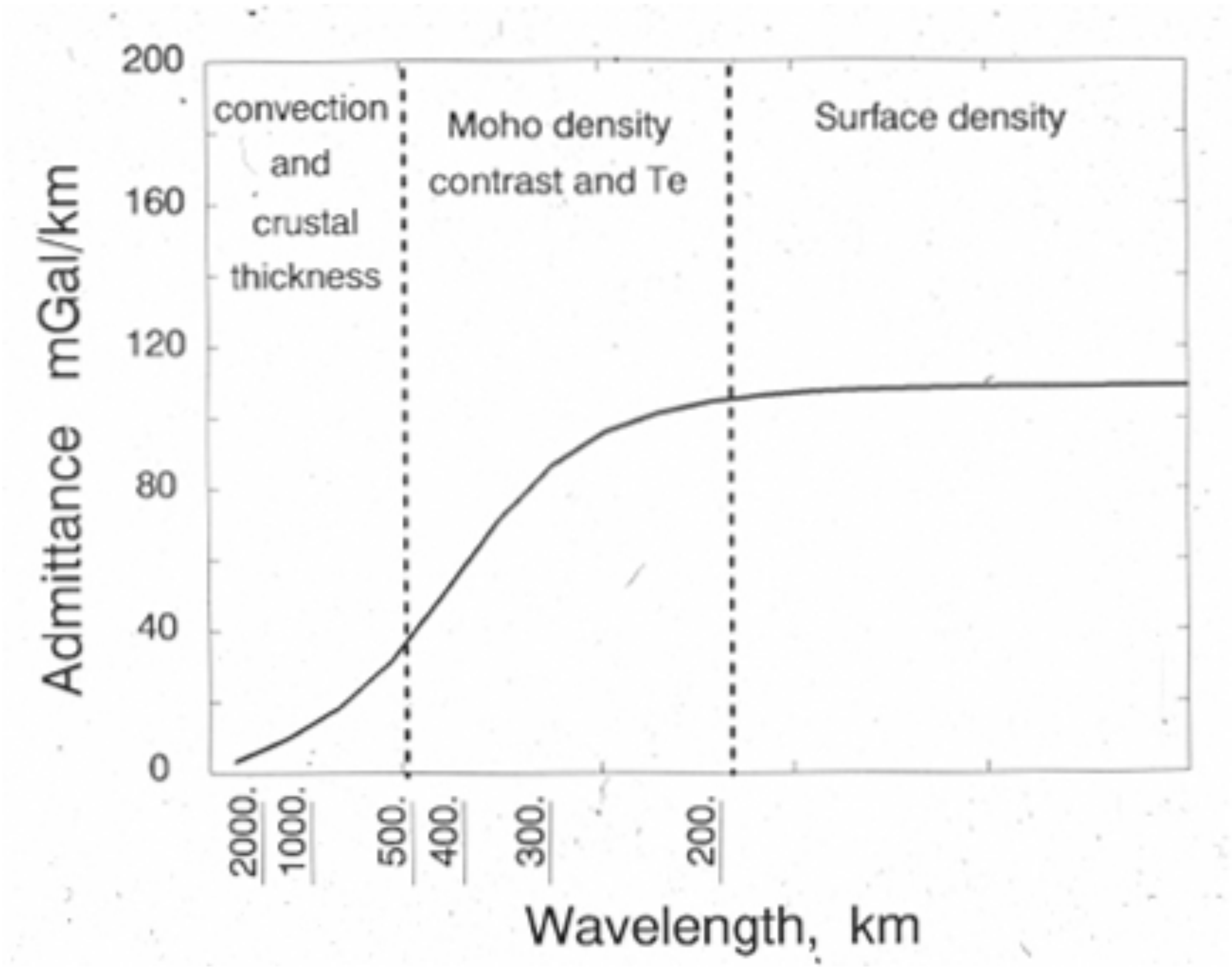
1. 火星の地殻は鉄に富んでいる
2. 鉄に富んだ系でのBET
3. BET が起きるとdelamination が進行
4. Delamination による火成活動の可能性

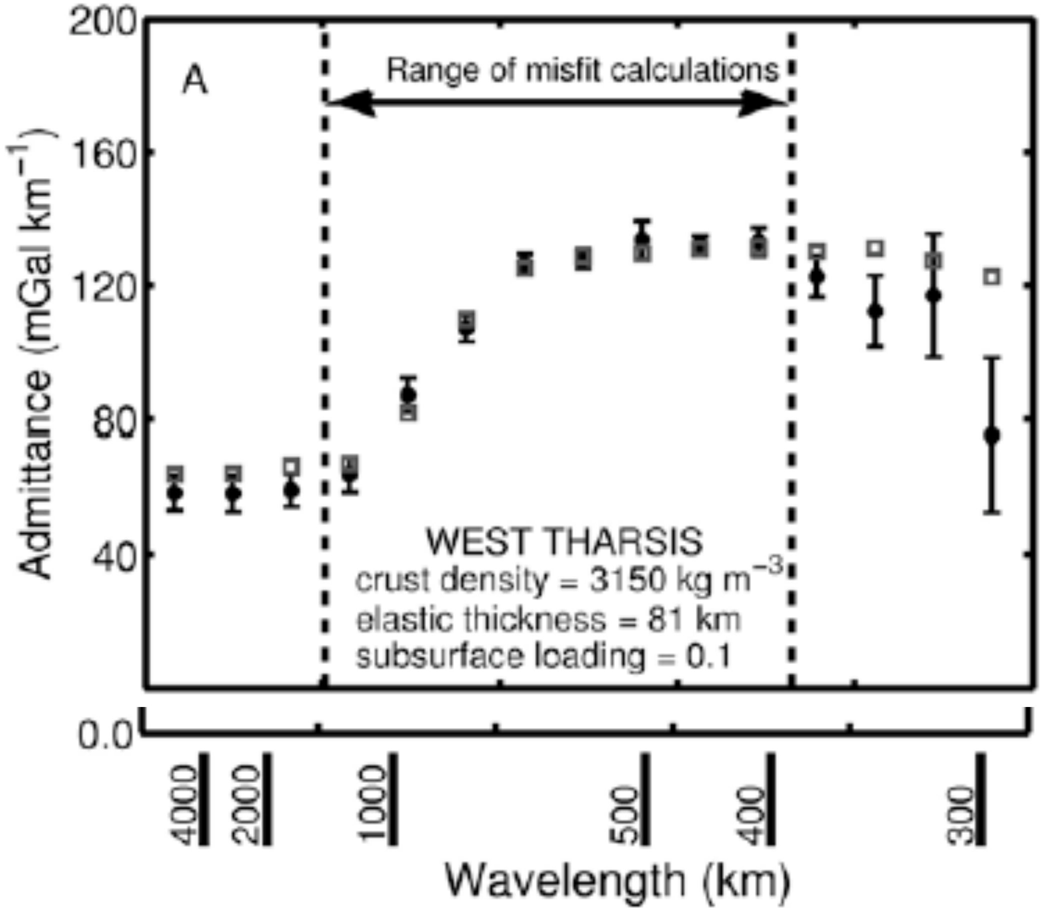
火星の地殻は鉄に富んでいる

1. 重力
2. 火星隕石
3. 探査・APX
4. 探査・リモートセンシング

admittance analysis

$$Z(k, T_e) = 2\pi G\rho_c[1 - \frac{exp(-kt)}{1 + \frac{Dk^4}{g(\rho_m - \rho_c)}}]$$





crustal density estimated by gravity data

name	density	method
Pauer & Breuer 2008	3020	GTR+Bouger,single layer
Zuber et al 2000	2900	Bouger,single
McGovern et al 2002	2900-3150	admittance,load
Neumann et al 2004	2900	average crustal density
Wieczorek & Zuber 2004	2900-3100	39-81 km
Belleguic et al 2005	3270	load,Elysium

地殻の密度

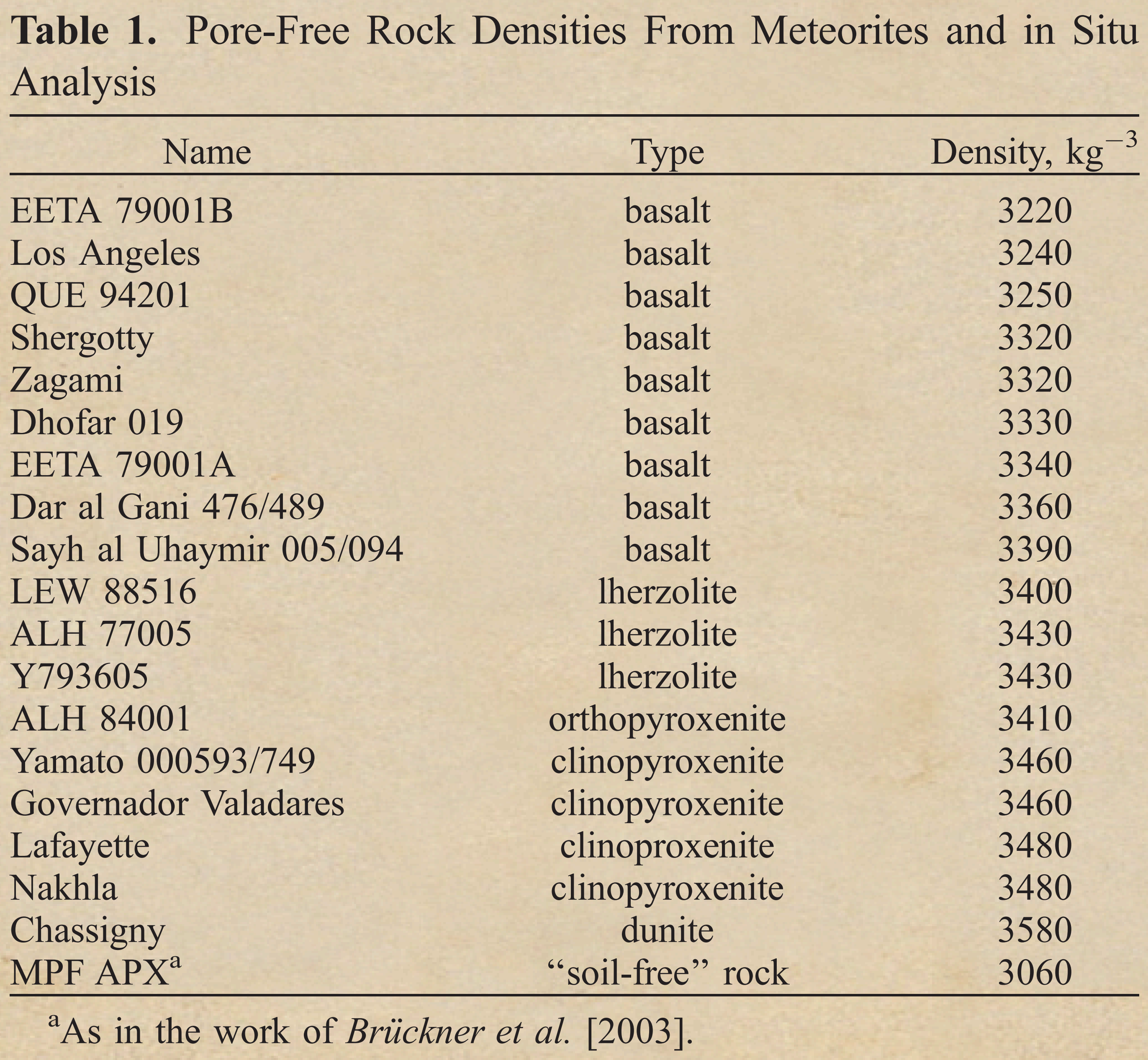


Table 1. Pore-Free Rock Densities From Meteorites and in Situ Analysis

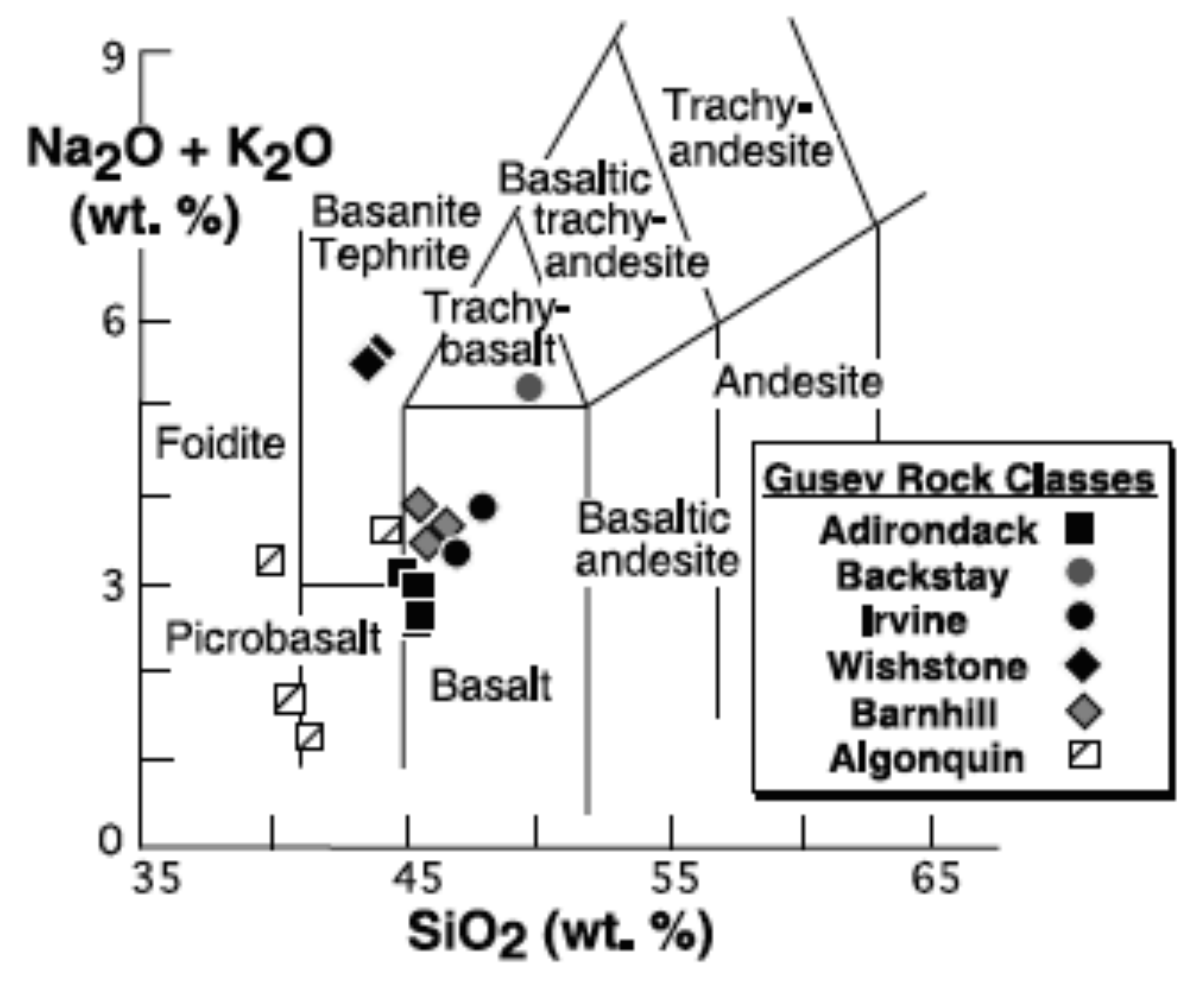
Name	Type	Density, kg^{-3}
EETA 79001B	basalt	3220
Los Angeles	basalt	3240
QUE 94201	basalt	3250
Shergotty	basalt	3320
Zagami	basalt	3320
Dhofar 019	basalt	3330
EETA 79001A	basalt	3340
Dar al Gani 476/489	basalt	3360
Sayh al Uhaymir 005/094	basalt	3390
LEW 88516	lherzolite	3400
ALH 77005	lherzolite	3430
Y793605	lherzolite	3430
ALH 84001	orthopyroxenite	3410
Yamato 000593/749	clinopyroxenite	3460
Governador Valadares	clinopyroxenite	3460
Lafayette	clinoproxenite	3480
Nakhla	clinopyroxenite	3480
Chassigny	dunite	3580
MPF APX[a]	“soil-free” rock	3060

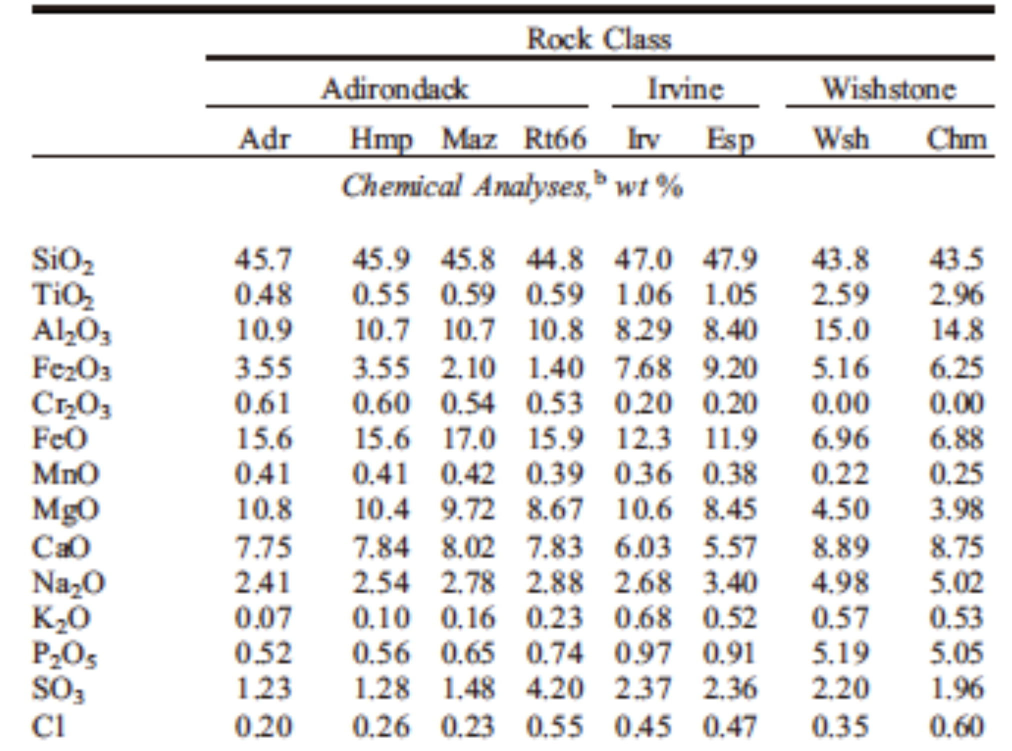
[a] As in the work of *Brückner et al.* [2003].

Neumann et al. JGR 109E,2004

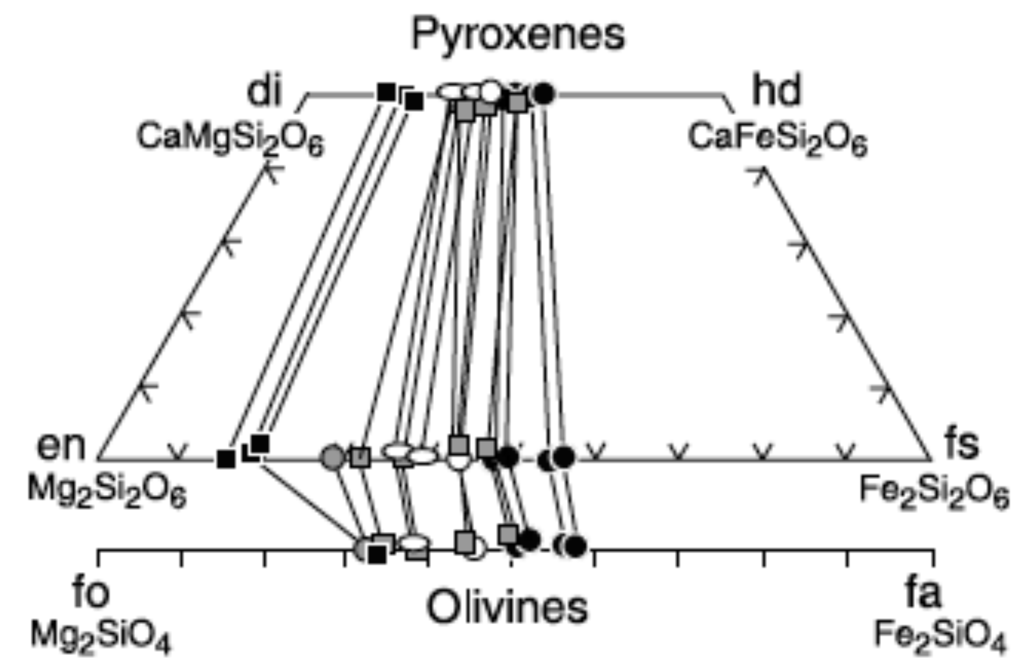
APXS at Gusev

APXS + Mossbauer + THEMIS



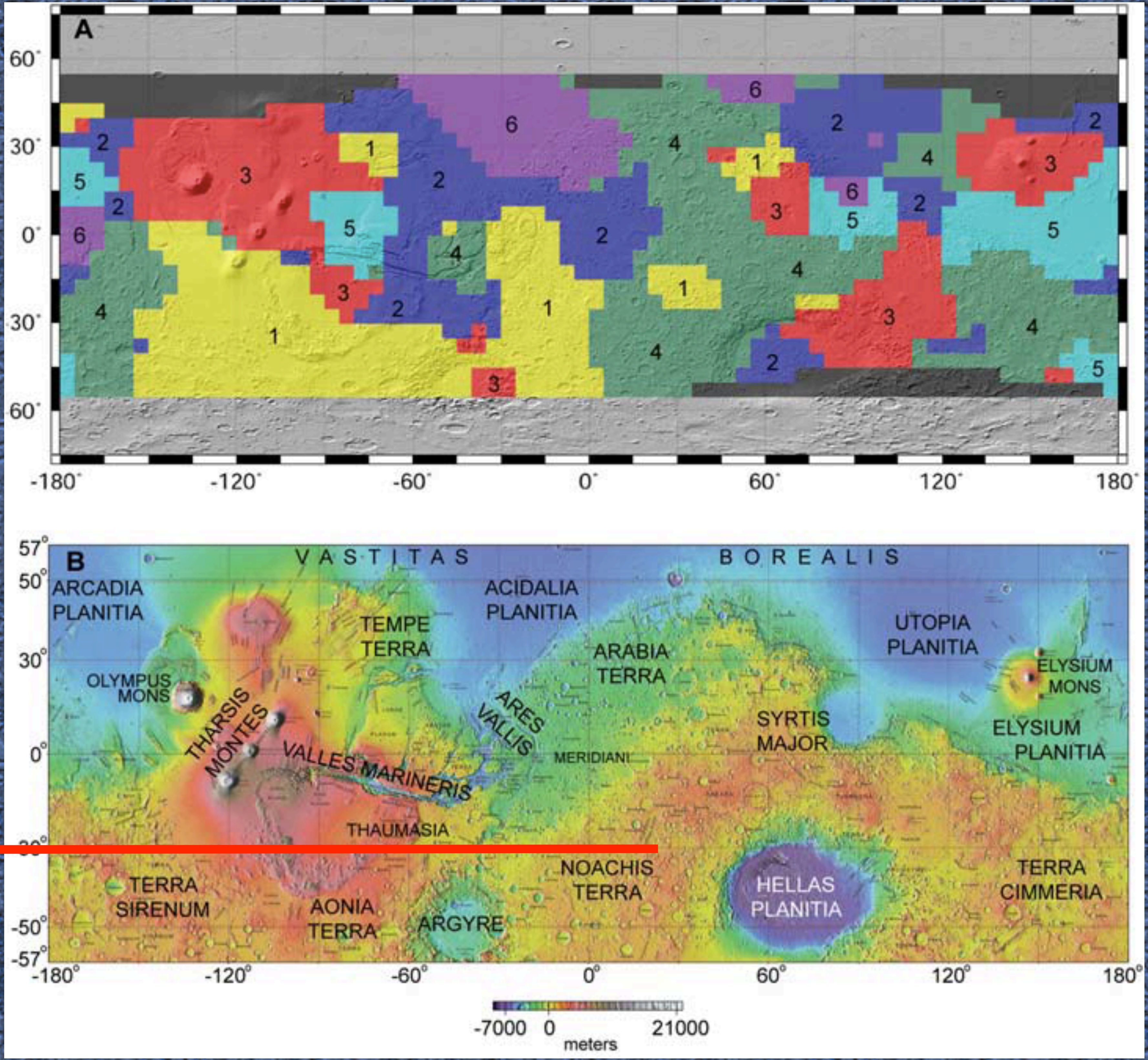


	Rock Class							
	Adirondack				Irvine		Wishstone	
	Adr	Hmp	Maz	Rt66	Irv	Esp	Wsh	Chm
	Chemical Analyses,[b] *wt %*							
SiO_2	45.7	45.9	45.8	44.8	47.0	47.9	43.8	43.5
TiO_2	0.48	0.55	0.59	0.59	1.06	1.05	2.59	2.96
Al_2O_3	10.9	10.7	10.7	10.8	8.29	8.40	15.0	14.8
Fe_2O_3	3.55	3.55	2.10	1.40	7.68	9.20	5.16	6.25
Cr_2O_3	0.61	0.60	0.54	0.53	0.20	0.20	0.00	0.00
FeO	15.6	15.6	17.0	15.9	12.3	11.9	6.96	6.88
MnO	0.41	0.41	0.42	0.39	0.36	0.38	0.22	0.25
MgO	10.8	10.4	9.72	8.67	10.6	8.45	4.50	3.98
CaO	7.75	7.84	8.02	7.83	6.03	5.57	8.89	8.75
Na_2O	2.41	2.54	2.78	2.88	2.68	3.40	4.98	5.02
K_2O	0.07	0.10	0.16	0.23	0.68	0.52	0.57	0.53
P_2O_5	0.52	0.56	0.65	0.74	0.97	0.91	5.19	5.05
SO_3	1.23	1.28	1.48	4.20	2.37	2.36	2.20	1.96
Cl	0.20	0.26	0.23	0.55	0.45	0.47	0.35	0.60



