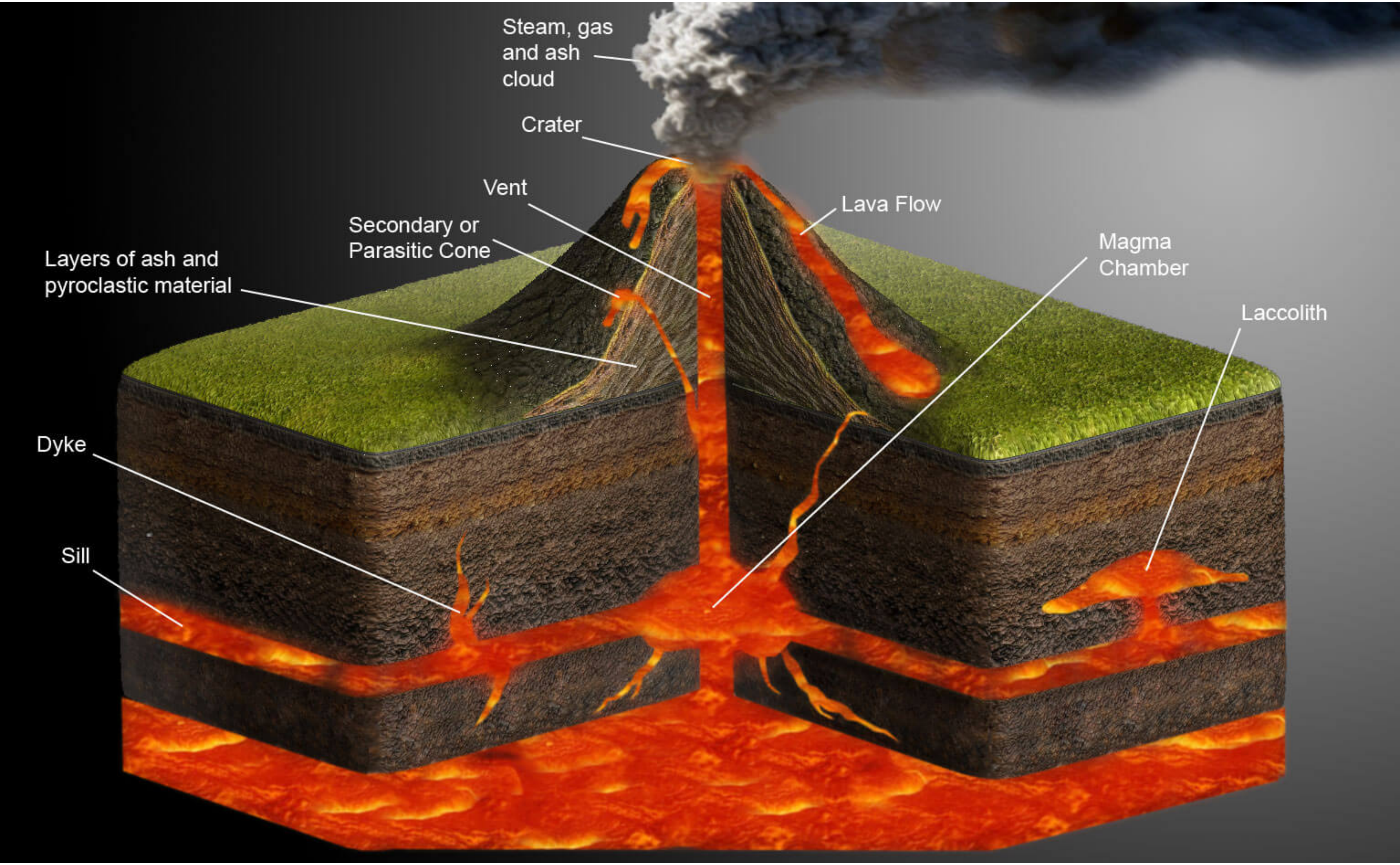
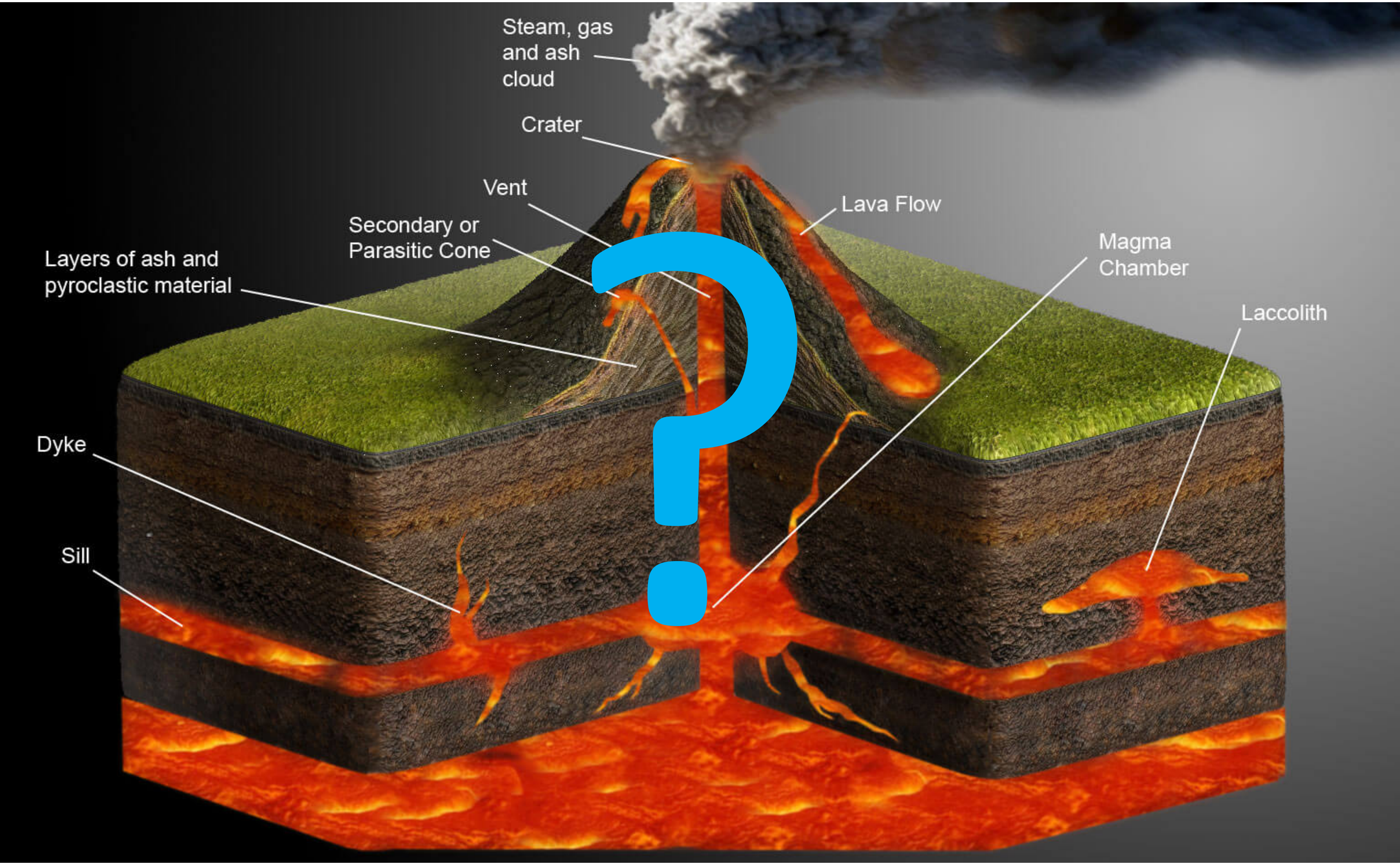
Geometrie e orientazioni delle intrusioni tabulari