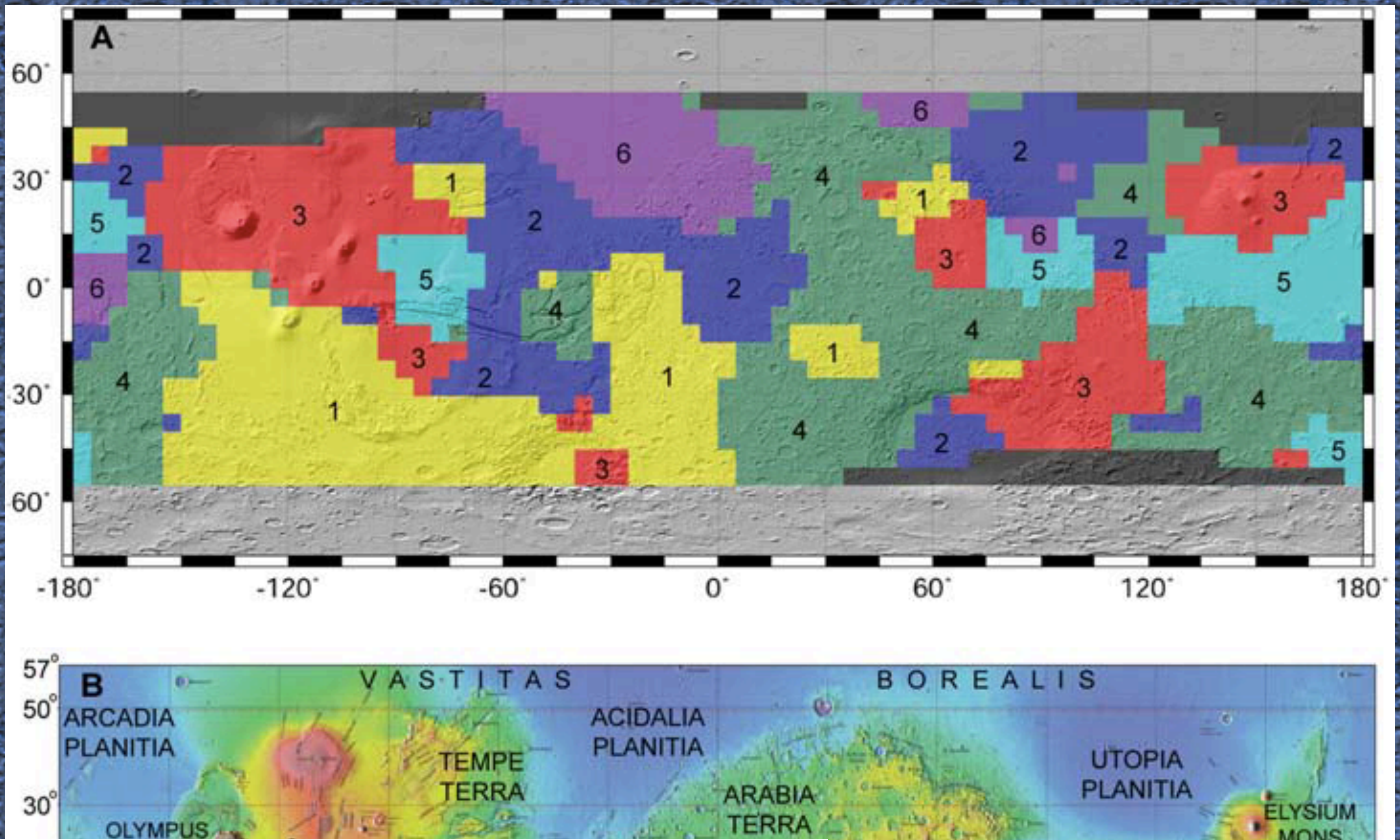
MaSween et al JGRE 113,2008

Geological Map



Taylor et al. Geol. 38,183 (2010)

Geological Map



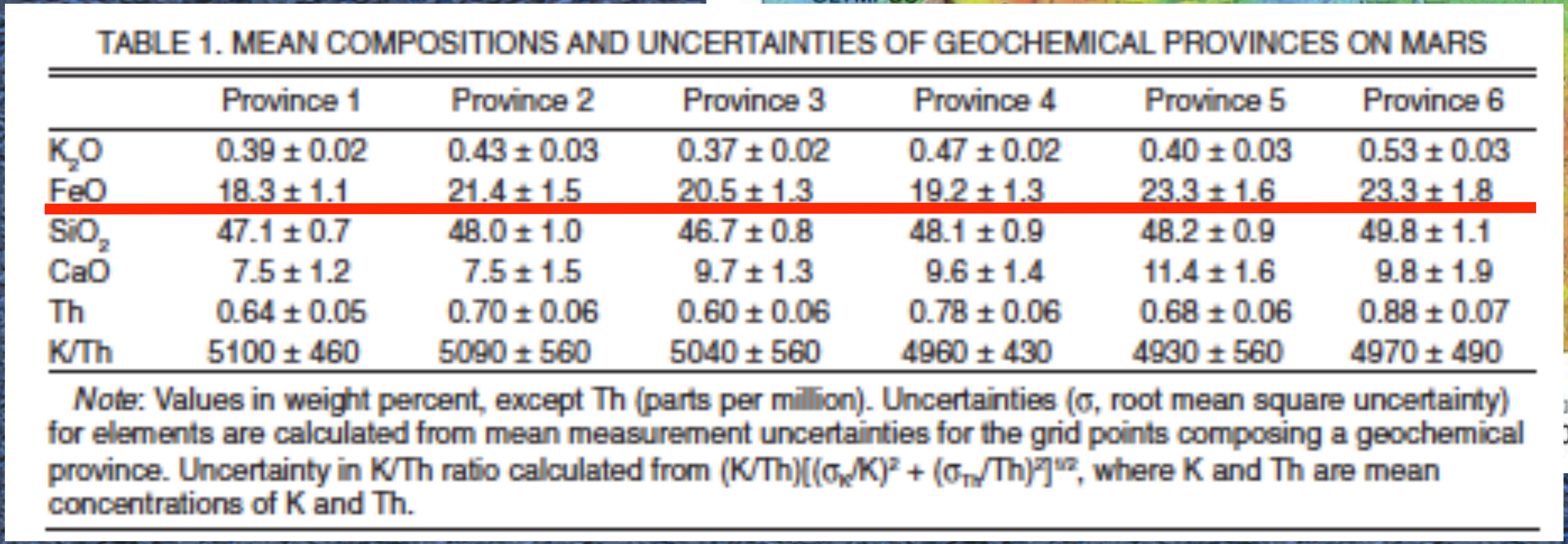
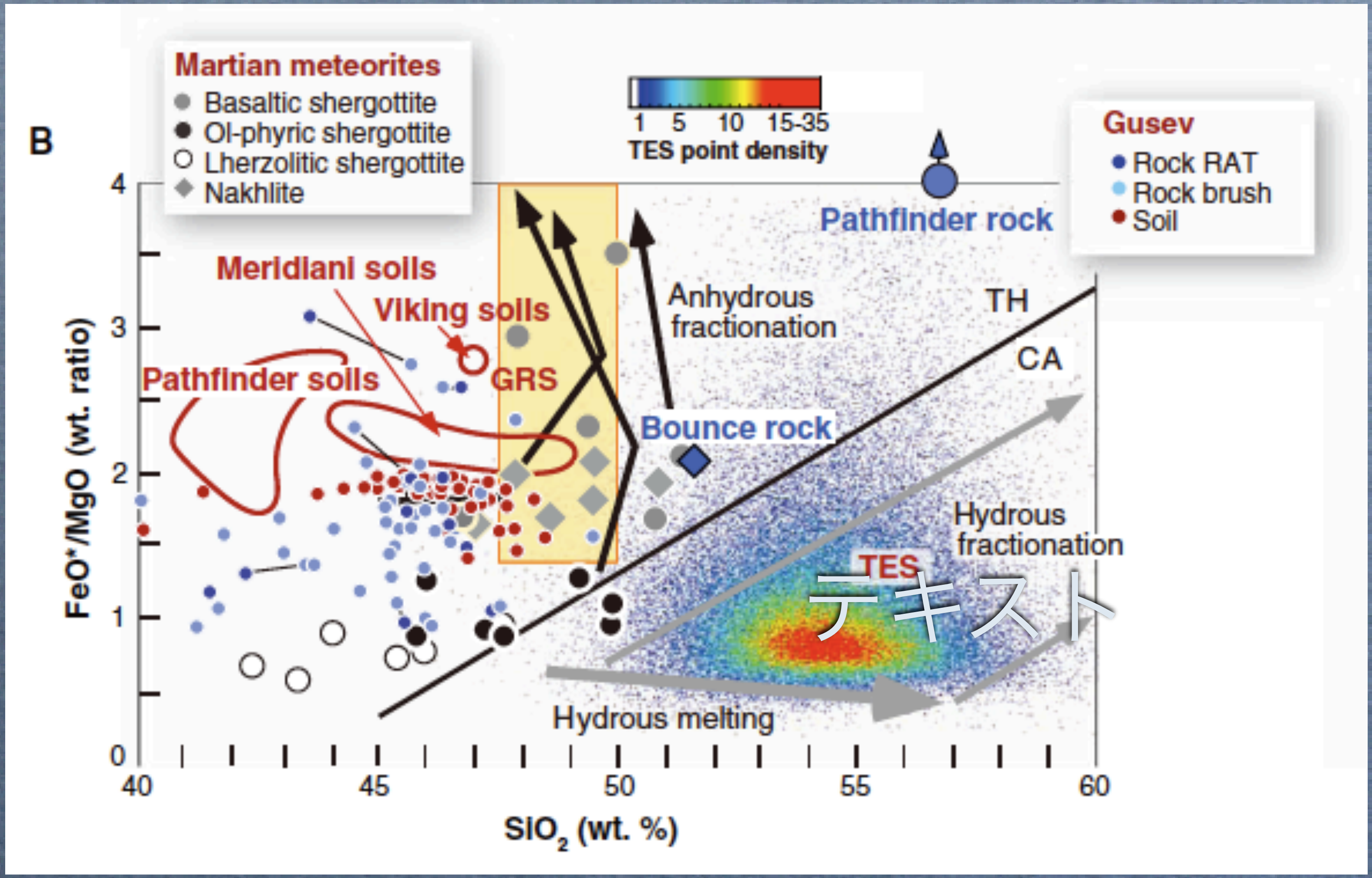


TABLE 1. MEAN COMPOSITIONS AND UNCERTAINTIES OF GEOCHEMICAL PROVINCES ON MARS

	Province 1	Province 2	Province 3	Province 4	Province 5	Province 6
K_2O	0.39 ± 0.02	0.43 ± 0.03	0.37 ± 0.02	0.47 ± 0.02	0.40 ± 0.03	0.53 ± 0.03
FeO	18.3 ± 1.1	21.4 ± 1.5	20.5 ± 1.3	19.2 ± 1.3	23.3 ± 1.6	23.3 ± 1.8
SiO_2	47.1 ± 0.7	48.0 ± 1.0	46.7 ± 0.8	48.1 ± 0.9	48.2 ± 0.9	49.8 ± 1.1
CaO	7.5 ± 1.2	7.5 ± 1.5	9.7 ± 1.3	9.6 ± 1.4	11.4 ± 1.6	9.8 ± 1.9
Th	0.64 ± 0.05	0.70 ± 0.06	0.60 ± 0.06	0.78 ± 0.06	0.68 ± 0.06	0.88 ± 0.07
K/Th	5100 ± 460	5090 ± 560	5040 ± 560	4960 ± 430	4930 ± 560	4970 ± 490

Note: Values in weight percent, except Th (parts per million). Uncertainties (σ, root mean square uncertainty) for elements are calculated from mean measurement uncertainties for the grid points composing a geochemical province. Uncertainty in K/Th ratio calculated from $(K/Th)[(\sigma_K/K)^2 + (\sigma_{Th}/Th)^2]^{1/2}$, where K and Th are mean concentrations of K and Th.

Taylor et al. Geol. 38,183 (2010)



McSween et al.Sci. 324,736 (2009)

鉄の多い系で地殻下部はどうなるのか？

Basalt-Eclogite Transition

Ca Plagioclase-Grossular Garnet **Garnet Granulite**

2.75 3.59

$\mathbf{CaAl_2Si_2O_8}$ $\mathbf{Ca_3Al_2(SiO_4)_3}$

Na Feldspar-Jadite **Eclogite**

2.98 3.39

$\mathbf{NaAl_Si_3O_8}$ $\mathbf{NaAl_Si_2O_6}$

Basalt-Eclogite Transition

Ca Plagioclase-Grossula

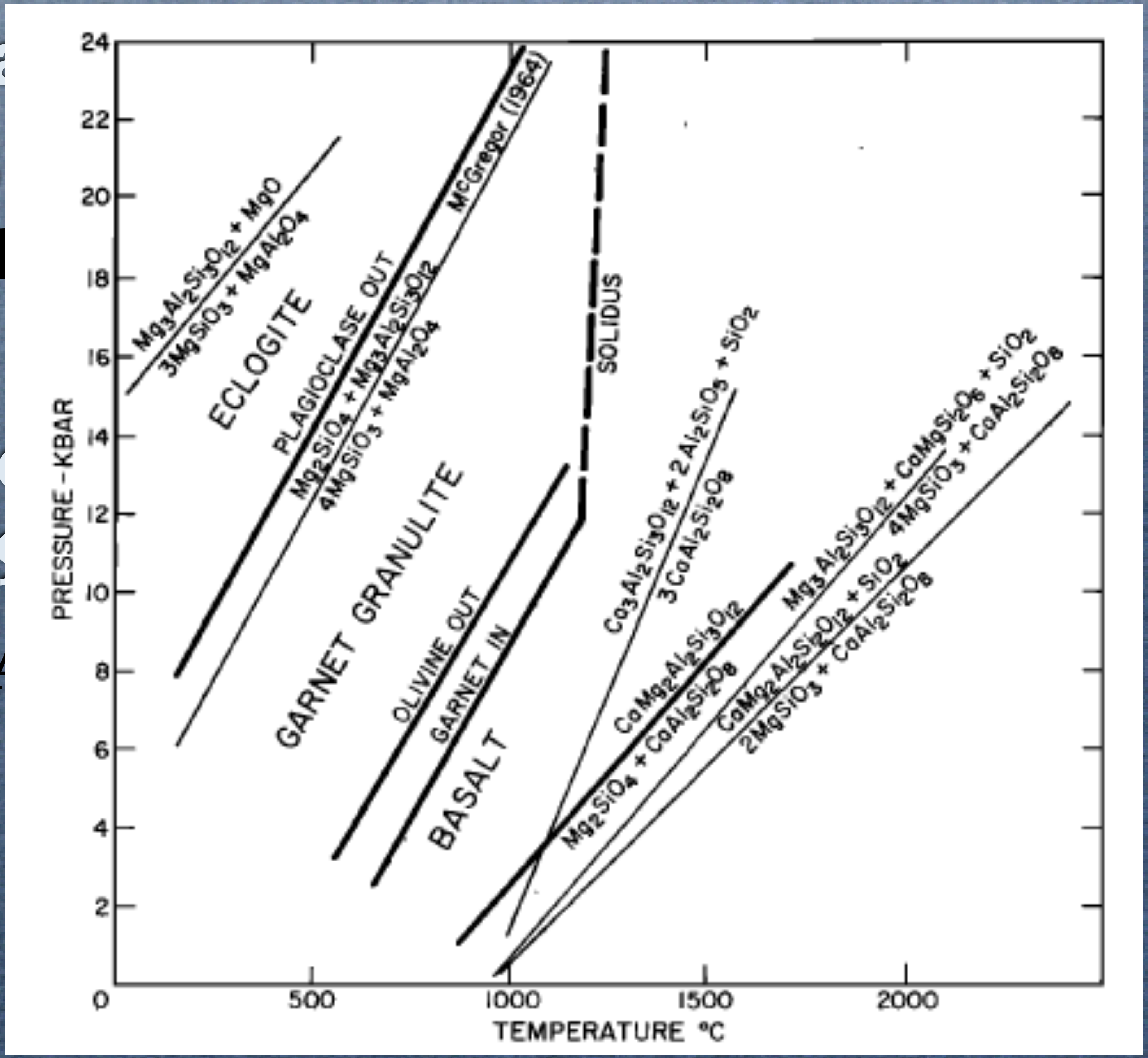
2.75 3

$CaAl_2Si_2O_8$ Ca_3Al

Na Feldspar-Jadit

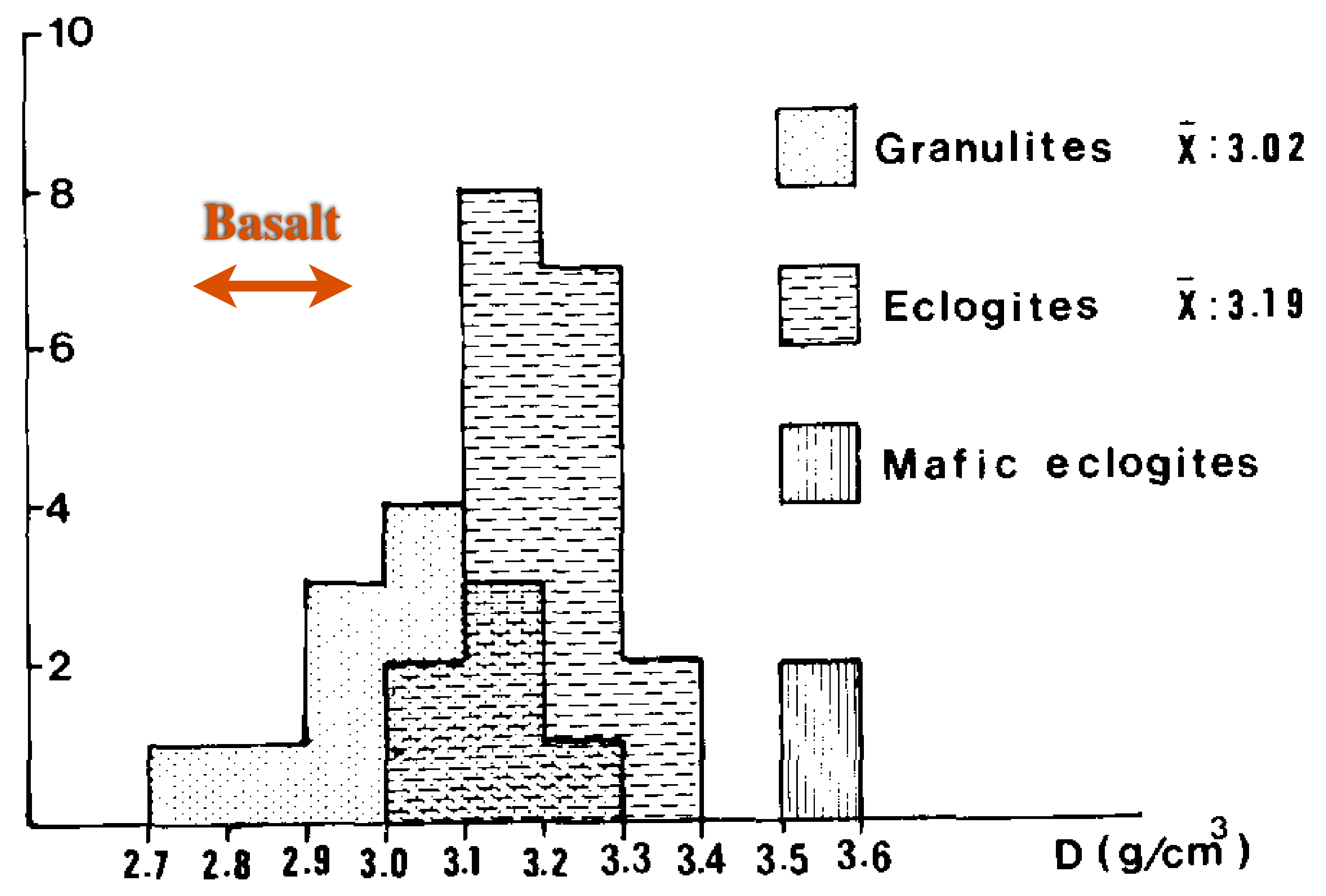
2.98 3.3

$NaAlSi_3O_8$ NaA



Density Data

EPSL81,211 (1987)
Austrheim



方法：

- 内部整合的熱力学データセットを用いた，相平衡計算

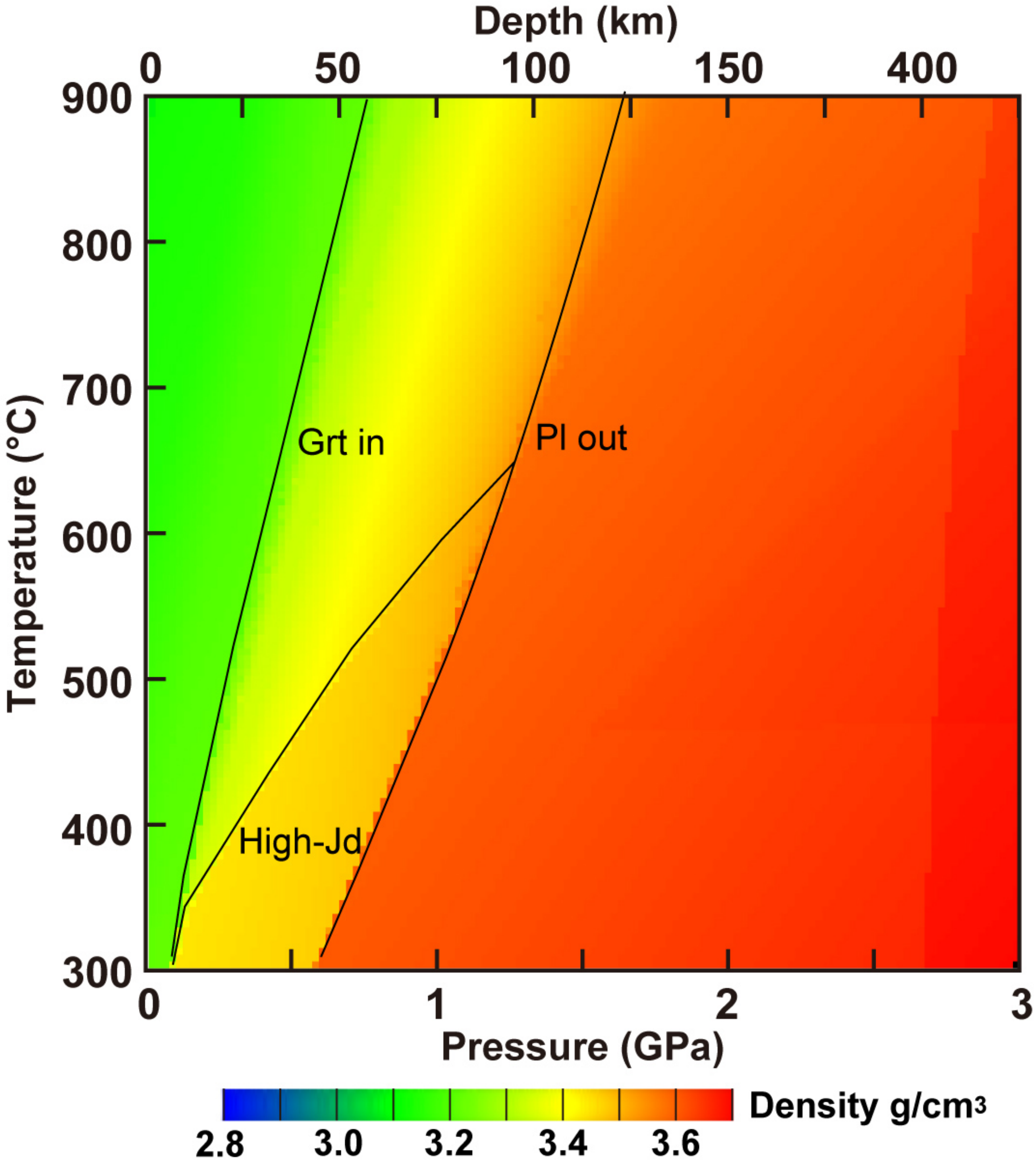
  Holland and Powell (1998 & updates)
  Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-H_2O 系

- 相平衡計算プログラム　Perplex 7 (Connolly, 2005)

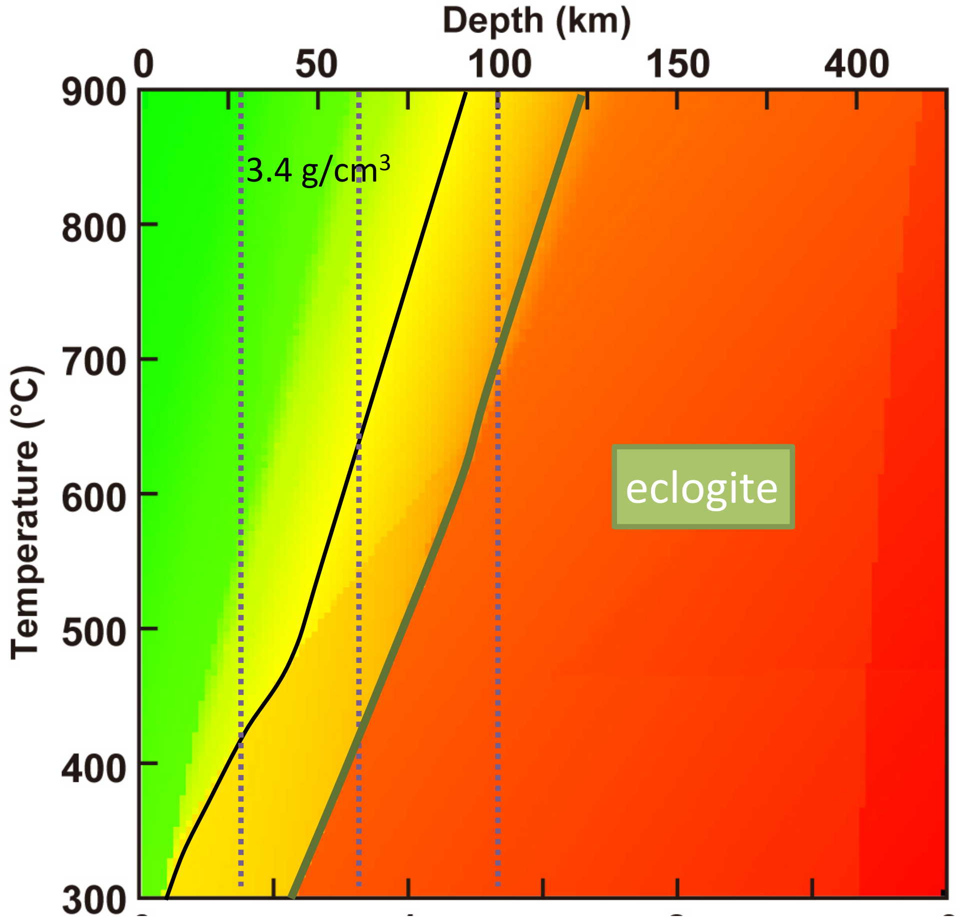
- 玄武岩質シャーゴッタイトの全岩組成　± H_2O

  1. Los Angels (Warren et al. 2000)
  2. Dhofar 378 (feldspasic: Ikeda et al., 2006)

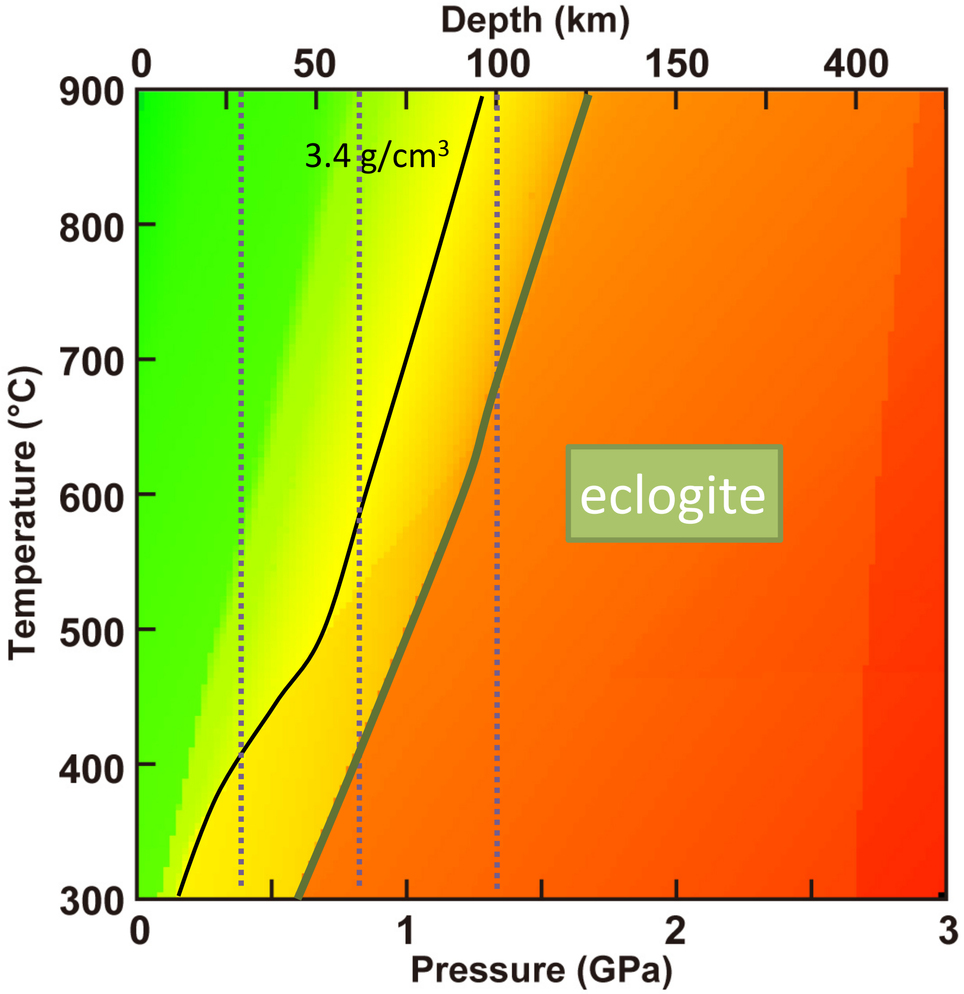
Mars Los Angeles dry

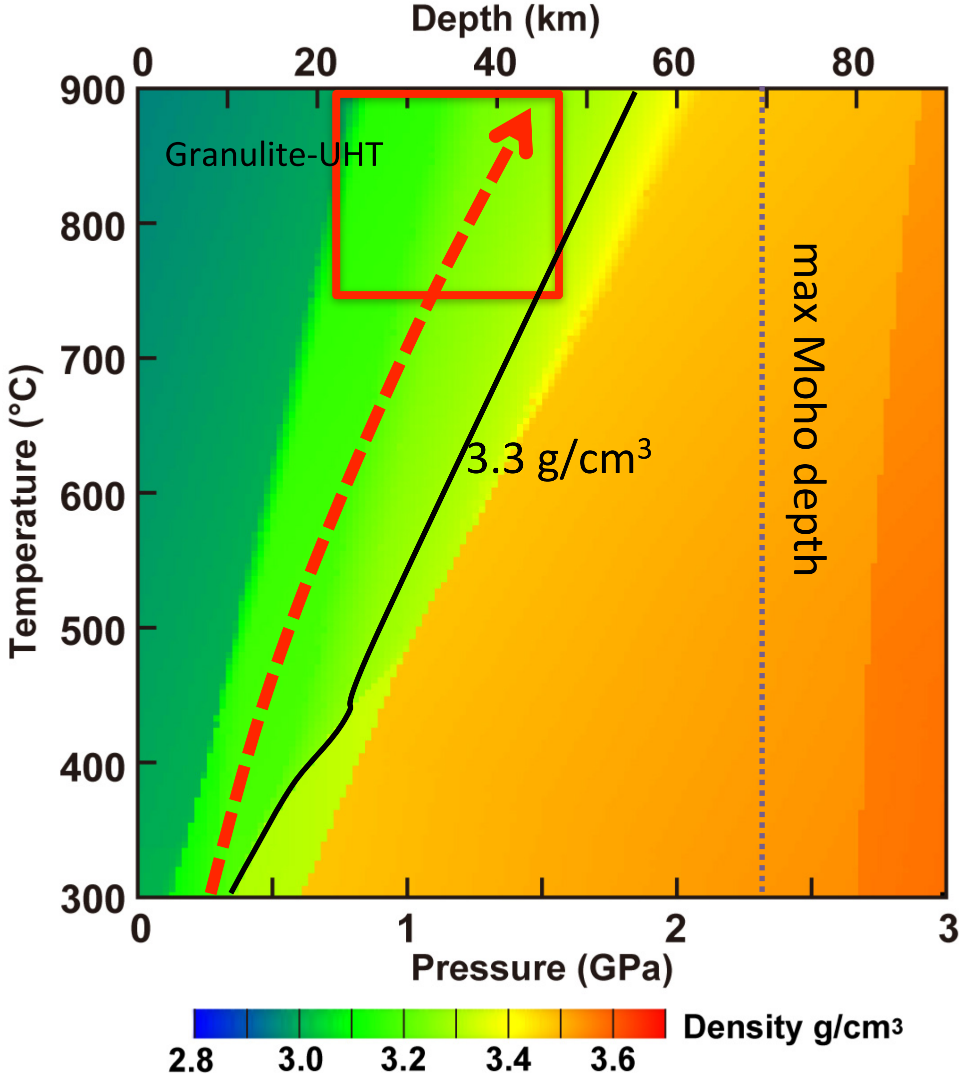


Los Angeles dry



Dhofar 378 dry





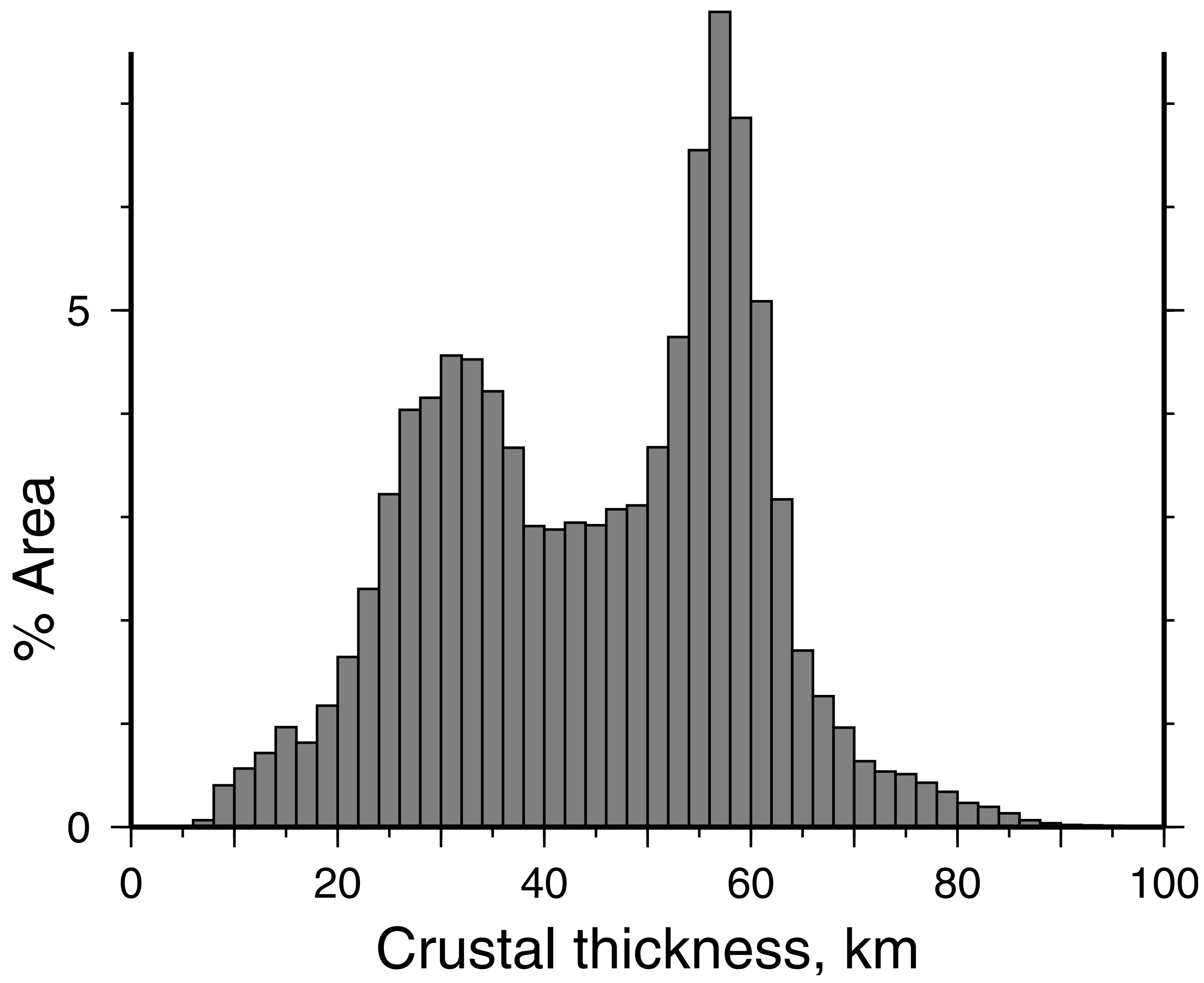
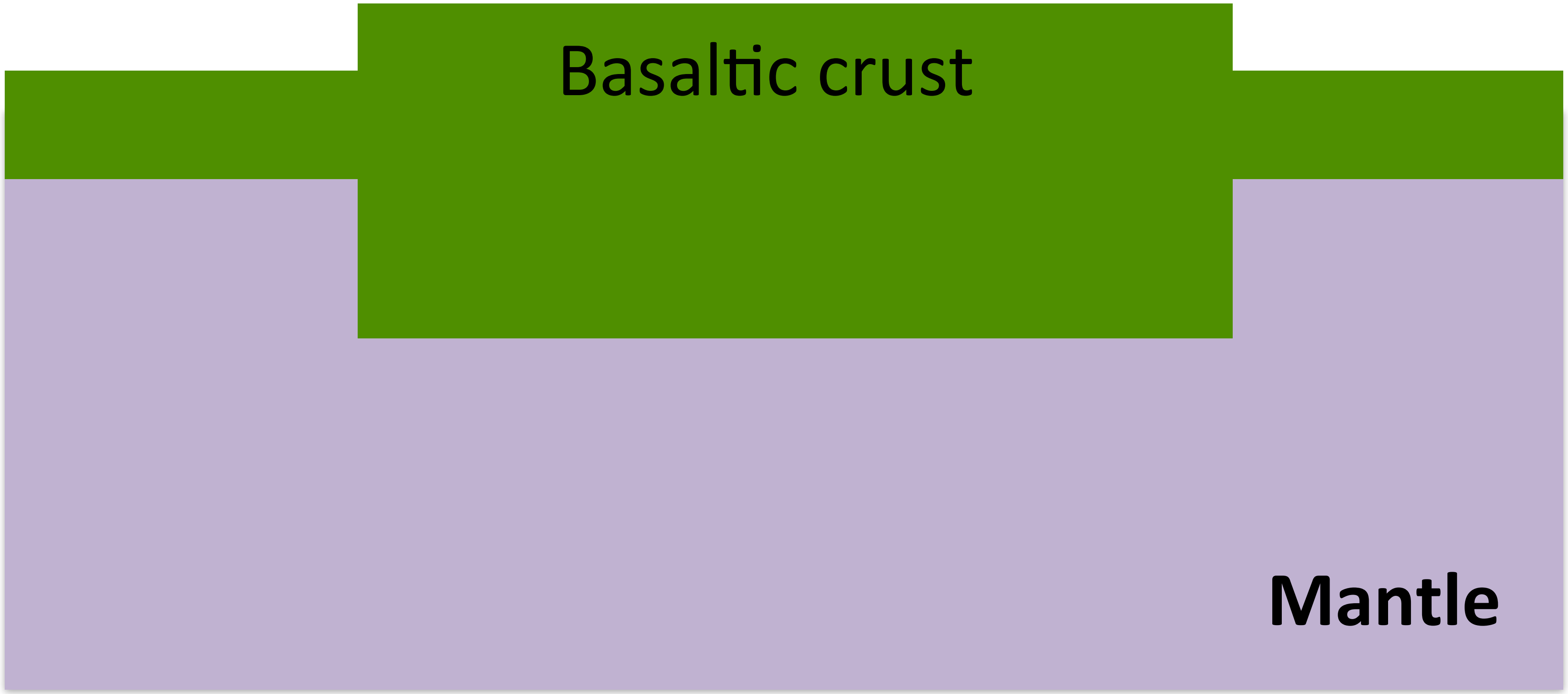


Figure 5. Histogram of crustal thickness, the difference between surface and mantle relief, versus area.

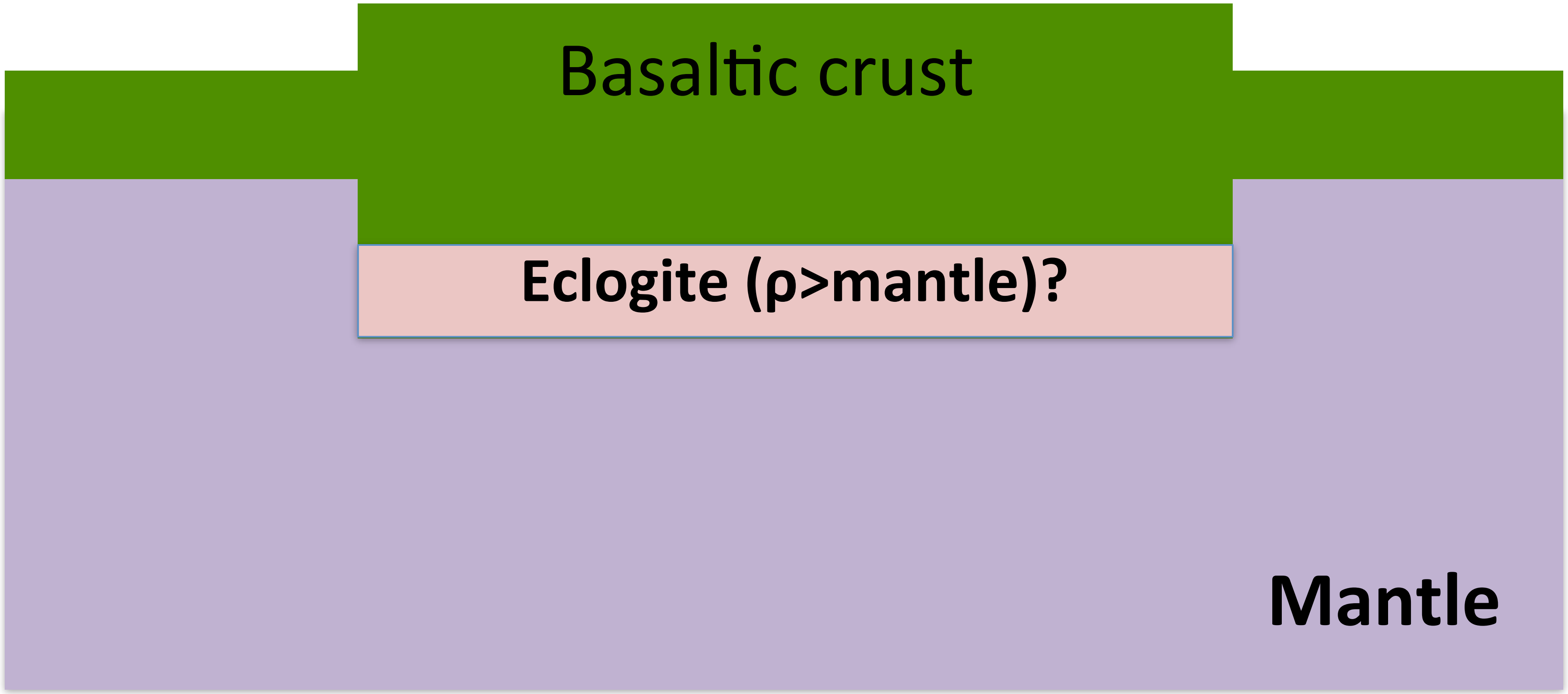
with density contrast:600kg/m^3 and 2900kg/m^3
crustal thickness range: 5~105 km

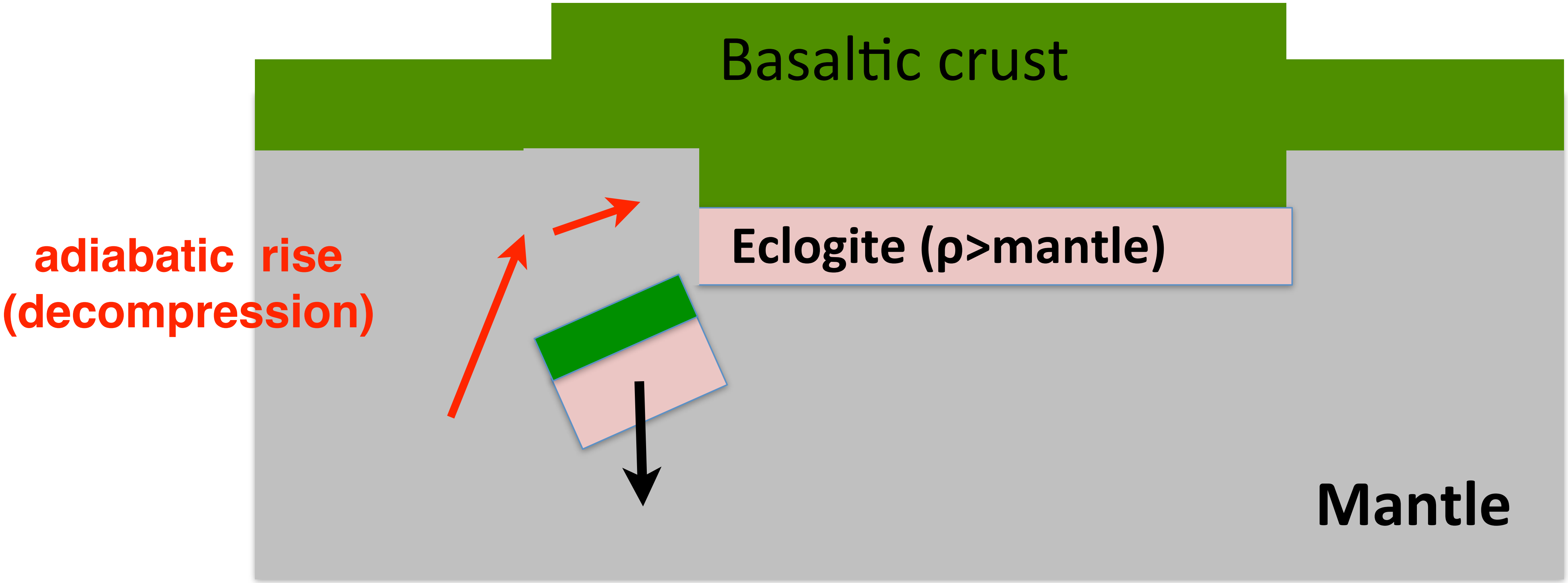
Neumann et al. JGR 109E,2004

背景



背景





Basaltic crust

Eclogite (ρ>mantle)

adiabatic rise
(decompression)

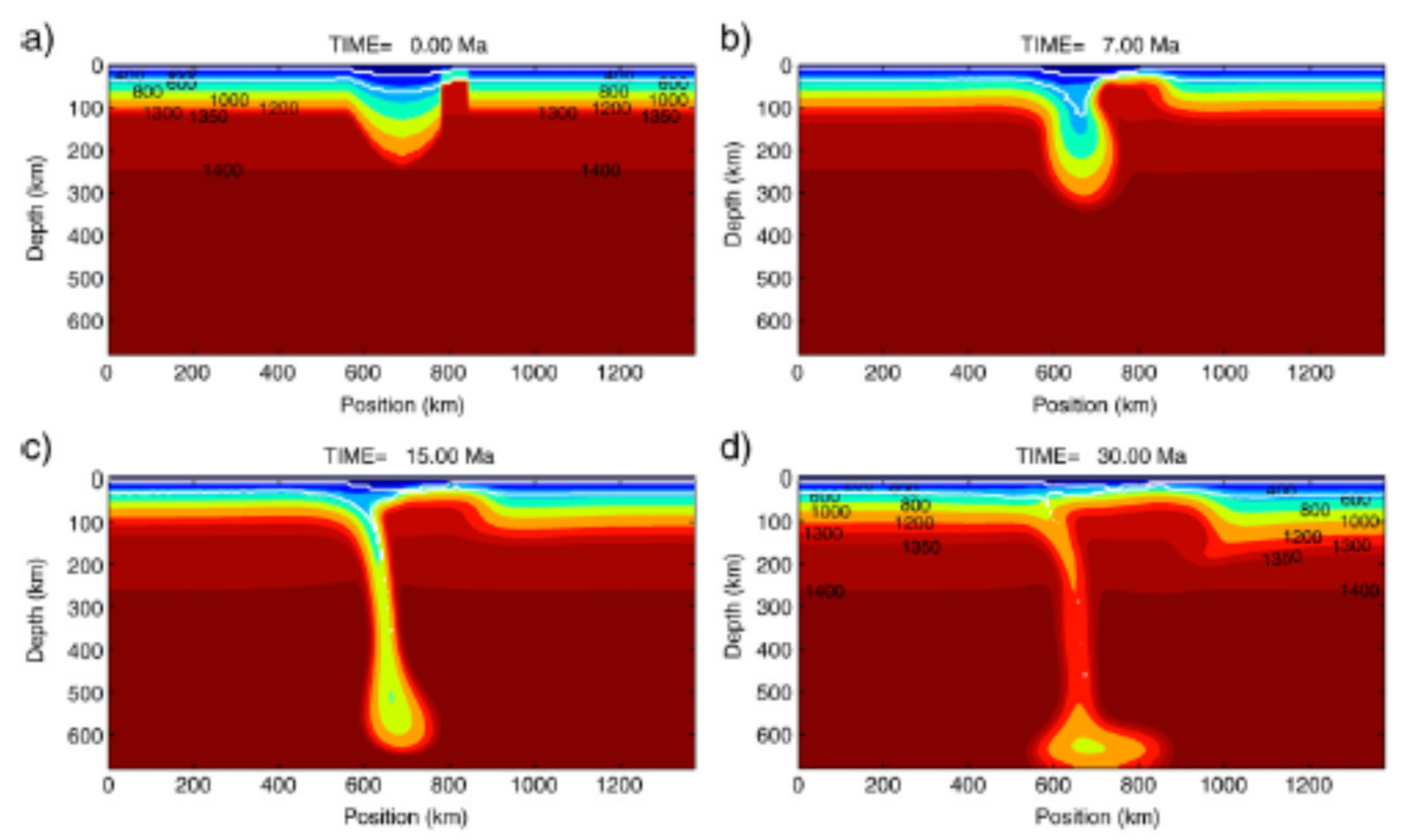
Mantle

Delamination

adiabatic rise of mantle material induced by delamination (decompressional melting)