https://www.911metallurgist.com/blog/volcanic-rock-formations

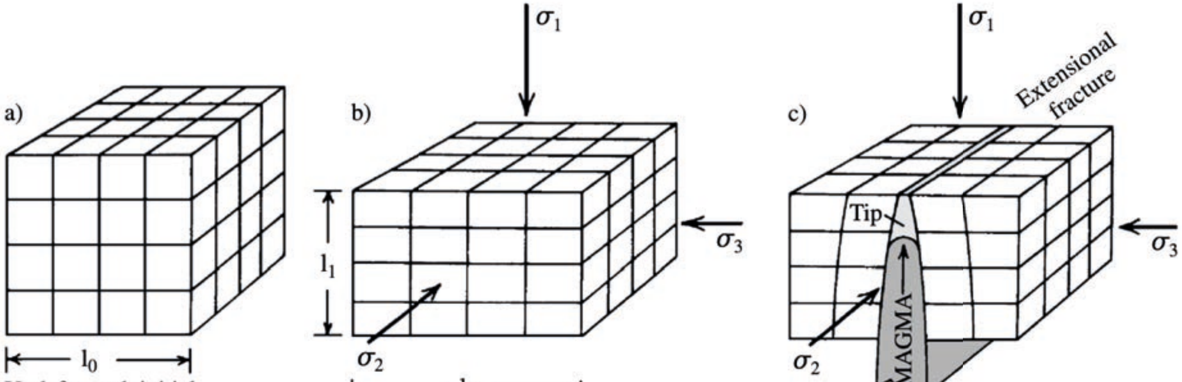
Geometrie e orientazioni delle intrusioni tabulari



https://www.911metallurgist.com/blog/volcanic-rock-formations

Geometrie e orientazioni delle intrusioni tabulari

Le orientazioni dei corpi magmatici intrusi nella crosta sono governate dallo stato di stress.
La fratturazione da parte di magmi in sovrapressione crea delle fratture parallele a σ_1 e σ_2, che si aprono in direzione dello stress principale minore, σ_3 . Quindi, queste fratture in dilatazione riempite da magma servono anche come indicatrici di paleo-stress.