Deep and near-surface consequences of root removal by asymmetric continental delamination

Valera et al.,Tectonophys. 502 (2011) 257-265



問題　：Delamination-Induce Volcanism の実態？

1. タイムスケールは？
    1. 基本的にはRayleigh-Taylor Instability、しかし下部地殻はviscoplastic,non-Newtonian. レオロジーの正当な取り扱いは未知.
    2. RTIから融解へはもうワンステップ必要.
        1. 断熱上昇過程、粘性散逸・Viscous Heating
2. 表面形状は？
    1. CEP,Utopia では割れ目噴火（2次元形状）.
3. 融解が生じる条件
    1. 上部マントルがソリダス近傍の温度状態にあること
    2. 水の存在？

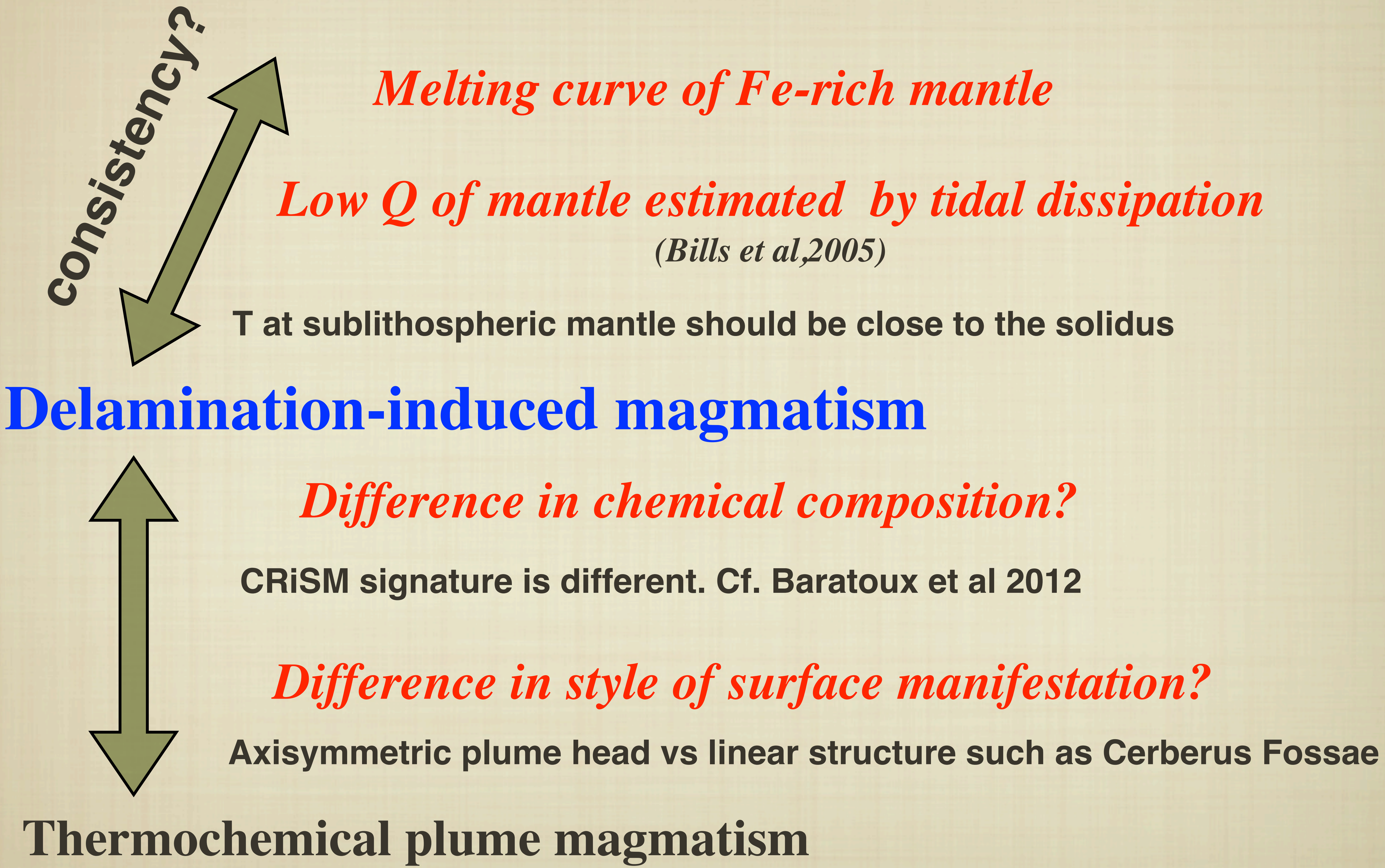
クリックしてタイトルを入力

クリックしてサブタイトルを入力

問題　：地球上に類似火山はないか？

Garrotxa Volcanic Zone の紹介

Future perspectives



Melting curve of Fe-rich mantle

Low Q of mantle estimated by tidal dissipation

(Bills et al,2005)

T at sublithospheric mantle should be close to the solidus

Delamination-induced magmatism

Difference in chemical composition?

CRiSM signature is different. Cf. Baratoux et al 2012

Difference in style of surface manifestation?

Axisymmetric plume head vs linear structure such as Cerberus Fossae

Thermochemical plume magmatism

最後に

- CEP は次期固体火星探査ミッション・InSight の着陸地点候補
- InSight は広帯域地震計観測が主要なテーマ

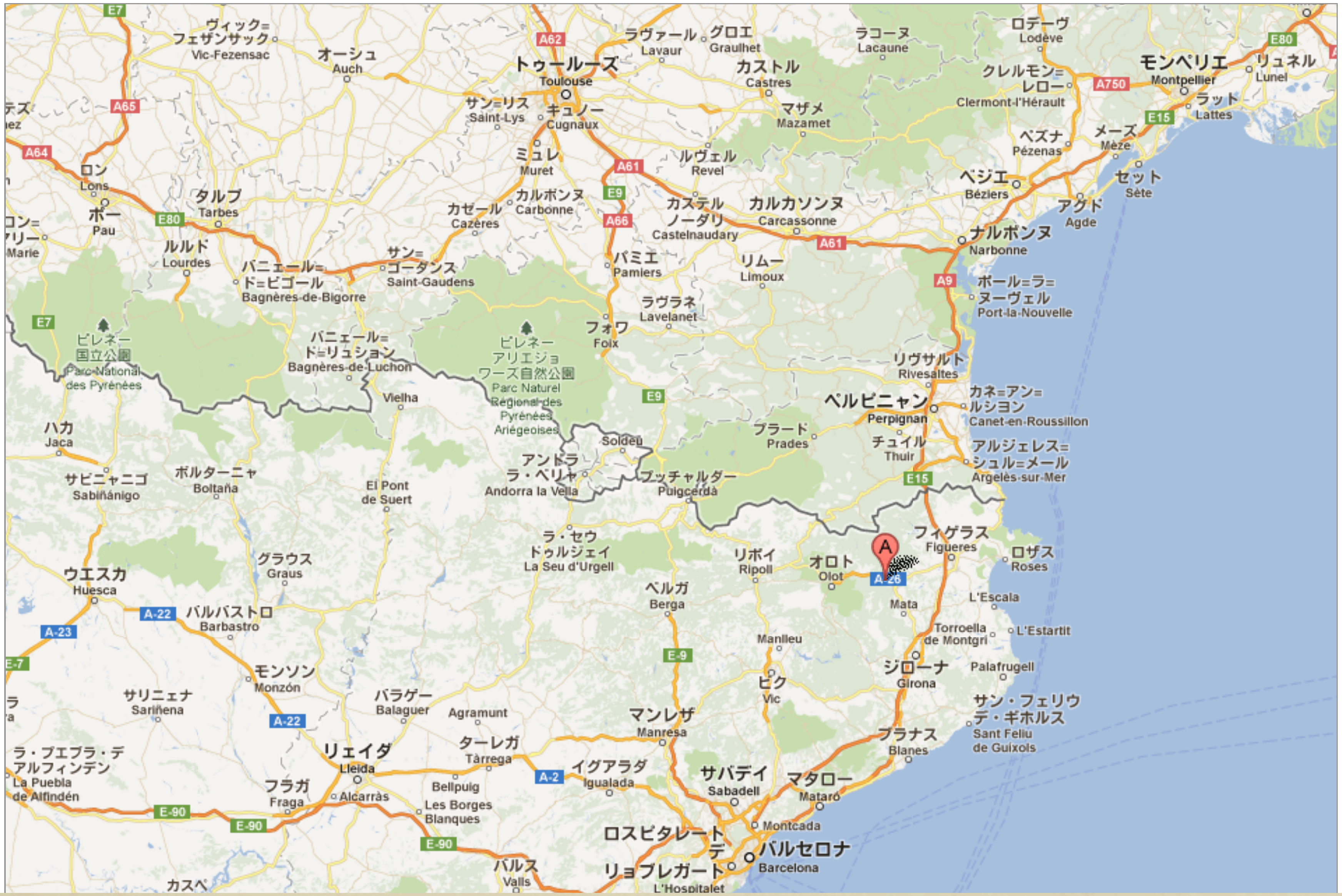
JSPS・科研費、２国間共同研究
CNRS 研究費
ANR 国際共同研究（仏・独・日）

火星の最近の火山活動と内部構造進化に関する
International Workshop の開催予定
2013年中、多分EPSC2013の直後

Castellfoli de la Roca

Google

画面上の情報をすべて見るには、印刷 をクリックします。



Map of the area

Besalú, Espanya - Google マップ

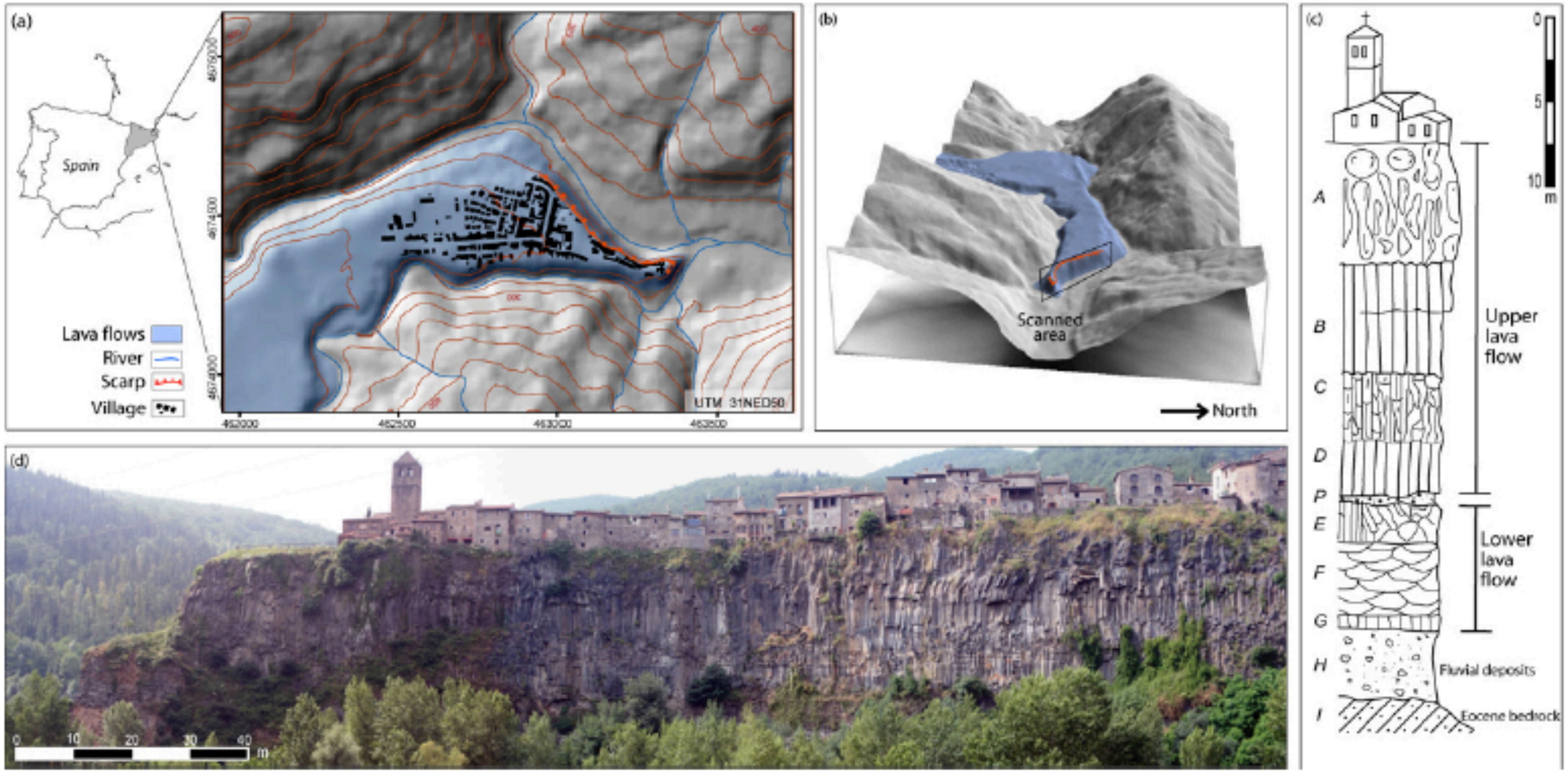
12/10/03 9:24

Google

画面上の情報をすべて見るには、印刷 をクリックします。

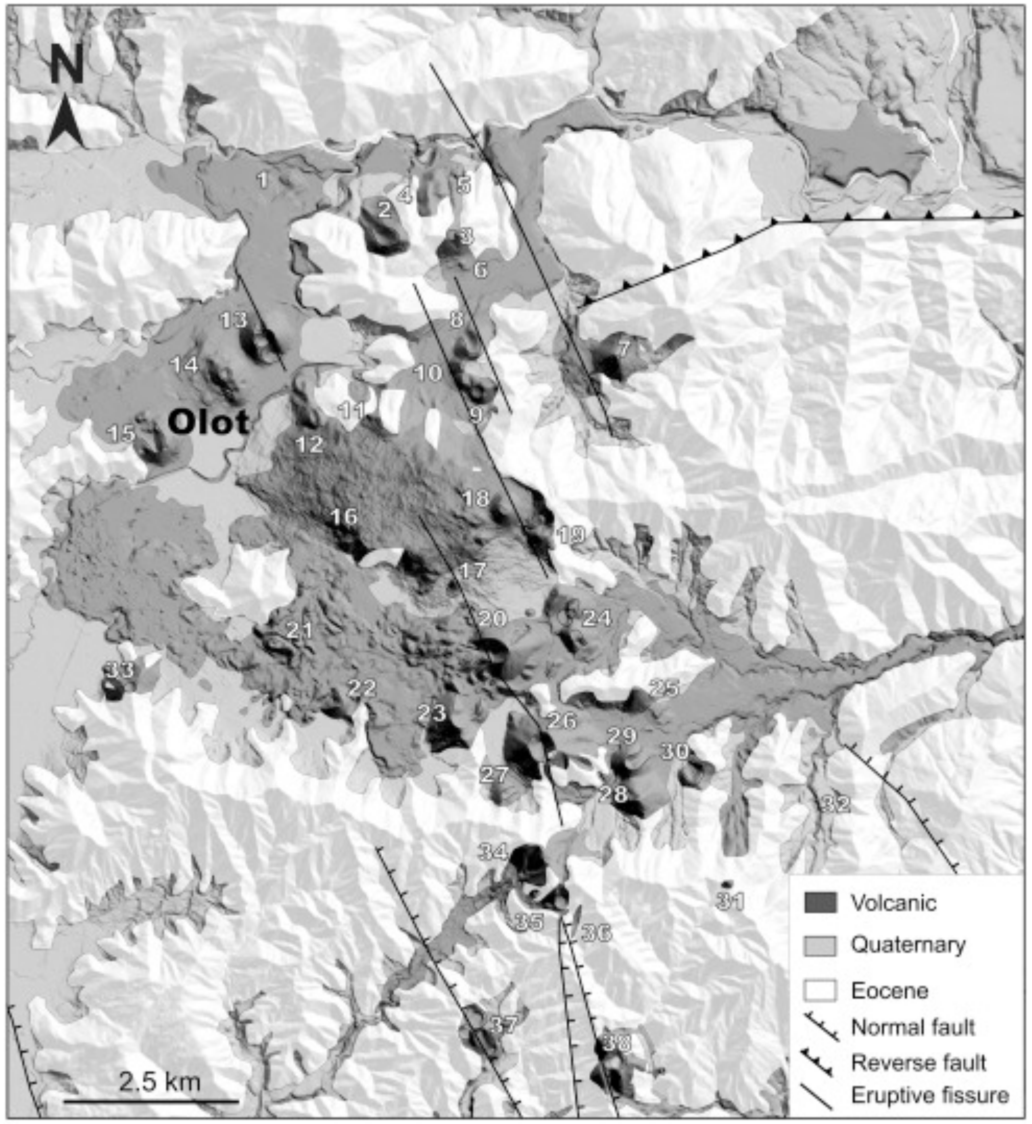
http://maps.google.co.jp/

1/2 ページ



Abellan et al, Nat.Hazards Earth System Sci.,11,829 (2011)

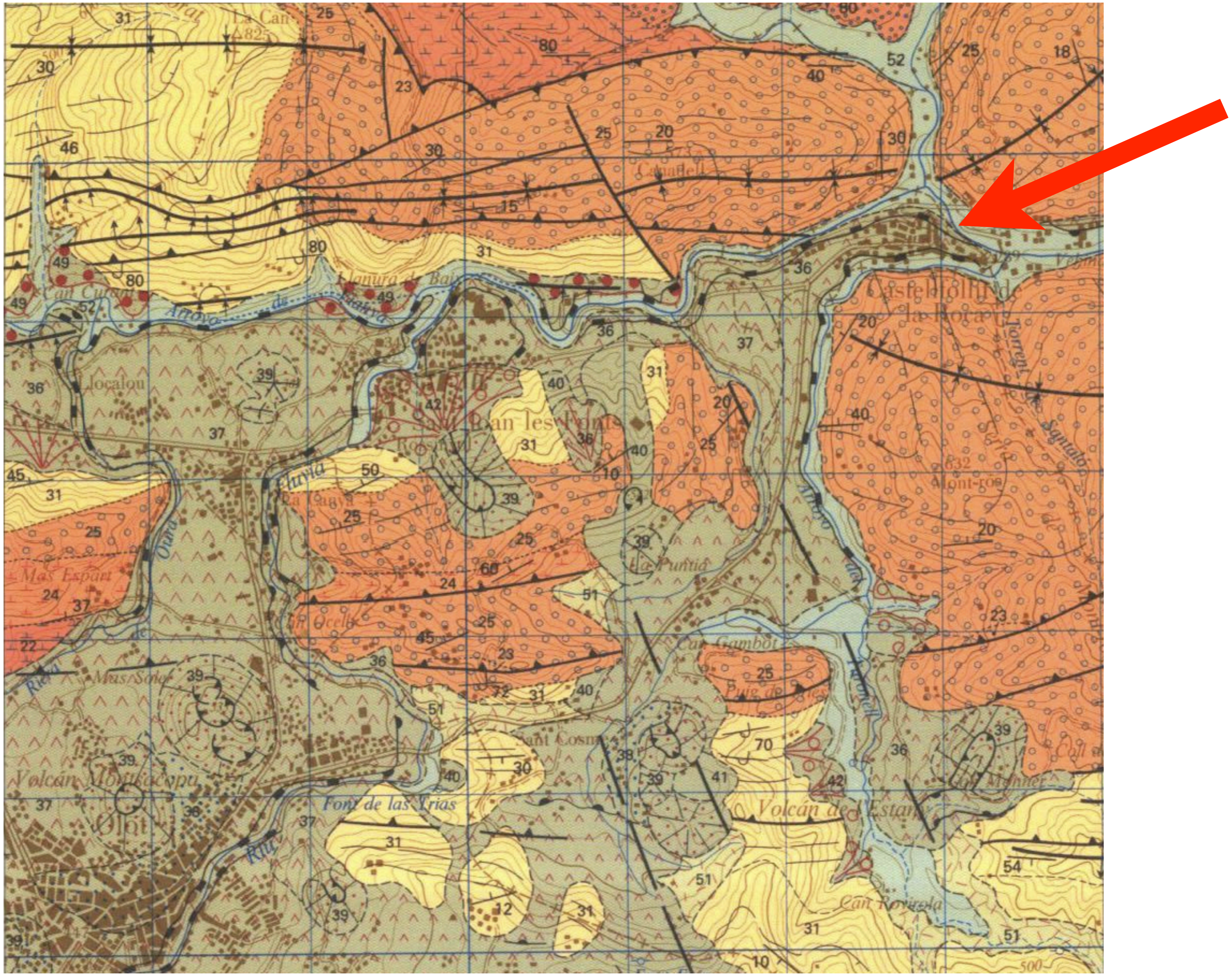
Geological Map



1 Canya
2 Aiguanegra
3 Repàs
4 Repassot
5 Cairat
6 Claperols
7 Puig de l'Ós
8 Puig de l'Estany
9 Puig de Bellaire
10 Gengí
11 Bac de les Tries
12 Bisaroques
13 Garrinada
14 Montsacopa
15 Montolivet
16 Can Barraca
17 Puig Astrol
18 Pujalós
19 Puig de la Garsa
20 Croscat
21 Cabrioler
22 Puig Jordà
23 Puig de la Costa
24 Puig de Martinyà
25 Puig de Mar
26 Santa Margarida
27 Comadega
28 Puig Subià
29 Rocanegra
30 Simon
31 Pla sa Ribera
32 Sant Jordi
33 Racó
34 Fontpobra
35 Tuta de Colltort
36 Can Tià
37 Traiter
38 Les Medes