Undeformed, initial state

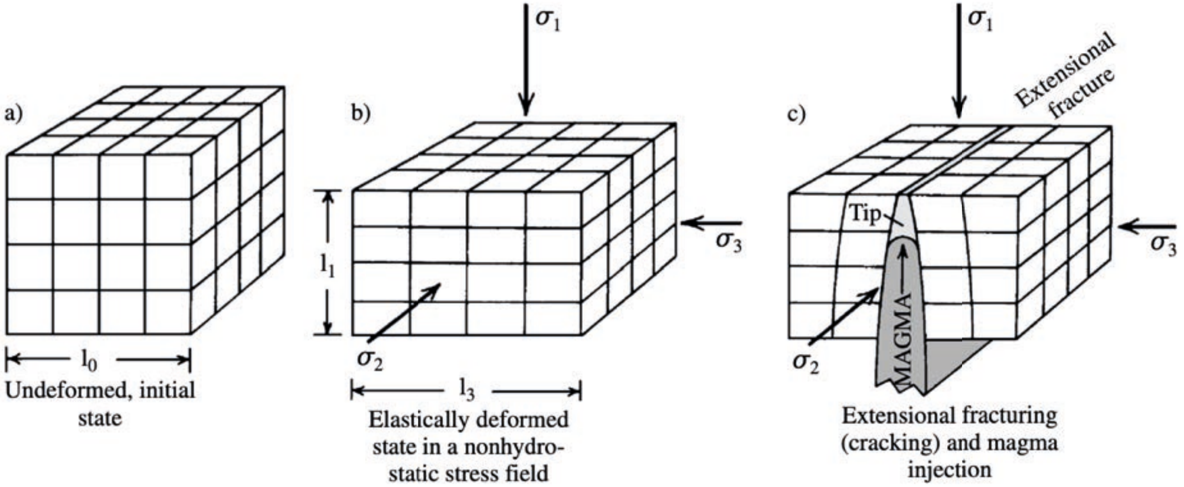
Elastically deformed state in a nonhydro-static stress field

Extensional fracturing (cracking) and magma injection

8.2 Deformation of a body under a nonhydrostatic state of stress, $\sigma_1 > \sigma_2 > \sigma_3$. (a) Undeformed body represented by a cubical stack of smaller cubes. (b) Principal stresses of unequal magnitude cause a change in shape—a **strain.** Actual recoverable elastic strain produces only a small percentage of strain, far less than is represented here for illustrative purposes. However, the relative amounts of strain are as expected, that is, flattening perpendicular to the maximal principal compressive stress, σ_1, and elongation, or extension, parallel to the least principal compressive stress, σ_3. Strain parallel to σ_2 can be either elongation or flattening or nil. (c) Nonhydrostatic stresses may exceed the brittle (essentially elastic) strength of a rock so that an **extensional fracture** forms perpendicular to the least principal compressive stress, σ_3. These open cracks may be subsequently filled with magma or fluid. The pressure exerted by the magma or fluid itself may be sufficient to create an extensional fracture by **hydraulic fracturing.** Just beyond the injecting fluid or magma that wedges apart the walls of rock is a tip cavity where transient low pressure can suck out volatiles dissolved in the magma or pore fluids lodged in the wall rock.

Geometrie e orientazioni delle intrusioni tabulari

I magmi in risalita da sorgenti profonde, come magmi basaltici formati nel mantello e intrusi in dicchi sub-verticali nella crosta, implicano che σ_3 sia orizzontale, cioè la tipica orientazione sopra i *mantle plumes* e in altri regimi estensionali. Sciami di dicchi subparalleli e subverticali esposti in aree molto grandi indicano uno stato uniforme di estensione della crosta al tempo dell'intrusione.



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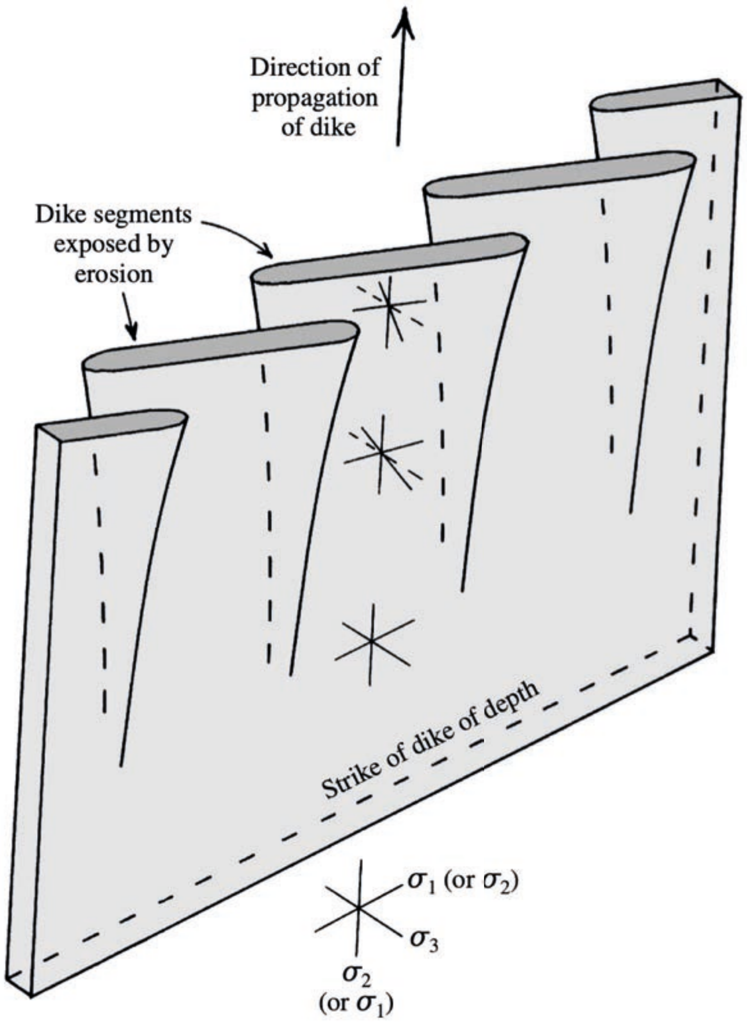
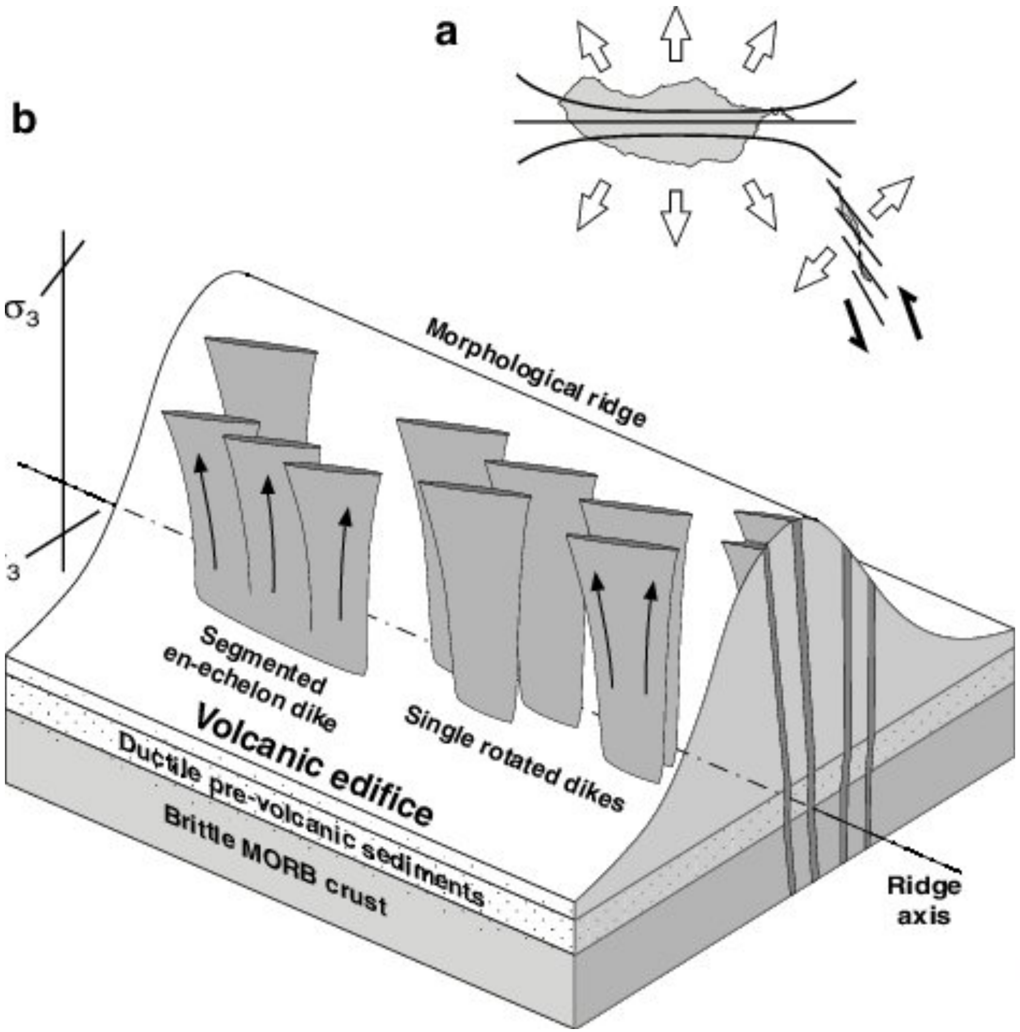
I dicchi si presentano spesso come segmenti disposti ad *en-echelon*. Questa disposizione può essere legata ad un cambiamento di direzione di σ_3 con la profondità.