Castellfoli de la Roca

Geological Map

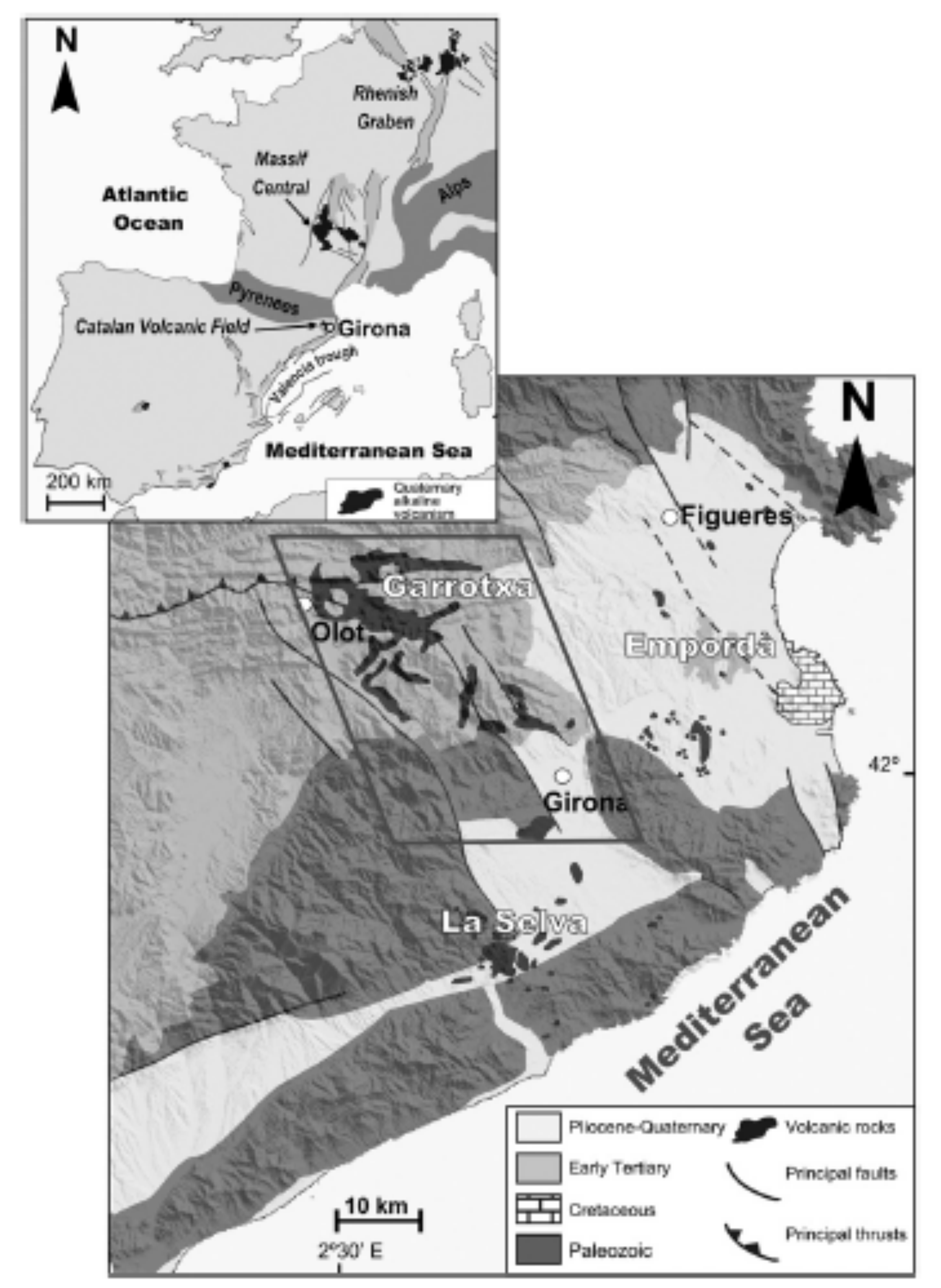


Besalu


restaurant
curia reial
bar terrassa

Girona

Catalan Volcanic Zone in east of Pyrenees



JVGR 201(2011) 178-193
Marti,Planaguma,Geyer,Canal and Pedrazzi

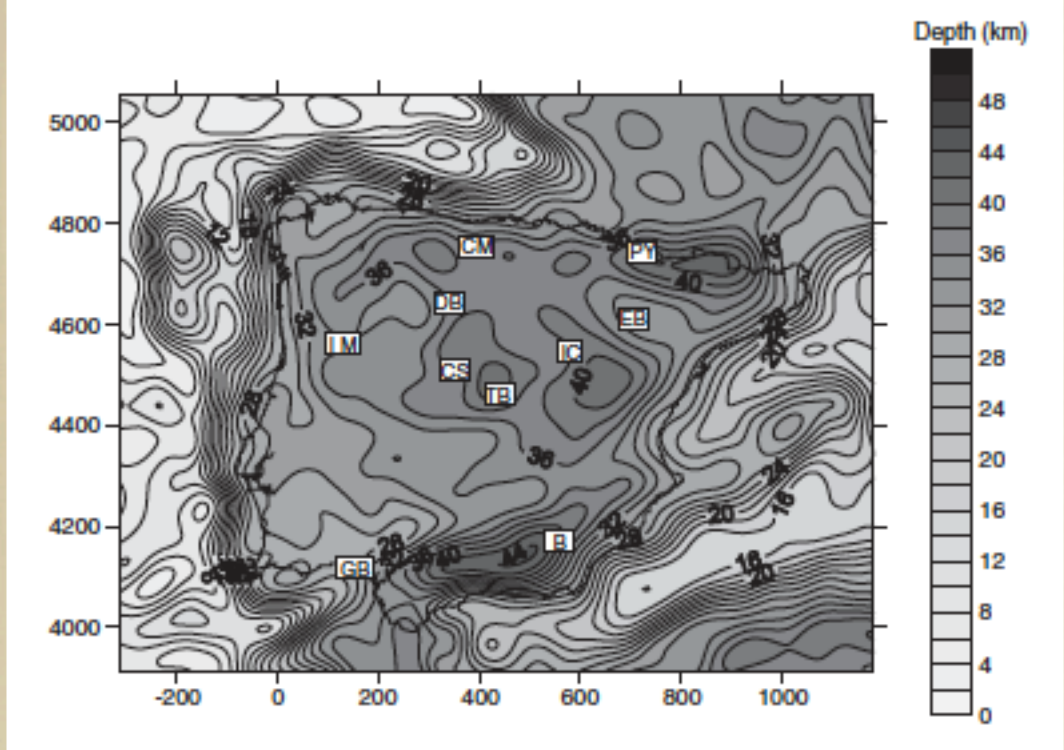
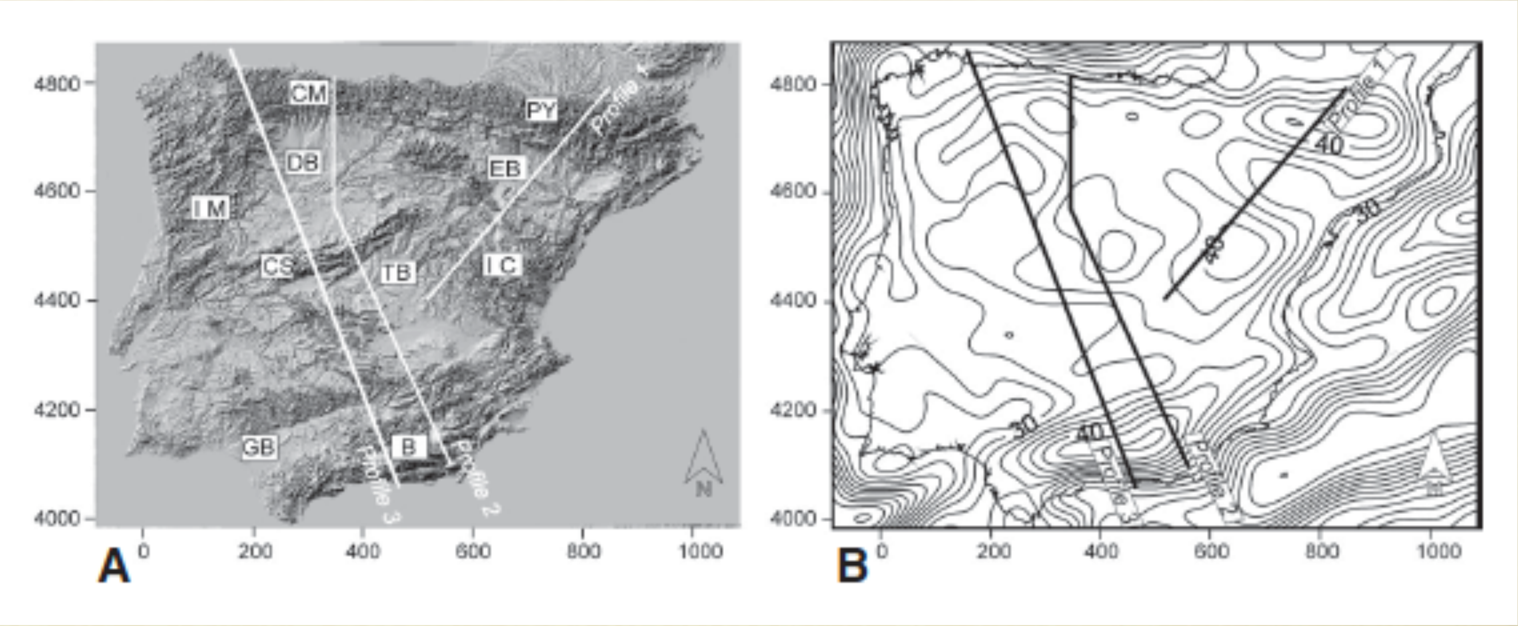
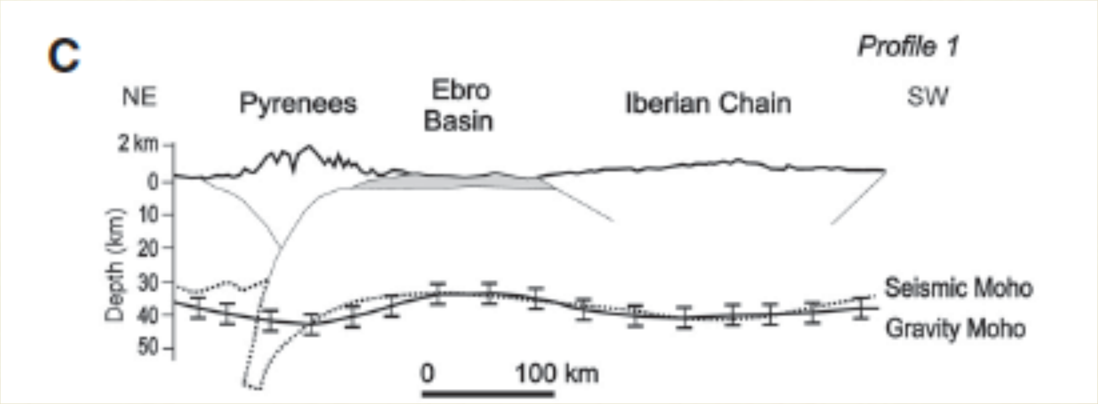
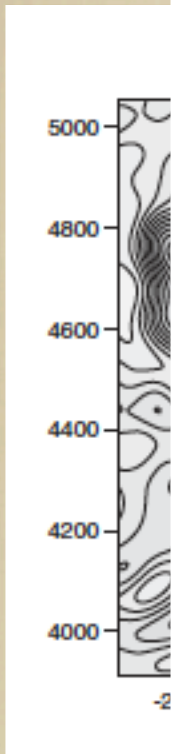


Figure 5. Gravity Moho depth map obtained by inverting the filtered gravity anomaly of Figure 4 using Tsuboi's (1979) method. UTM coordinates in kilometers, zone 30N. Abbreviations are as in Figure 2.





Catalan Volcanic Zone



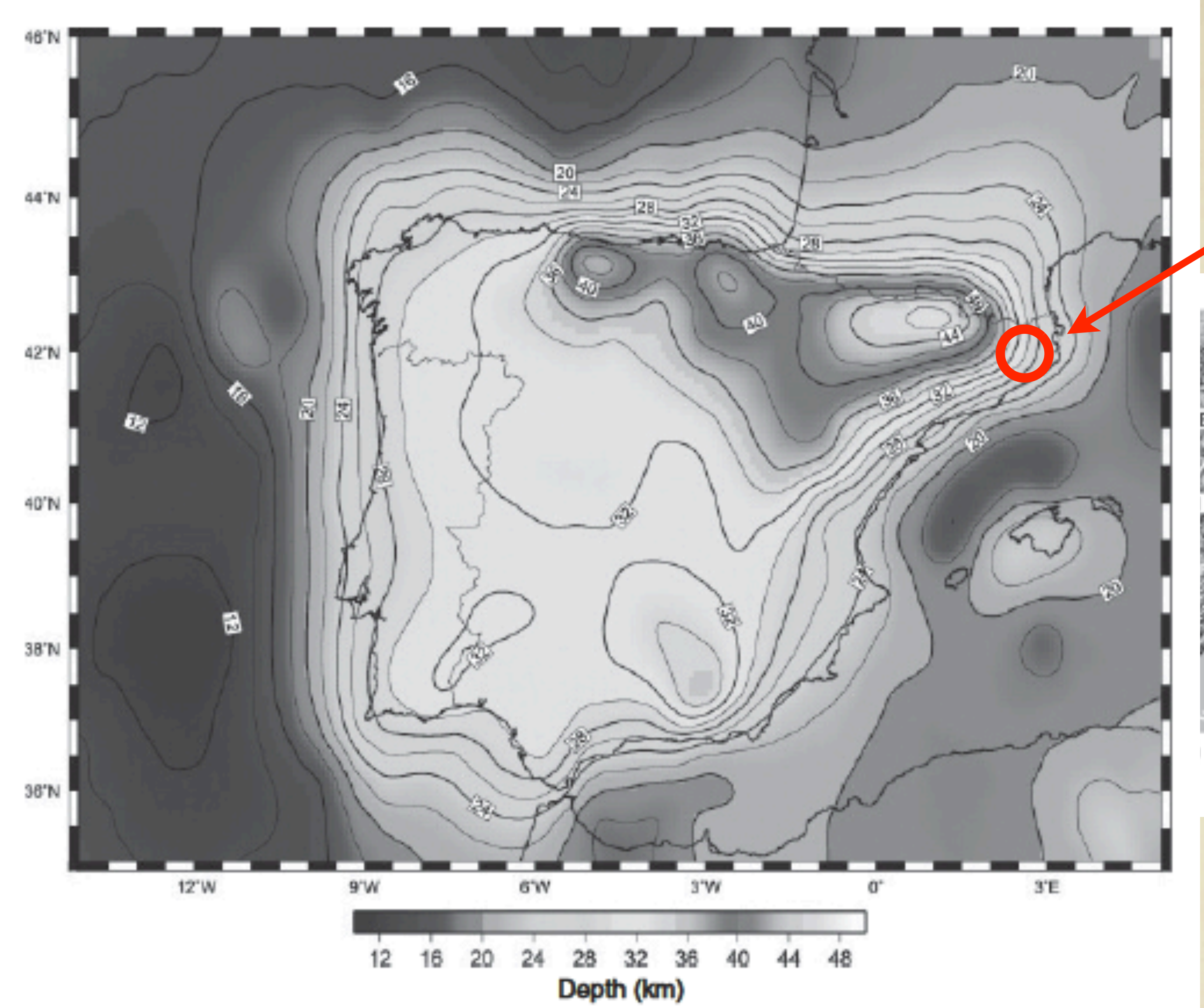
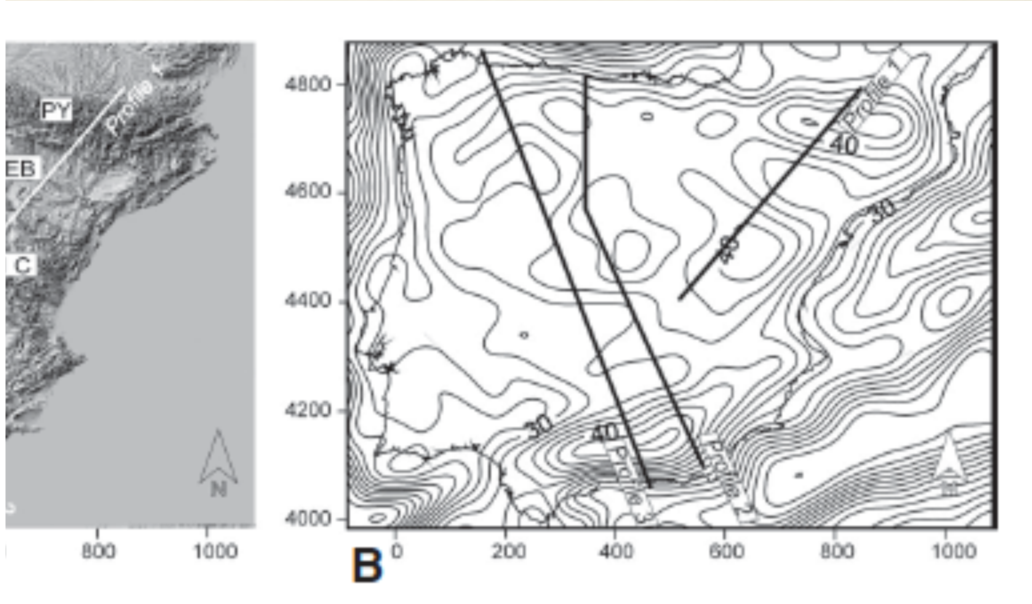
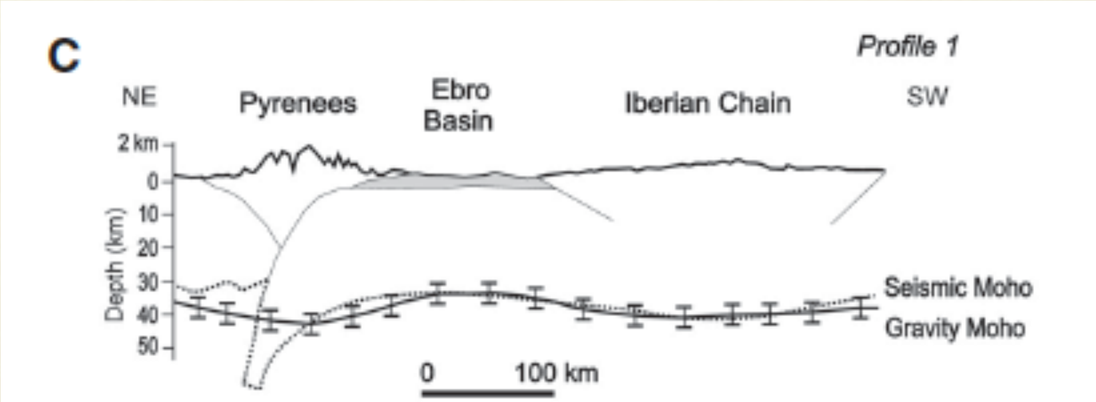
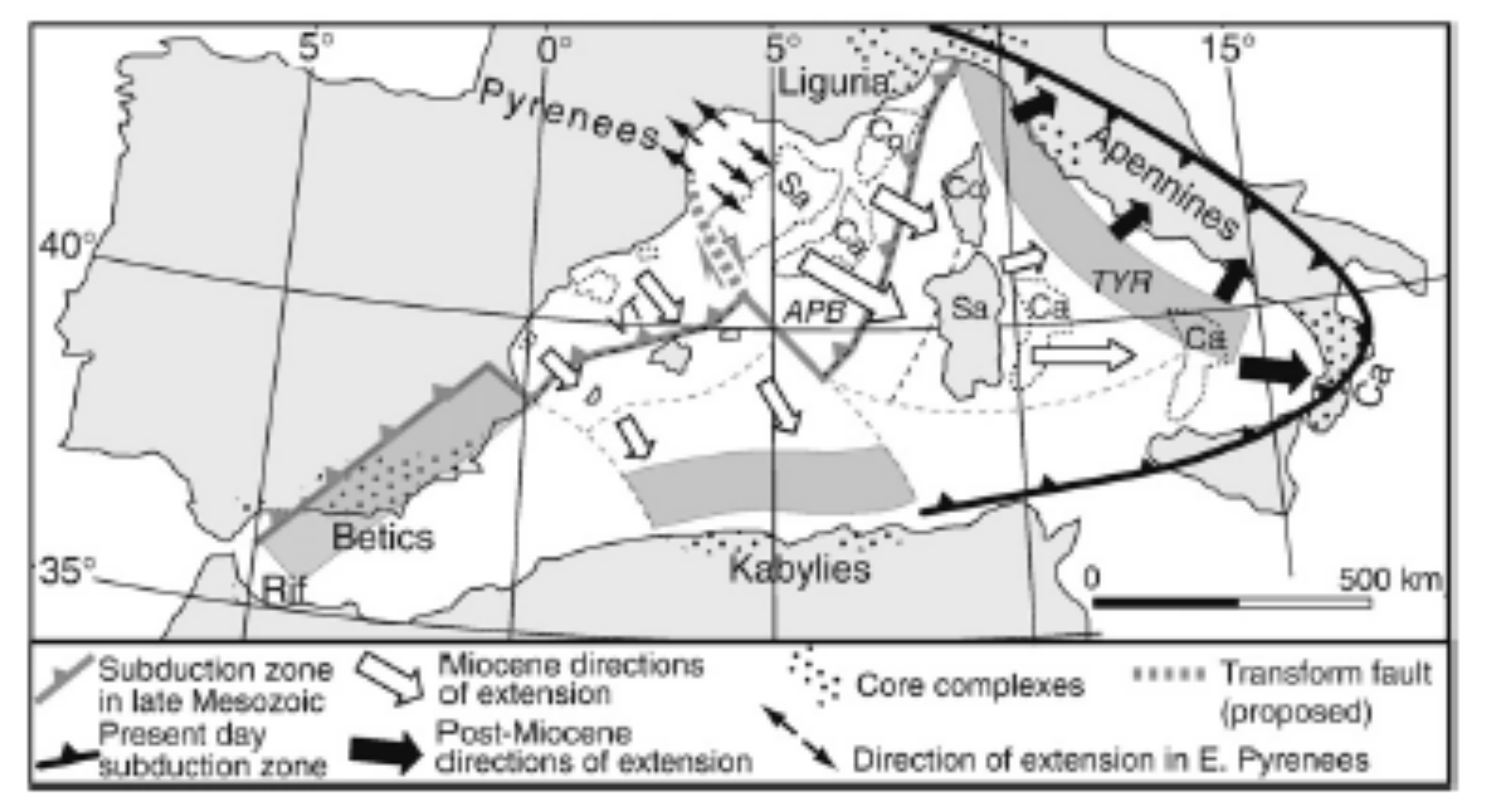
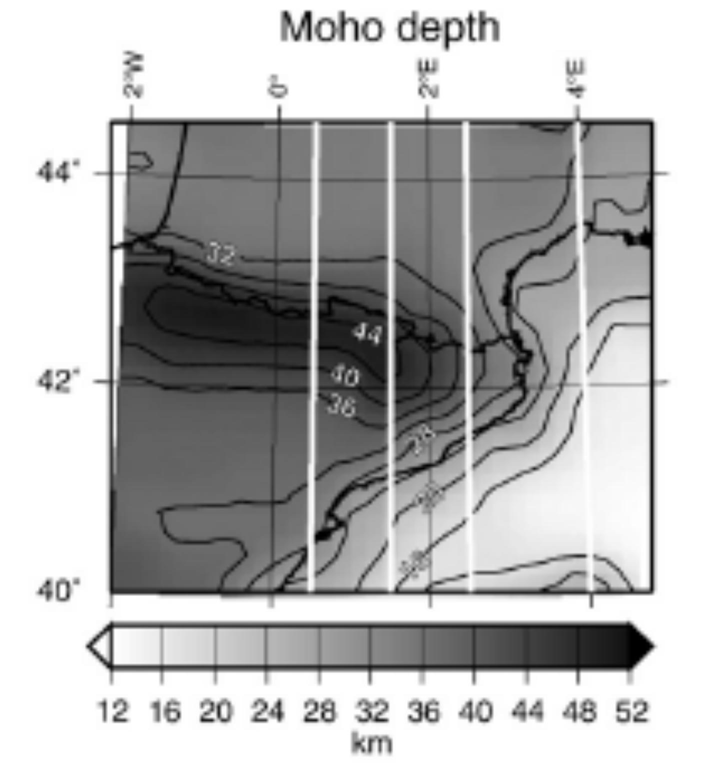


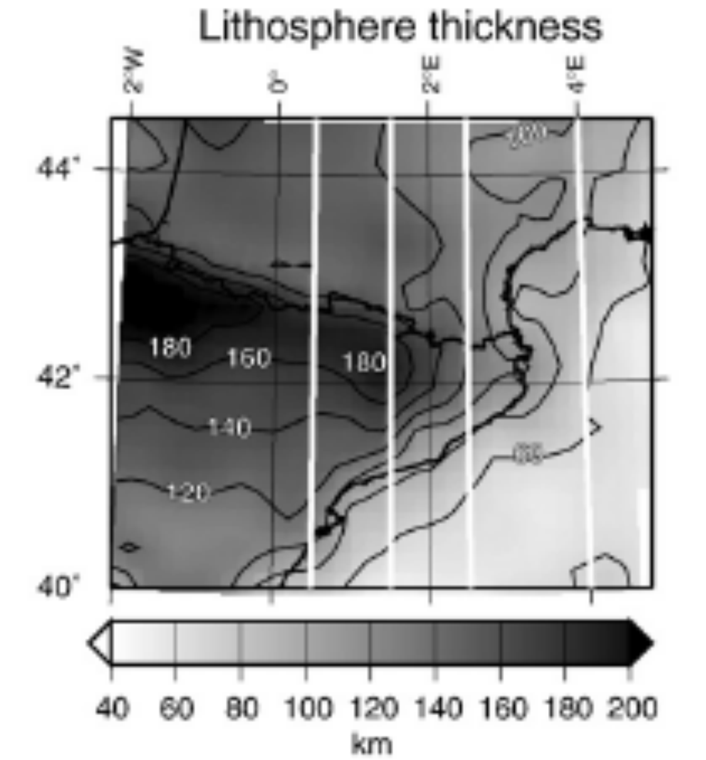
Fig
by i
of Figure 4 using Tsuboi's (1979) method.
UTM coordinates in kilometers, zone 30N.
Abbreviations are as in Figure 2.