Best (2003)

9.9 Schematic three-dimensional form and origin of subvertical **en echelon dike** segments. At some depth the dike is an unsegmented sheet intrusion whose orientation is controlled by the nonhydrostatic state of stress indicated by the thin-line orthogonal principal stresses below the dike. At progressively shallower depths the orientation of the least principal horizontal stress, σ_3, rotates progressively counterclockwise, as shown in the upper part of the dikes. Consequently, the least-work dike configuration there is an *en echelon* system of dike segments. Note that the other horizontal principal stress must also rotate. (Redrawn from Delaney and Pollard, 1981.)

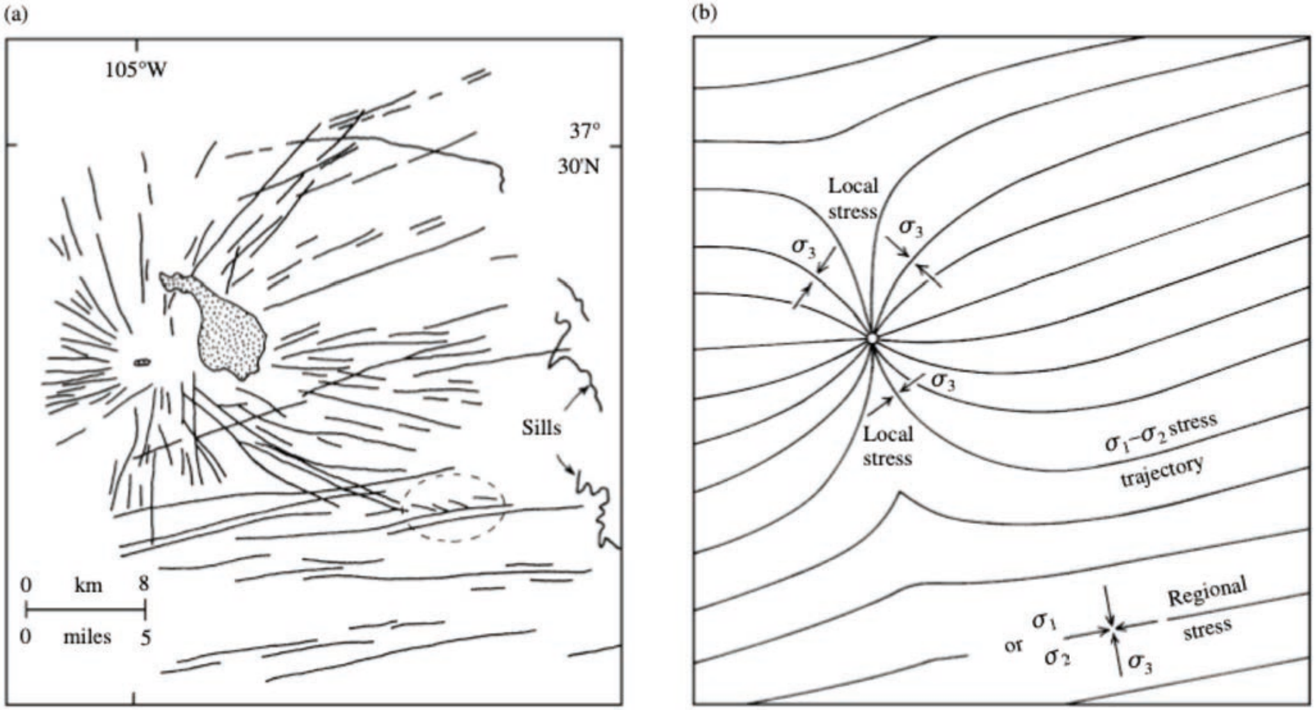


Klügel et al (2005; Bull Volc)

Fig. 8 (**a**) Simple sketch of potential dike directions indicates how spreading of Madeira (*open arrows*) causes a sinistral stress component and dike rotation at the Desertas Islands (*solid arrows*). (**b**) Sketch of dike rotation and en-echelon arrangement within the Desertas ridge (not to scale). Because of changing orientation of the principal stress axis σ_3, ascending dikes rotate counterclockwise around a vertical axis or become segmented. Both scenarios result in en-echelon arrangements of the dikes at the ridge surface.