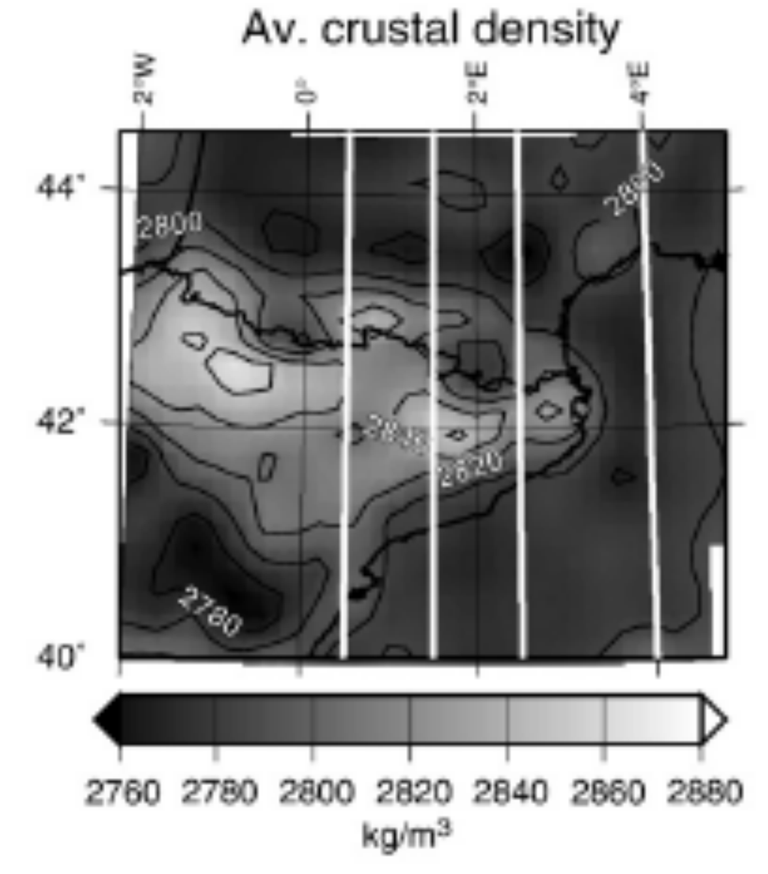







Moho depth

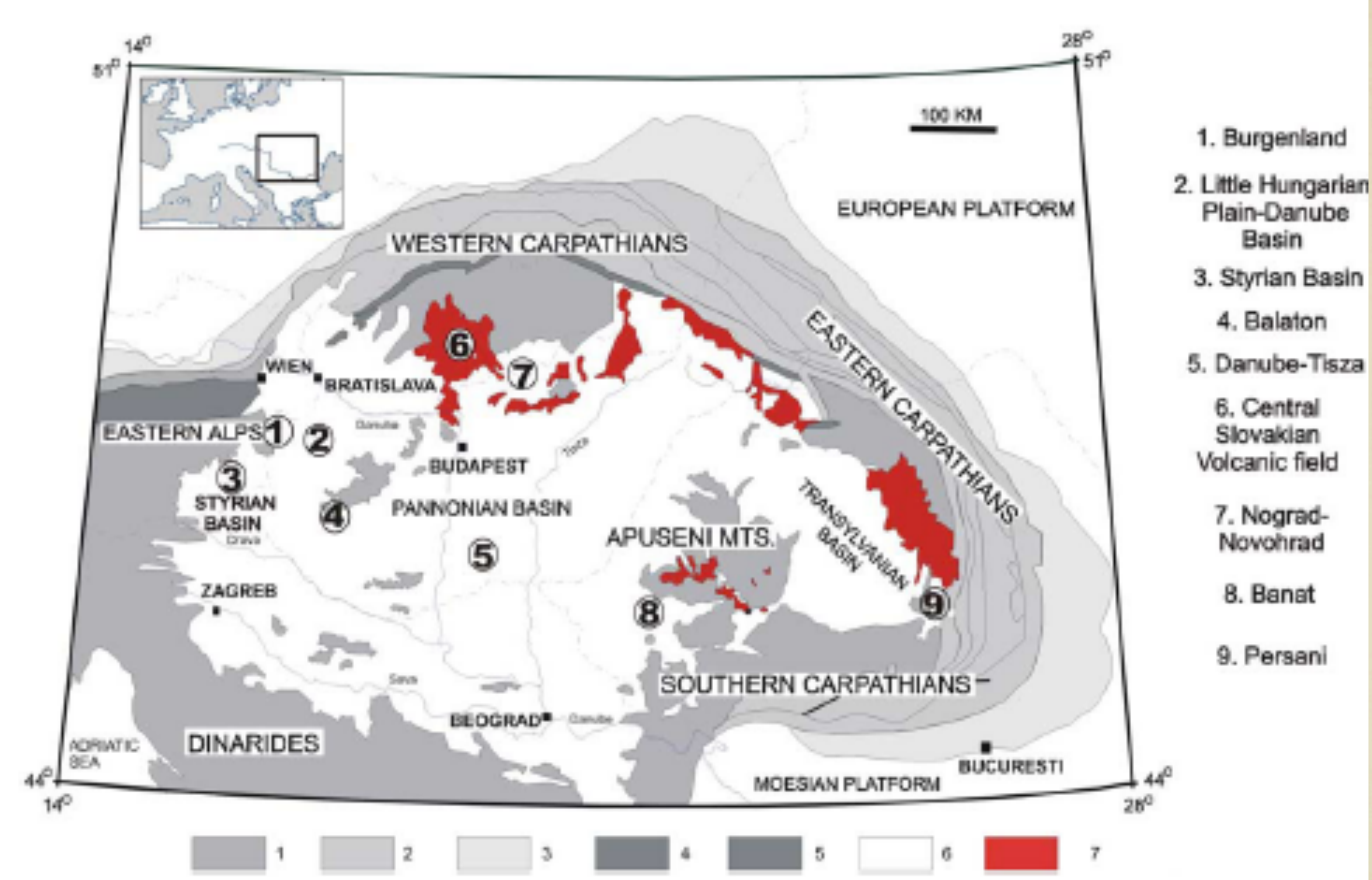

Lithosphere thickness


Av. crustal density

EPSL 276(2008) 302-313
Gunnell,Zeyen and Calvet

Volcanism at Carpathia?

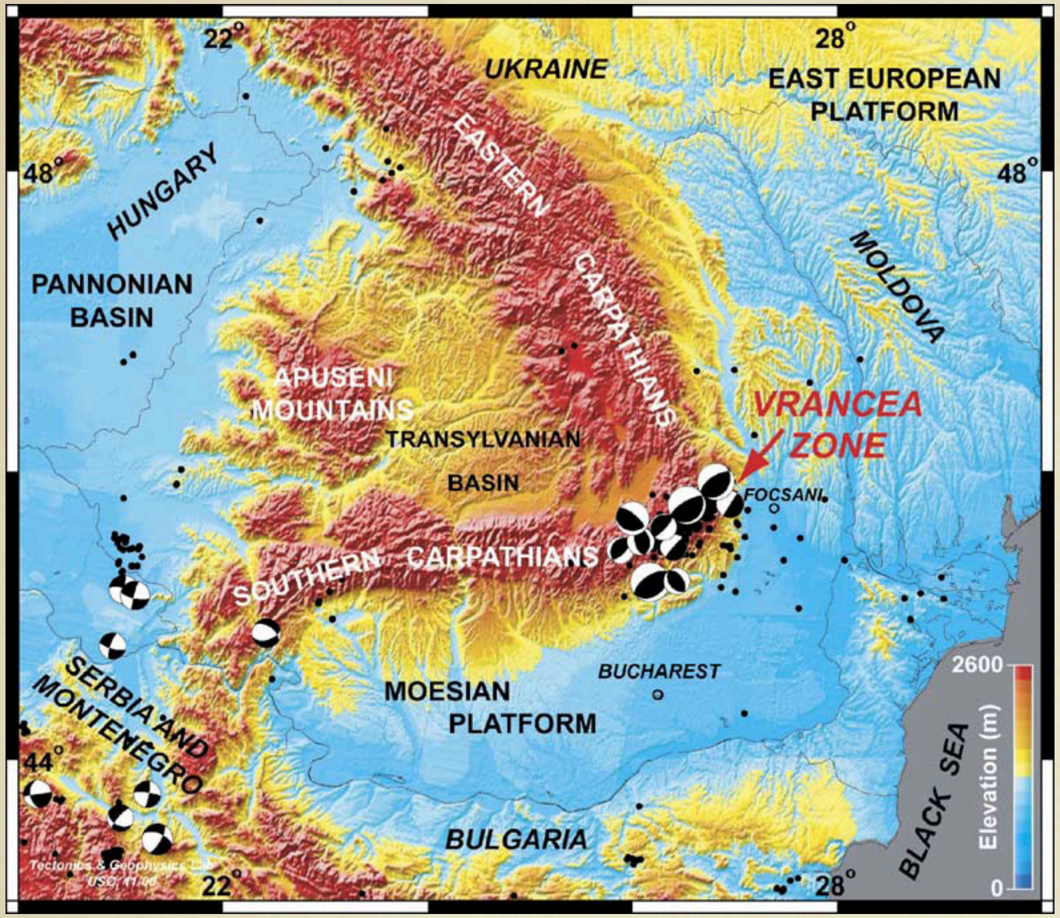
Tertiary-Quaternary mafic alkalic magmatism

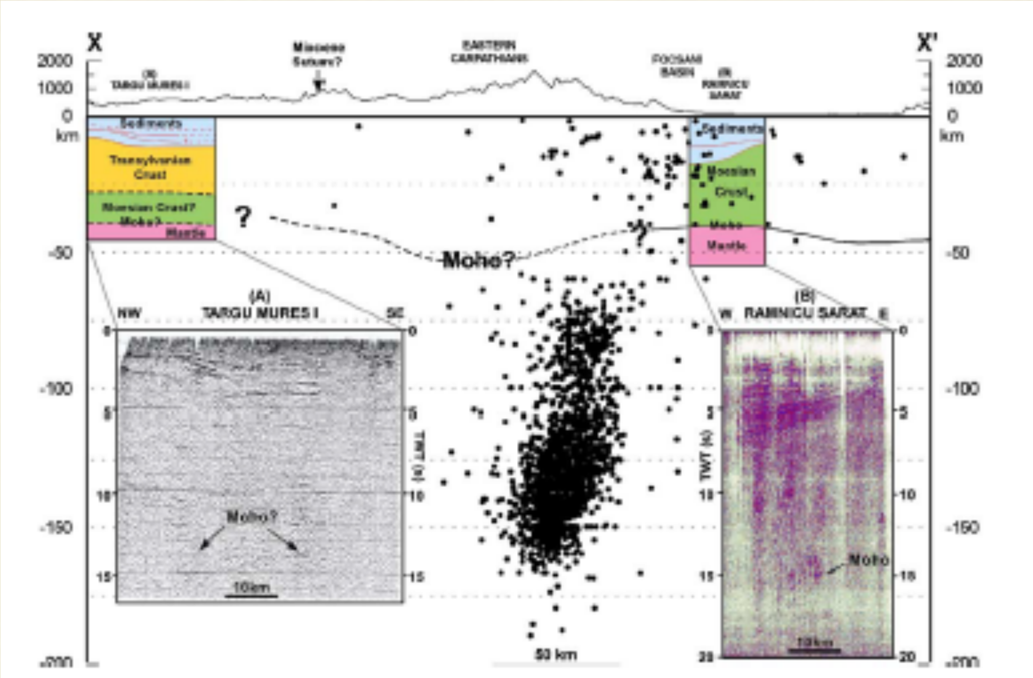


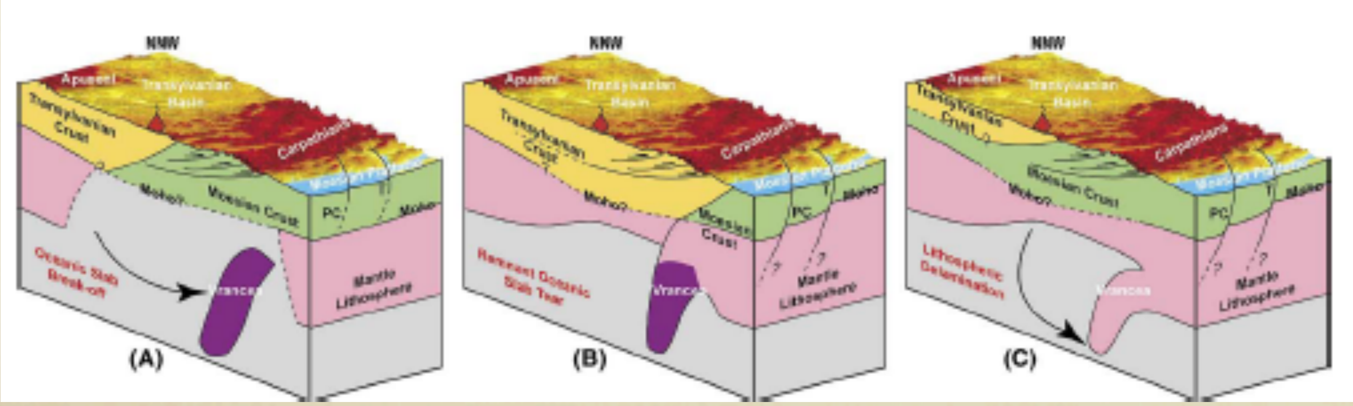
Seghedi et al, Tectonophysics
393(2004) 43-62

Crustal constraints on the origin of mantle seismicity in the Vrancea Zone,Romania

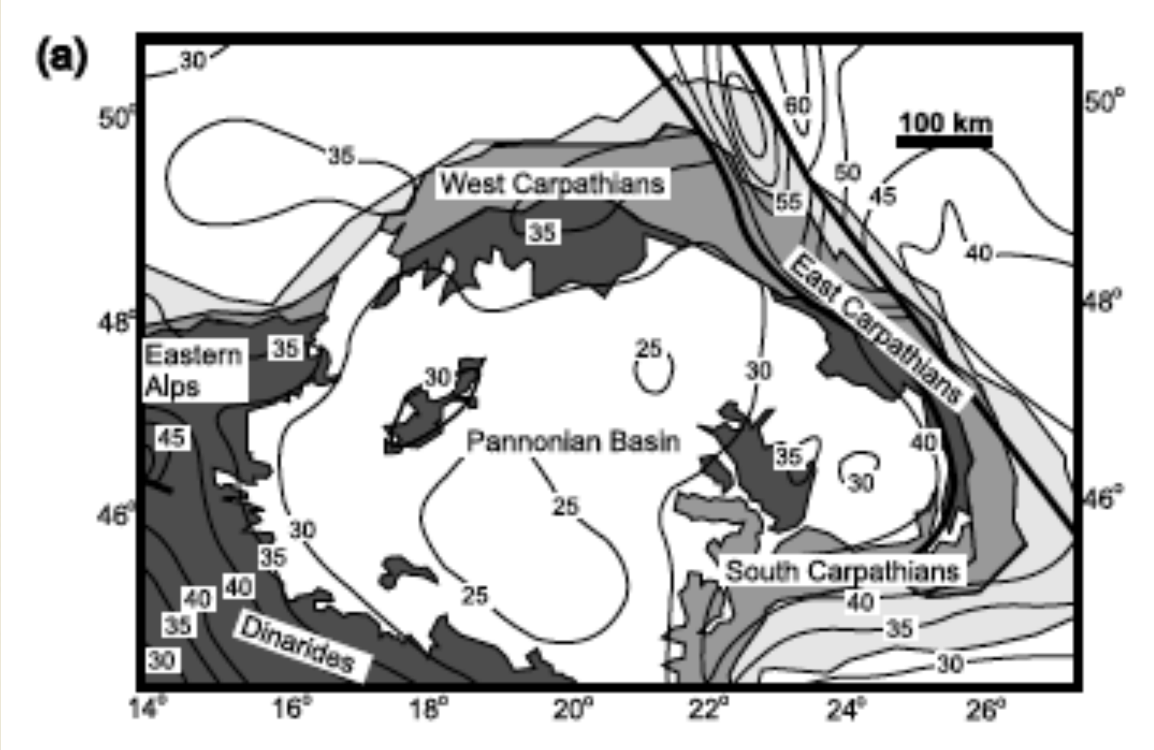
Knapp et al, Tectonoph. 410 (2005) 311-323

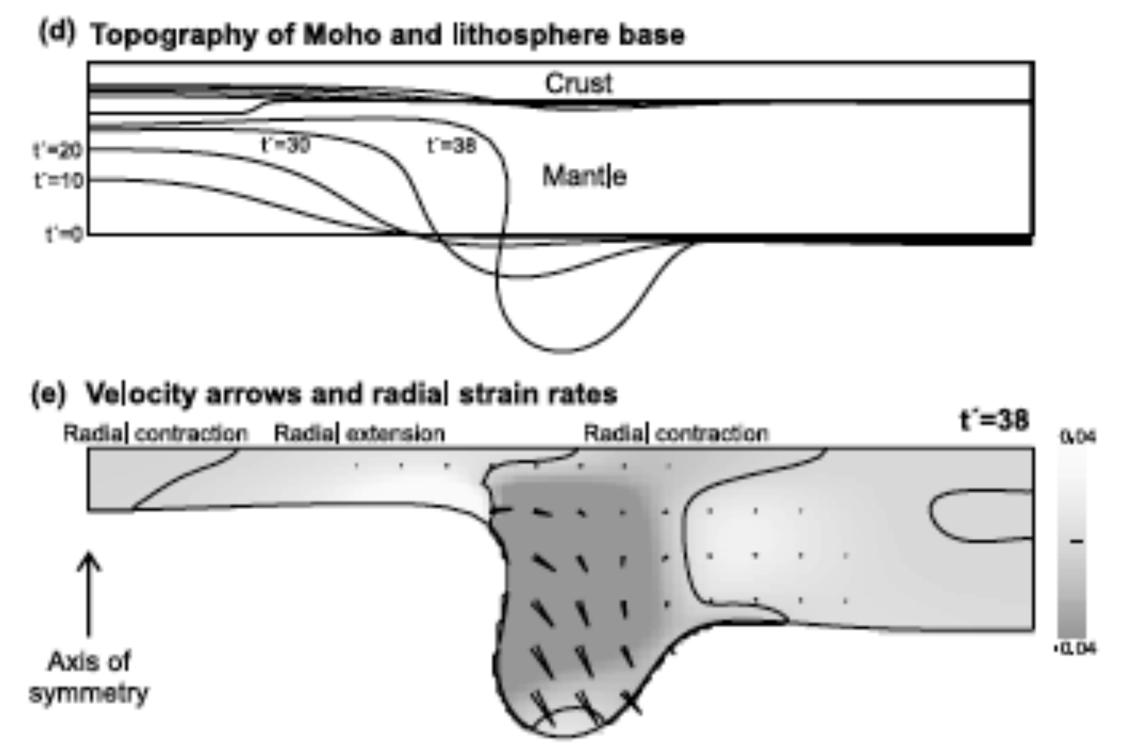




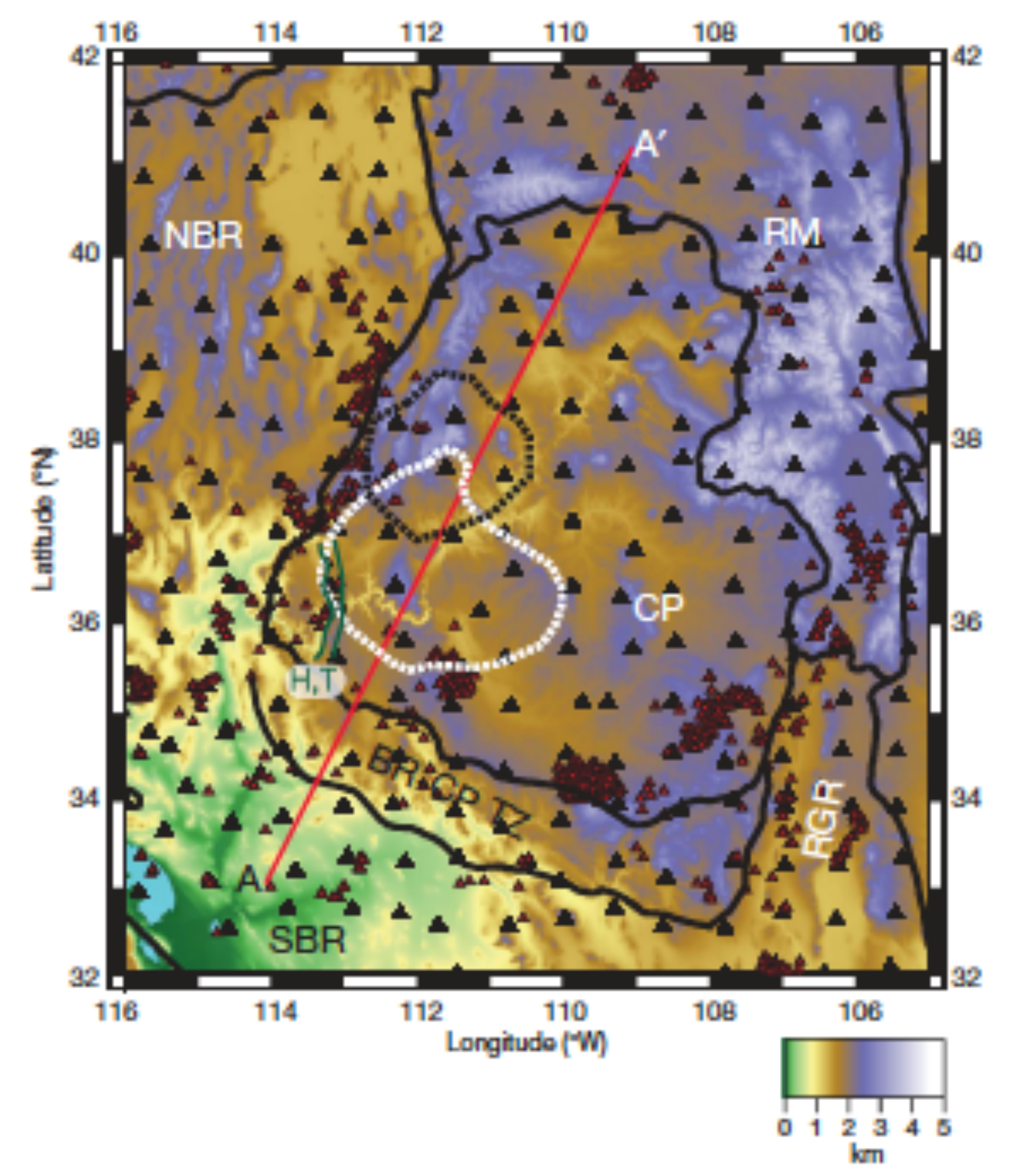


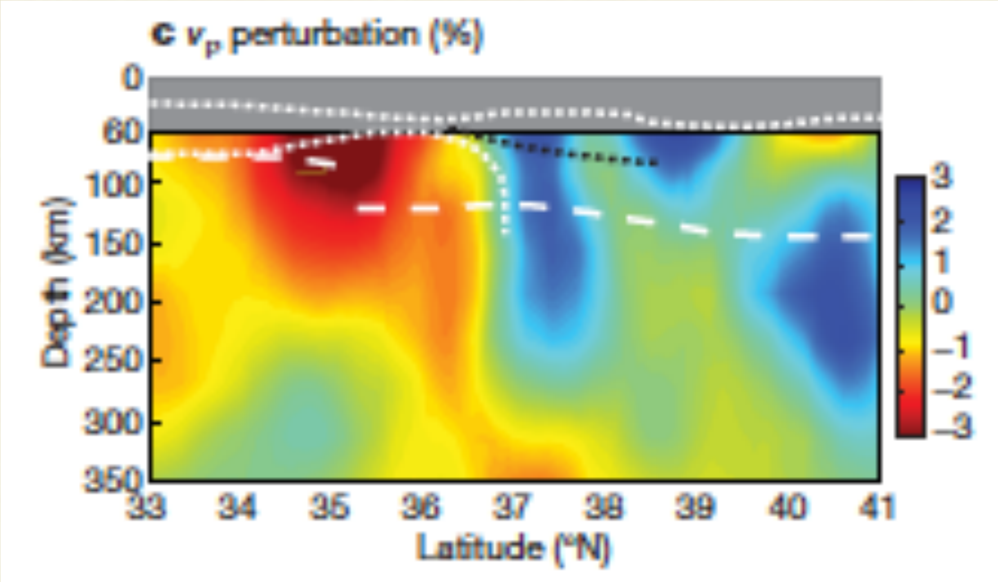
Convergence and extension driven by lithospheric gravitational instability
Gremmer & Houseman
Geophys.J.Int. 168(2007) 1276-1290

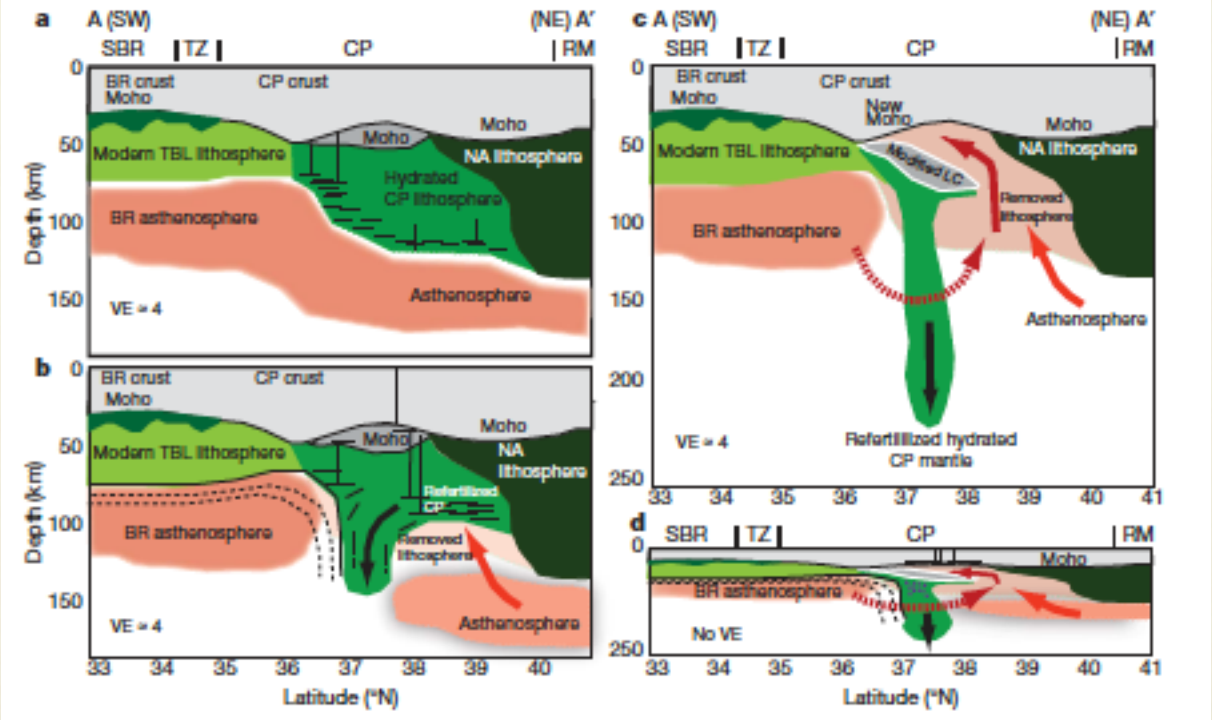




Continuing Colorado plateau uplift by delamination
Levander et al, Nature 472 (2011) 461

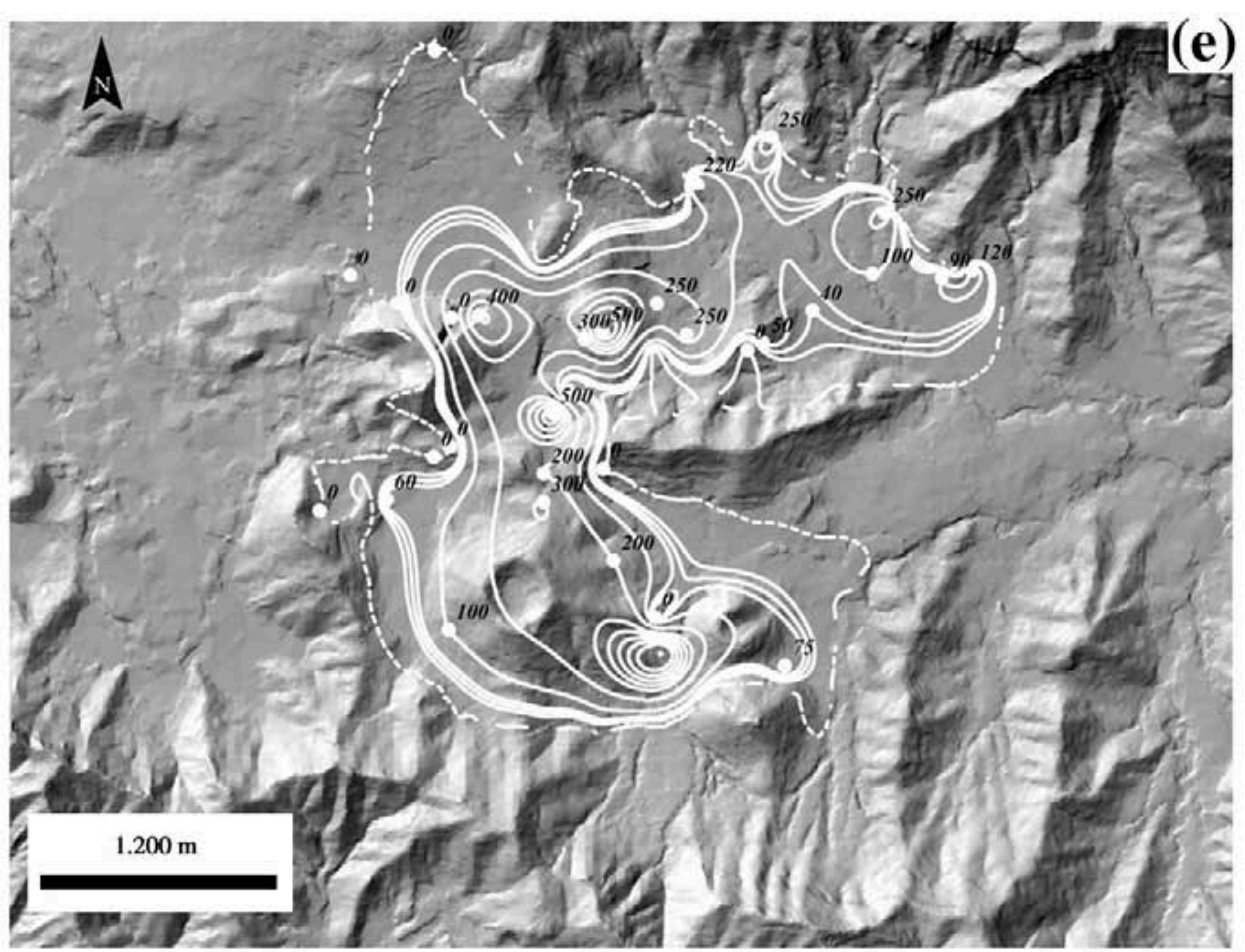




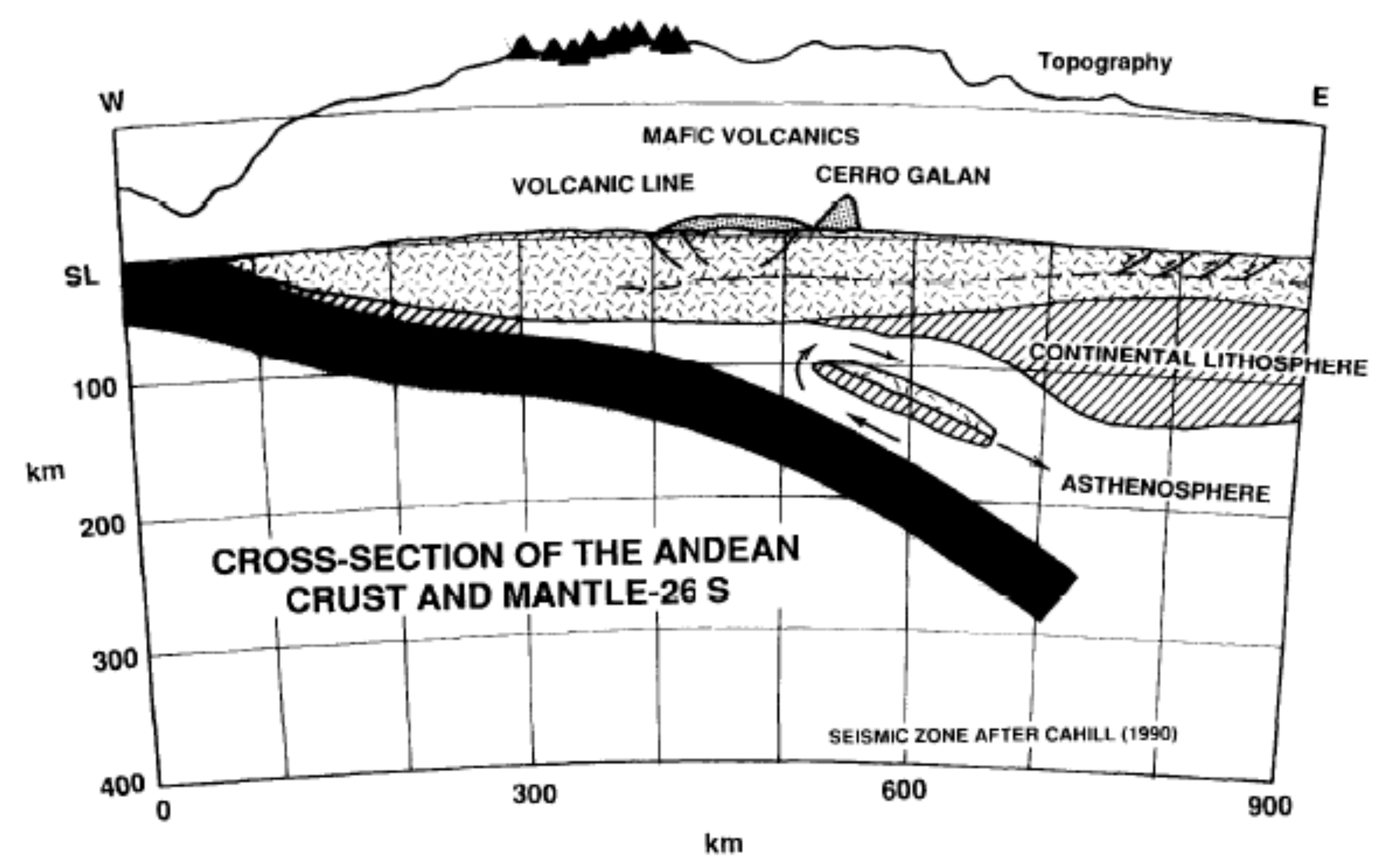


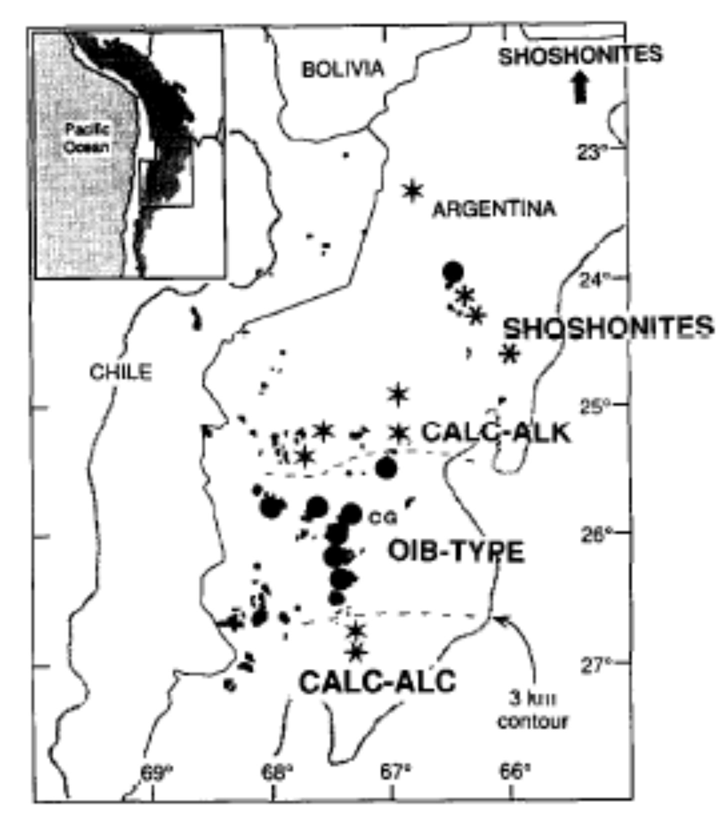
summary

- 火星地殻下部ではBET は生じうる
- BET により地殻下部の剥離が生じうる
- Delamination-induced magmatism が生じる
- Dechotomy境界付近に見られる小規模溶岩原の活動
- 火星内部の熱・組成進化に新たなプロセス

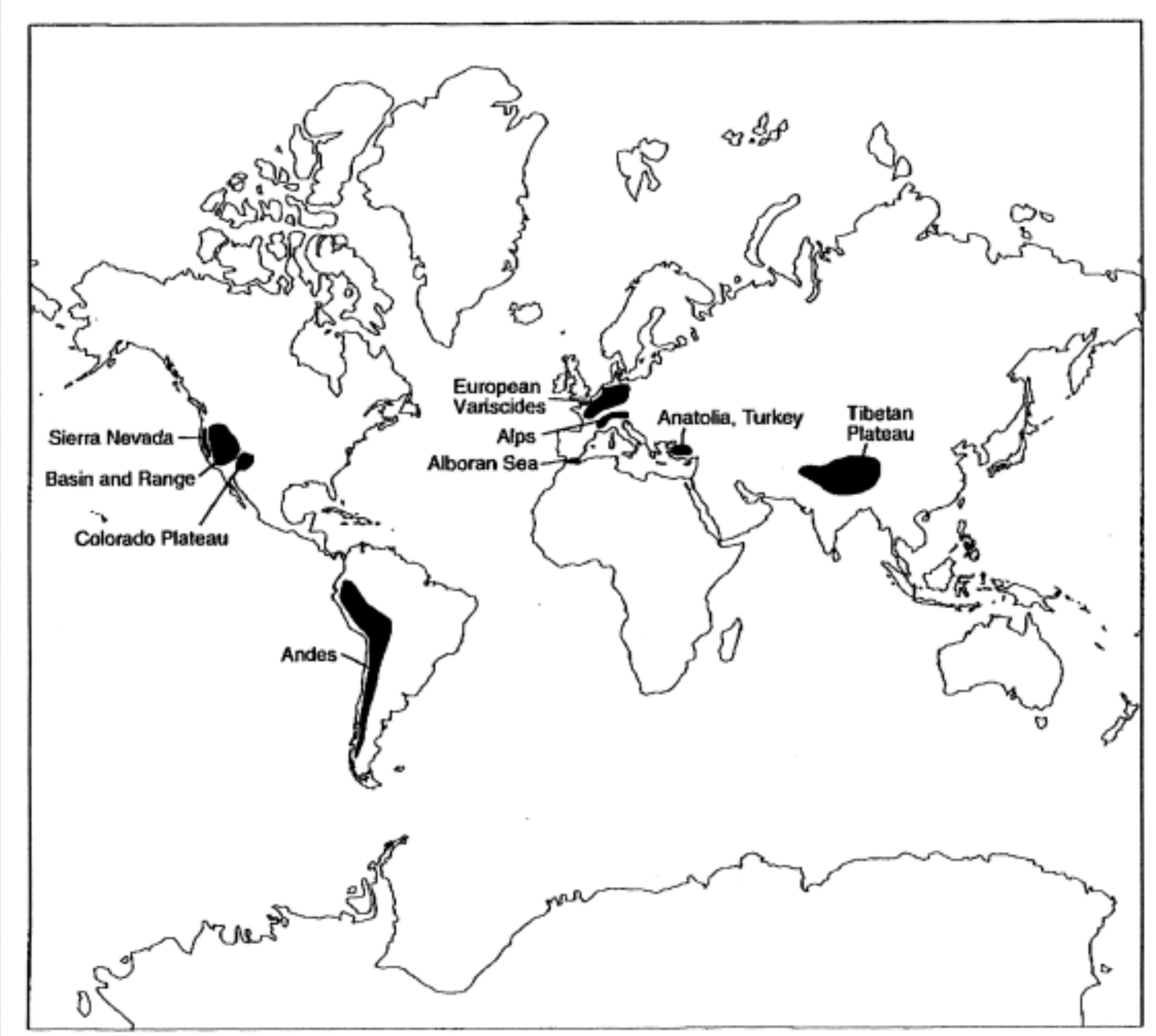

(e)
N
0
250
220
250
0
100
90
120
0
0
400
250
300
500
250
40
0 50
500
0
0
200
10
300
60
0
200
0
100
75
1.200 m

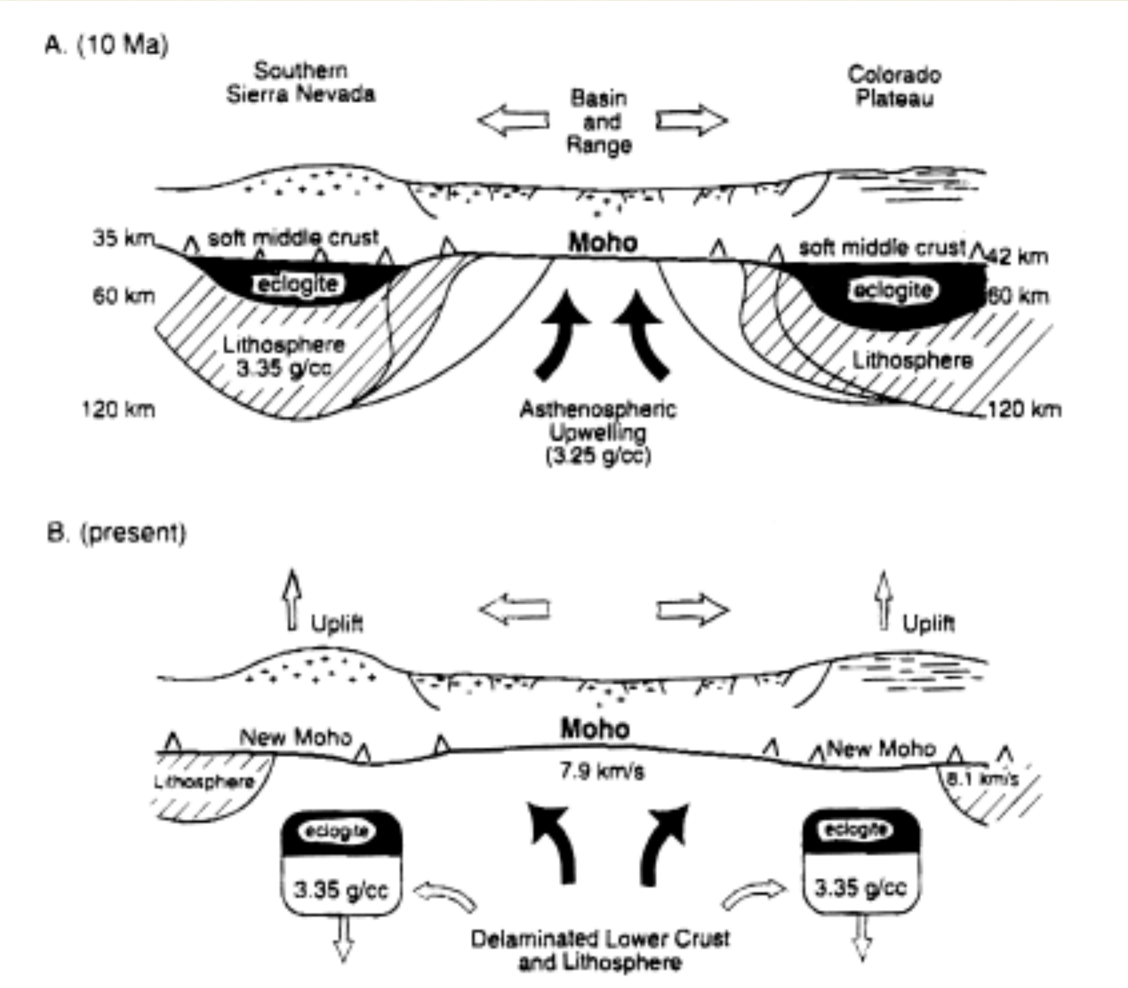
Delamination and delamination magmatism
Kay &b Kay
Tectonophyics 219(1993) 177-189



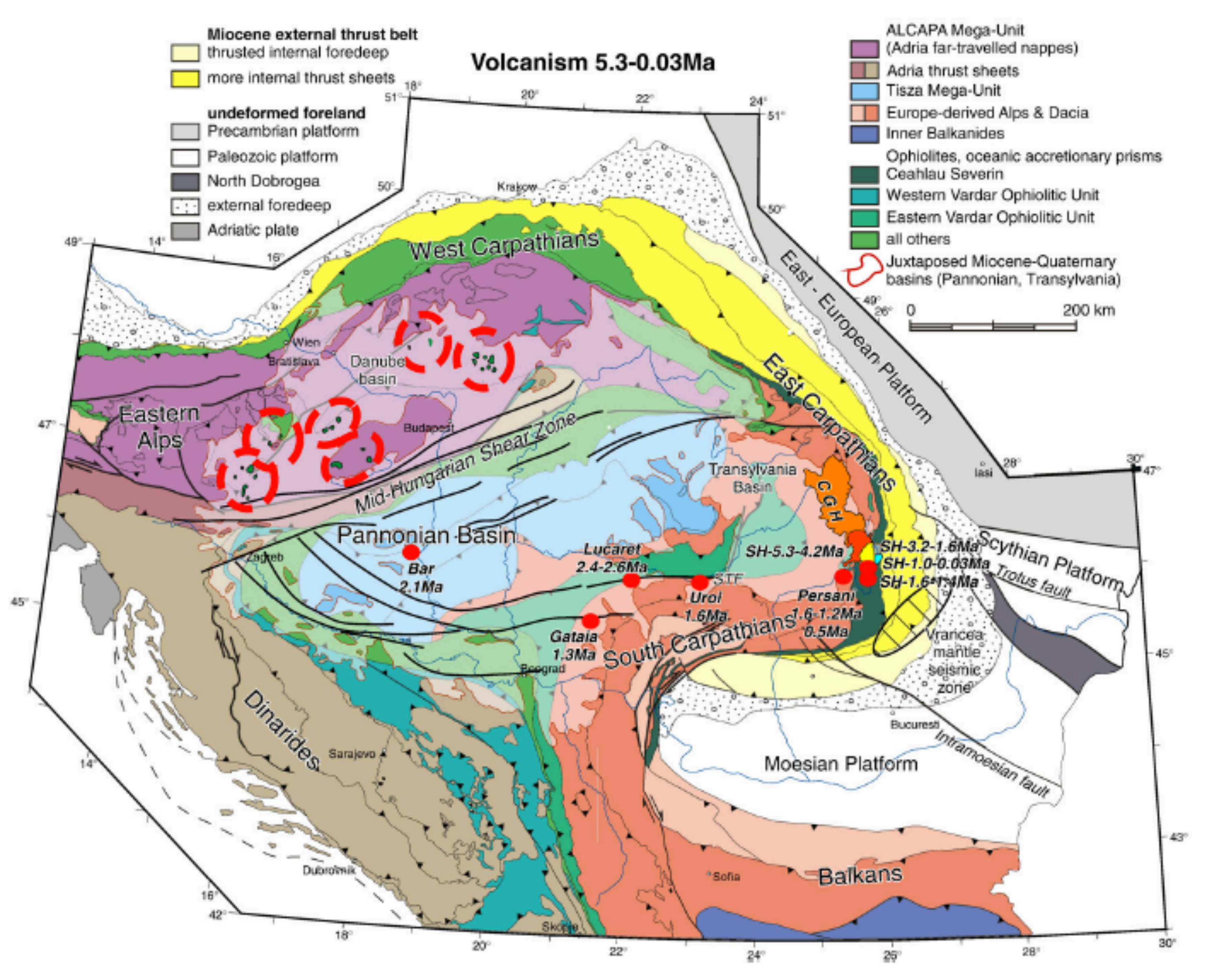


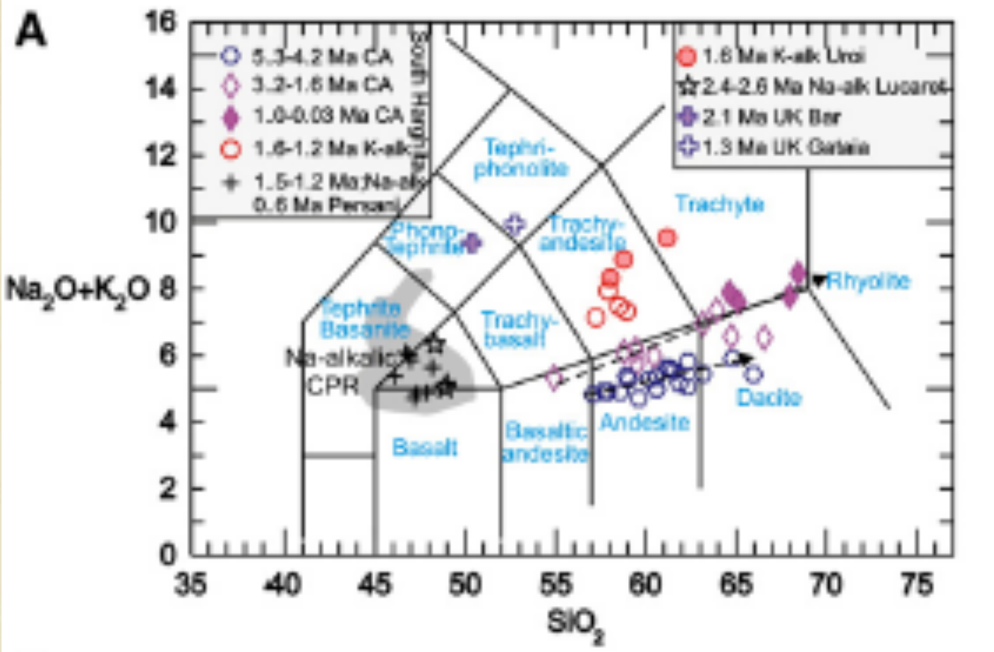
Weakness of the lower continental crust
Meissner & Mooney
Tectonophysics 296(1998) 47-60