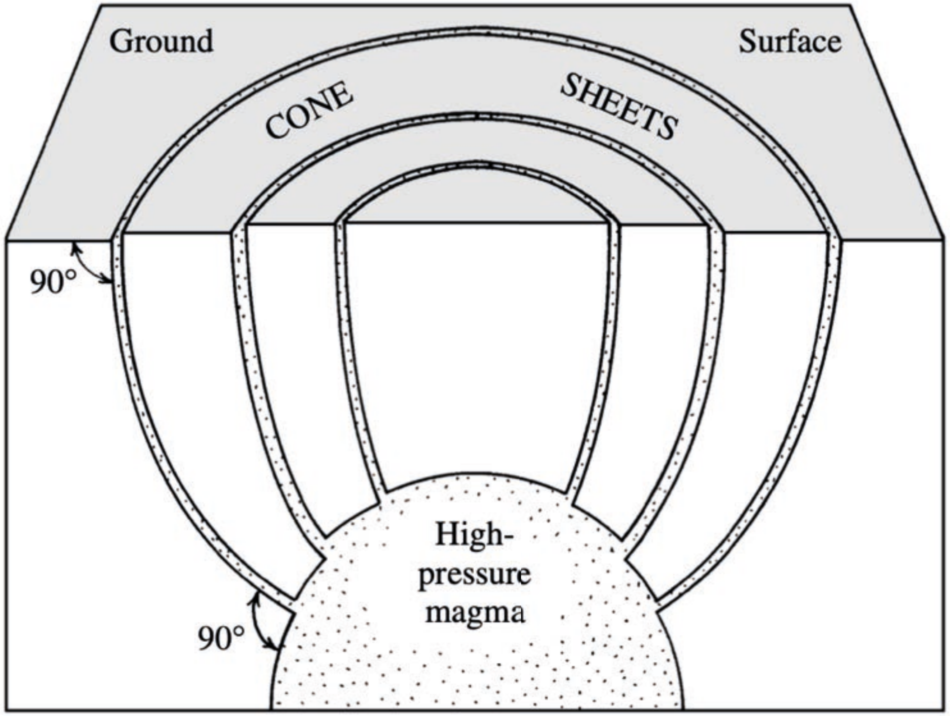
https://it.m.wikipedia.org/wiki/File:En-echelon_Dyke_Apophyses_Kosterhavet_Sweden.jpg

Le intrusioni tabulari sono comuni nella crosta superiore, dove circondano e si dispongono al di sopra delle intrusioni massive principali.
Queste intrusioni principali (di varia forma, cilindrica o a bottiglia) possono perturbare lo stress regionale presente nella zona.
Lo stress totale risultante sarà variabile nella sua orientazione attorno all’intrusione. In questo regime di stress, le intrusioni create dal magma alimentato dall’intrusione centrale avranno varie forma, come dicchi radiali, conici o ad anello.



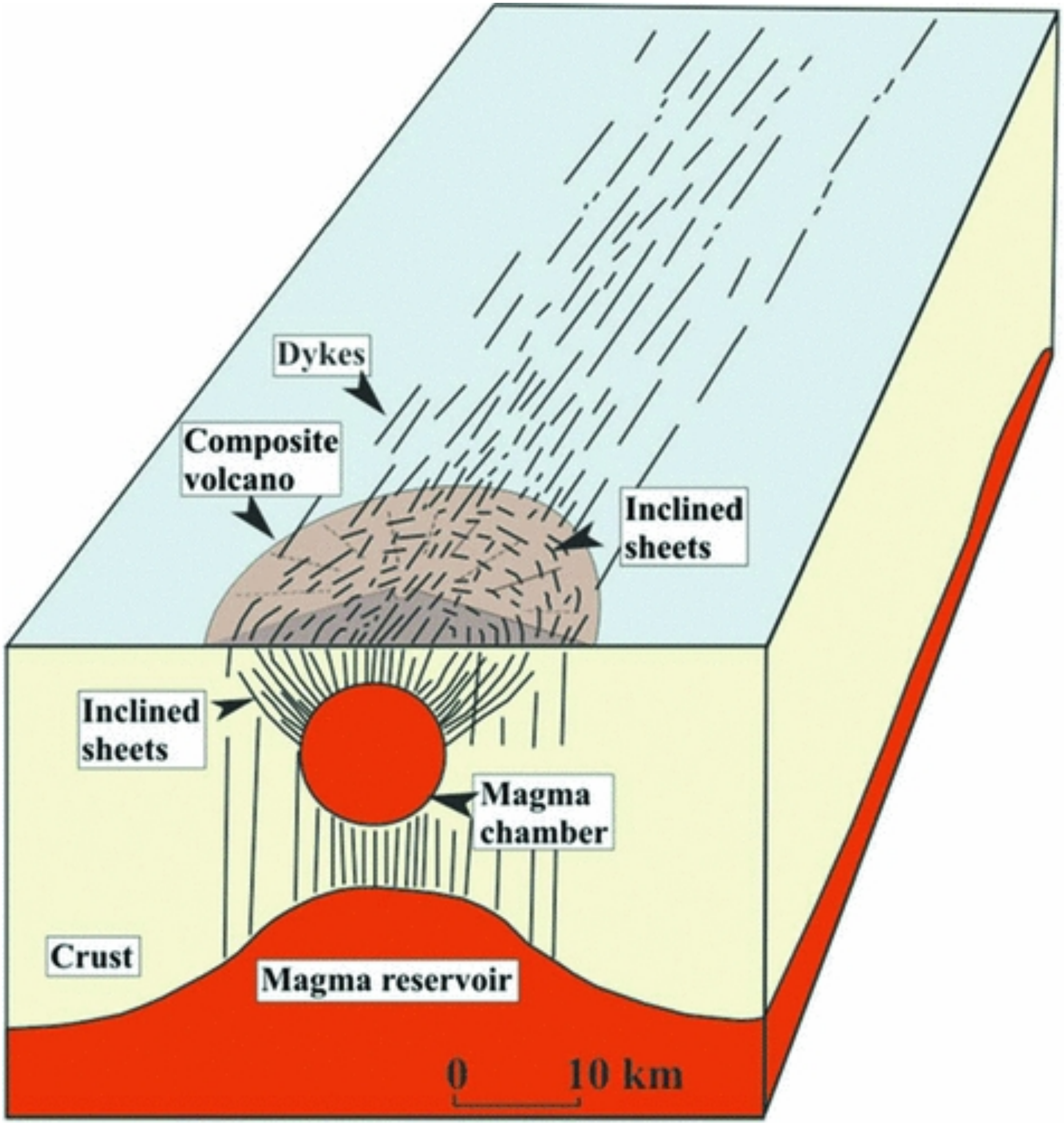
Best (2003)