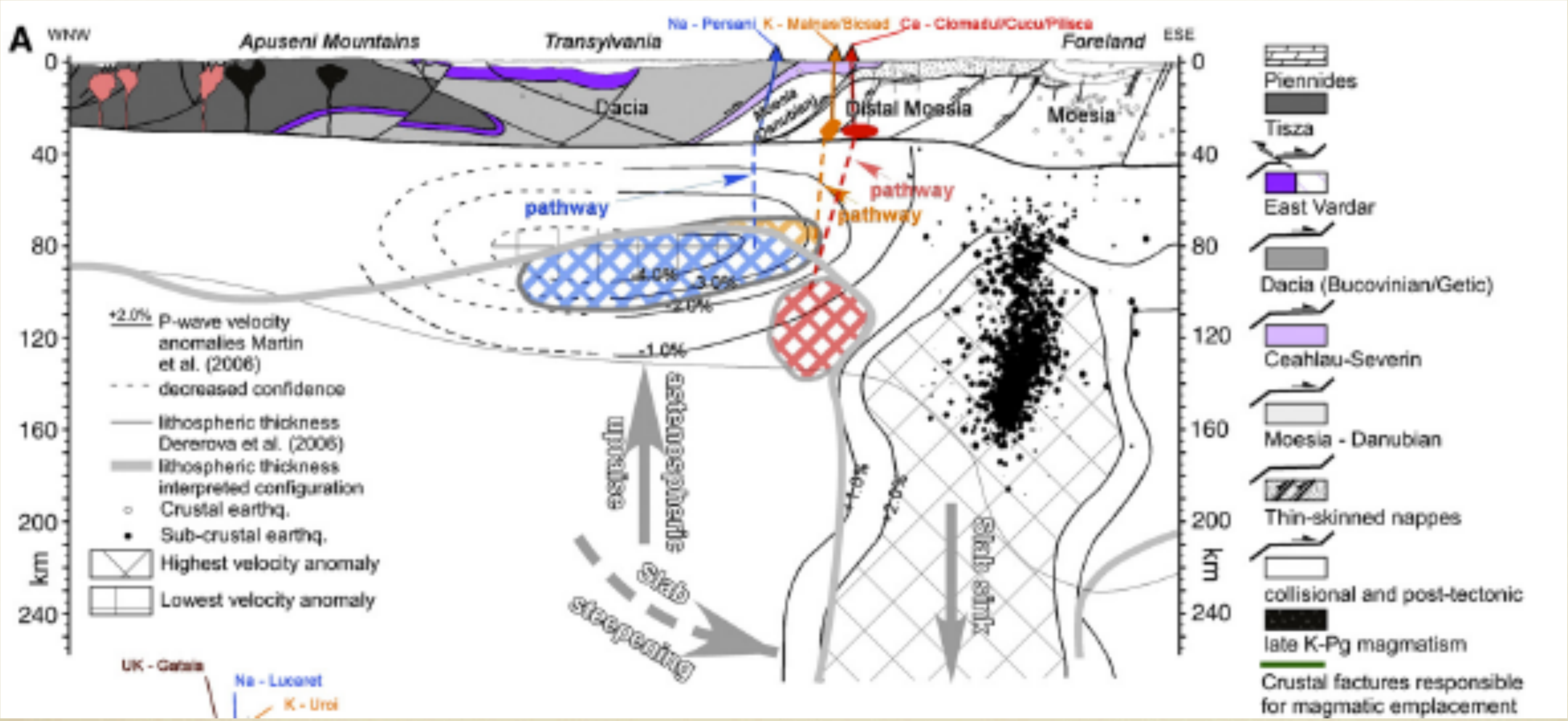




Tectonic significance of changes in post-subduction Pliocene-Quarternary magmatism in the sE part of the Carpatian-Pannonian Region
Seghedi et al, Tectonophysics 502 (2011) 146-157






A
WNW
Apuseni Mountains
Transylvania
Na - Persani
K - Malnas/Bicsad
Ca - Ciomadul/Cucu/Pilisca
Foreland
ESE
Dacia
Moesia (Danubian)
Distal Moesia
Moesia
pathway
pathway
pathway
-4.0%
-3.0%
-2.0%
-1.0%
-1.0%
-2.0%
asthenospheric upraise
Slab steepening
Slab sink
0
40
80
120
160
200
240
km
+2.0% P-wave velocity anomalies Martin et al. (2006)
decreased confidence
lithospheric thickness Dererova et al. (2006)
lithospheric thickness interpreted configuration
Crustal earthq.
Sub-crustal earthq.
Highest velocity anomaly
Lowest velocity anomaly
UK - Gataia
Na - Lucaret
K - Uroi
Piennides
Tisza
East Vardar
Dacia (Bucovinian/Getic)
Ceahlau-Severin
Moesia - Danubian
Thin-skinned nappes
collisional and post-tectonic
late K-Pg magmatism
Crustal factures responsible for magmatic emplacement

Schott & Schmeling Tectonophy. 296,(1998)

Delamination and detachment of a lithospheric root

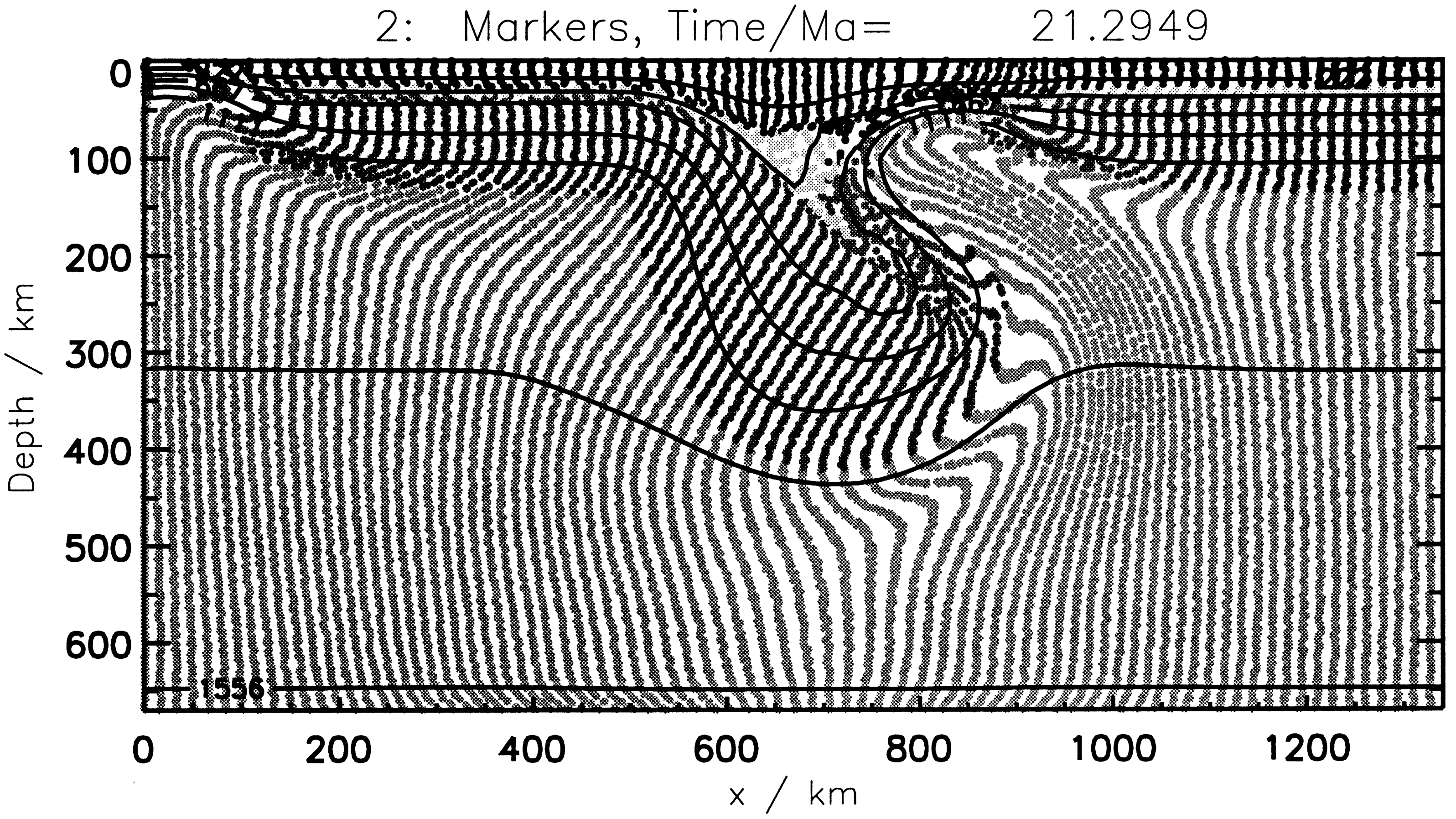


Fig. 12. Model 9c. Delamination of the mantle lithosphere from the upper crust. Hot asthenosphere is upwelling into the region left behind by the descending lithospheric root. In the crust, regions of compression or extension can be well recognized from the deformation of formerly equidistant stripes of passive markers.

Thick lithosphere to support volcano

- *Admittance analysis (gravity + topography)*
- *Te ~150 km,density 2900~3100 kg/m^3*

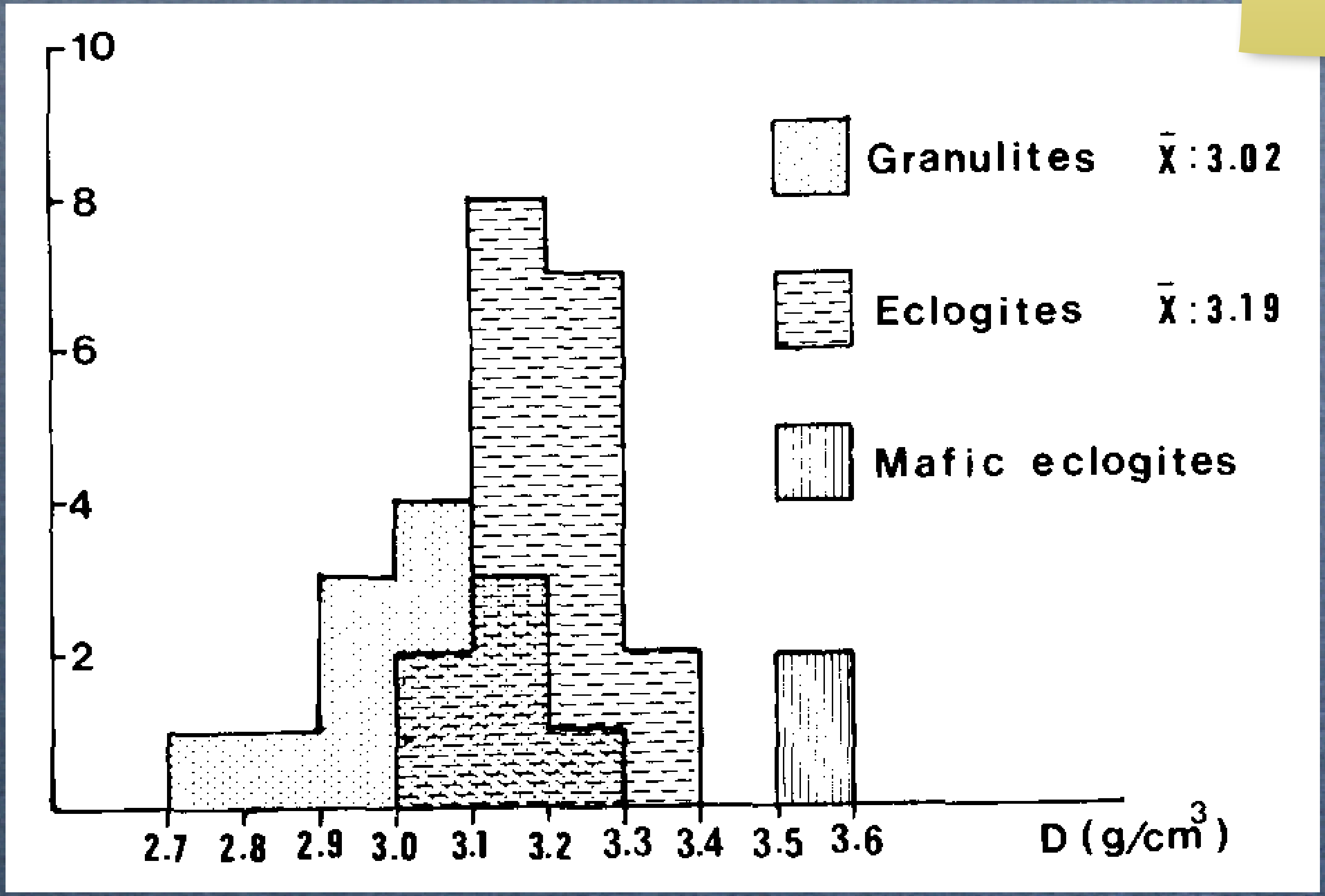
McGovern et al JGRE 107 (2002)

- *Te ~90 km, density 3200 kg/m^3*

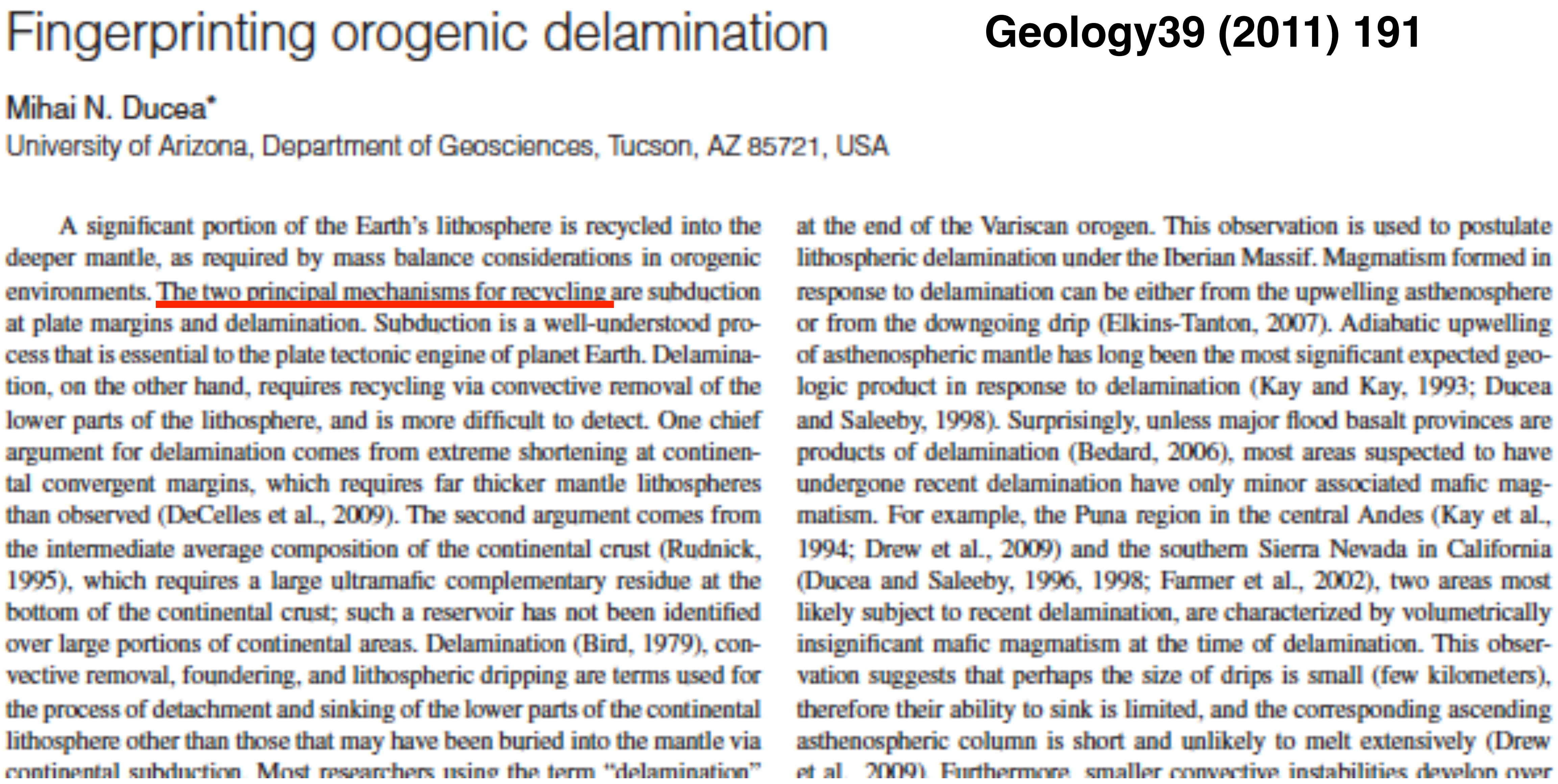
Belleguic et al. JGRE 110 (2005)

Density Data

EPSL 81, 211 (1987)
Austrheim



Geology39 (2011) 191

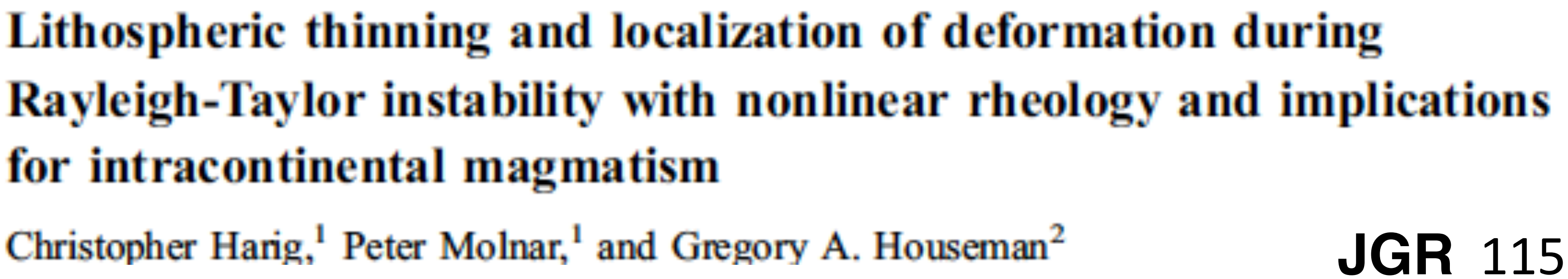


Fingerprinting orogenic delamination

Mihai N. Ducea*
University of Arizona, Department of Geosciences, Tucson, AZ 85721, USA

A significant portion of the Earth's lithosphere is recycled into the deeper mantle, as required by mass balance considerations in orogenic environments. The two principal mechanisms for recycling are subduction at plate margins and delamination. Subduction is a well-understood process that is essential to the plate tectonic engine of planet Earth. Delamination, on the other hand, requires recycling via convective removal of the lower parts of the lithosphere, and is more difficult to detect. One chief argument for delamination comes from extreme shortening at continental convergent margins, which requires far thicker mantle lithospheres than observed (DeCelles et al., 2009). The second argument comes from the intermediate average composition of the continental crust (Rudnick, 1995), which requires a large ultramafic complementary residue at the bottom of the continental crust; such a reservoir has not been identified over large portions of continental areas. Delamination (Bird, 1979), convective removal, foundering, and lithospheric dripping are terms used for the process of detachment and sinking of the lower parts of the continental lithosphere other than those that may have been buried into the mantle via continental subduction. Most researchers using the term "delamination"

at the end of the Variscan orogen. This observation is used to postulate lithospheric delamination under the Iberian Massif. Magmatism formed in response to delamination can be either from the upwelling asthenosphere or from the downgoing drip (Elkins-Tanton, 2007). Adiabatic upwelling of asthenospheric mantle has long been the most significant expected geologic product in response to delamination (Kay and Kay, 1993; Ducea and Saleeby, 1998). Surprisingly, unless major flood basalt provinces are products of delamination (Bedard, 2006), most areas suspected to have undergone recent delamination have only minor associated mafic magmatism. For example, the Puna region in the central Andes (Kay et al., 1994; Drew et al., 2009) and the southern Sierra Nevada in California (Ducea and Saleeby, 1996, 1998; Farmer et al., 2002), two areas most likely subject to recent delamination, are characterized by volumetrically insignificant mafic magmatism at the time of delamination. This observation suggests that perhaps the size of drips is small (few kilometers), therefore their ability to sink is limited, and the corresponding ascending asthenospheric column is short and unlikely to melt extensively (Drew et al., 2009). Furthermore, smaller convective instabilities develop over



Lithospheric thinning and localization of deformation during Rayleigh-Taylor instability with nonlinear rheology and implications for intracontinental magmatism

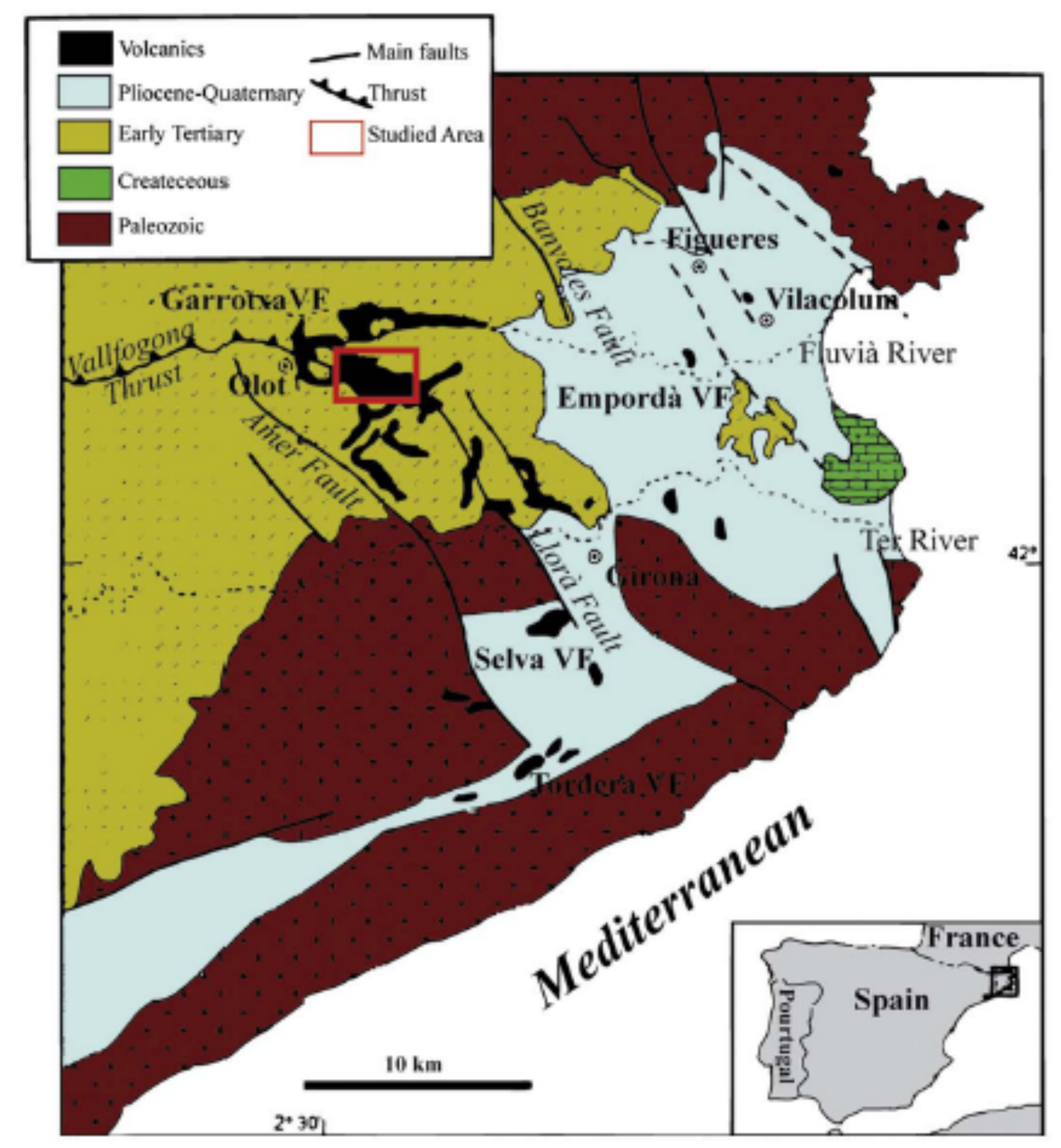
Christopher Harig,[1] Peter Molnar,[1] and Gregory A. Houseman[2]

JGR 115, B02205, 2010

1. Introduction

[2] Continental magmatism is a common occurrence in tectonically active regions of subduction or rifting. Subduction zone arc magmatism is produced mainly through chemical interaction between the subducted crust and mantle material [e.g., Kay, 1980; Morris et al., 1990]. Rifting, on the other hand, thins lithosphere to allow the underlying asthenosphere to melt through adiabatic decompression as it rises [e.g., McKenzie and Bickle, 1988]. **How then do we explain continental magmatism, that occurs several hundred kilometers from plate boundaries (e.g., northern Tibetan plateau, the North China Craton), in the absence of these tectonic processes?** Barring heat sources from below, produced perhaps by mantle plumes, or the introduction of a chemical process, we are left to explore another way to thin lithosphere and generate melt [e.g., Elkins-Tanton, 2005].

Garrotxa Volcanic Field



JVGR 180(2009) 89-100
Traglia,Cimarelli,Rita and Torrente