9.6 **Radial** and **parallel dike swarms.** (a) Subvertical dikes were emplaced at 28 to 20 Ma around **central intrusions** of the Spanish Peaks (stippled) in south central Colorado. Flow markers (aligned tabular phenocrysts, elongate vesicles) in the dikes indicate the central intrusions as the source of the radially diking magma. Most dikes consist of segments a few meters to several kilometers long; many segments are *en echelon* but cannot be shown on this small-scale map except some unusually well-expressed ones enclosed by the dashed-line ellipse. An origin for *en echelon* dikes is shown in Figure 9.9. (Redrawn from Smith, 1987.) (b) Theoretical stress analysis. Central intrusion (open circle) is responsible for a *local stress* field that allows for radial diking. The central intrusion perturbed a *regional stress* field that controlled emplacement of the mostly older swarm of subparallel east-northeast-striking dikes mainly of more mafic magma. Trajectory lines are traces (intersections) in the horizontal plane of vertical surfaces parallel to σ_1 and σ_2. Because these surfaces are perpendicular to σ_3, they are potential avenues for magma intrusion. Note that most radial dikes are oriented nearly parallel to the regional $\sigma_1 = \sigma_2$ trajectory. (Redrawn from Odé, 1957.)



Best (2003)

9.10 Idealized geometry of **cone sheets** above a shallow, forcefully intruded **central magma intrusion.** Inward-dipping cone sheets develop as high-pressure magma in the central intrusion invades conical extensional fractures that follow $\sigma_1 = \sigma_2$ trajectories above the apex of the intrusion. This geometry applies to situations in which the depth to the top of the intrusion is comparable to its width; in such cases, some of the magma commonly extrudes and the intrusive complex is referred to as *subvolcanic.* Many intrusions are emplaced farther beneath the surface and for this reason and other factors do not have cone sheets.



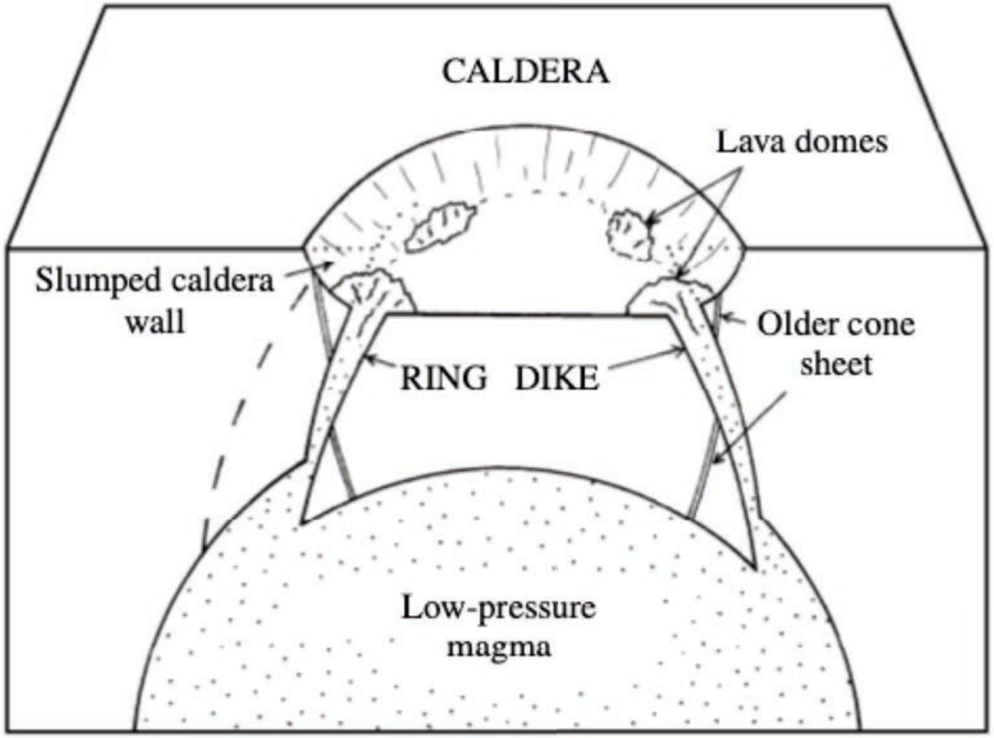
Gudmundsson et al (2014)

Dopo uno stato iniziale di sovrappressione di una certa intrusione magmatica massiva, i.e., una camera magmatica, in seguito alle eruzioni in superficie la pressione della camera magmatica possono diminuire.

Queste eruzioni o anche le intrusioni nelle vicine rocce incassanti possono creare dei vuoti in alcune porzioni della camera magmatica. Questo può causare una subsidenza della camera magmatica, creando una depressione topografica chiamata **caldera**.

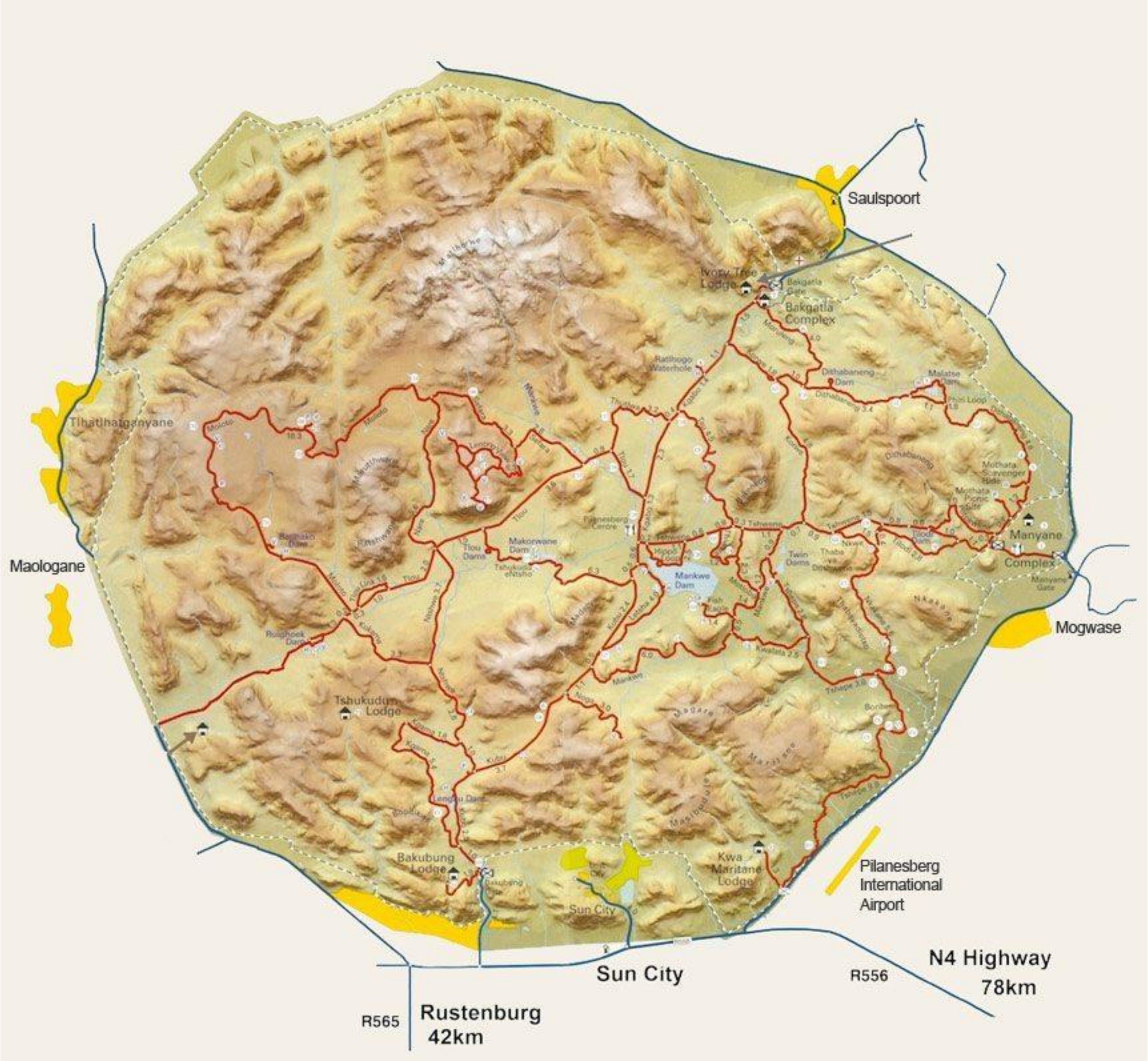
La fratturazione ad anello che fa da confine al tetto che va in subsidenza segue all’incirca la forma della camera magmatica. Durante questi processi, del magma può risalire in questa frattura ad anello, formando quello che viene chiamato **dicco ad anello**.

Best (2003)



9.11 Hypothetical **ring dike** and **caldera** above a shallow magma chamber. Postcollapse caldera fill consists of landslide debris that is produced by slumping of the unstable caldera wall and epiclastic (sedimentary) deposits shed off the eroding caldera wall. Magma rising in the ring dike locally extrudes to form lava domes or flows; their vents mark the position of the usually concealed underlying ring dike and the ring fault it followed.

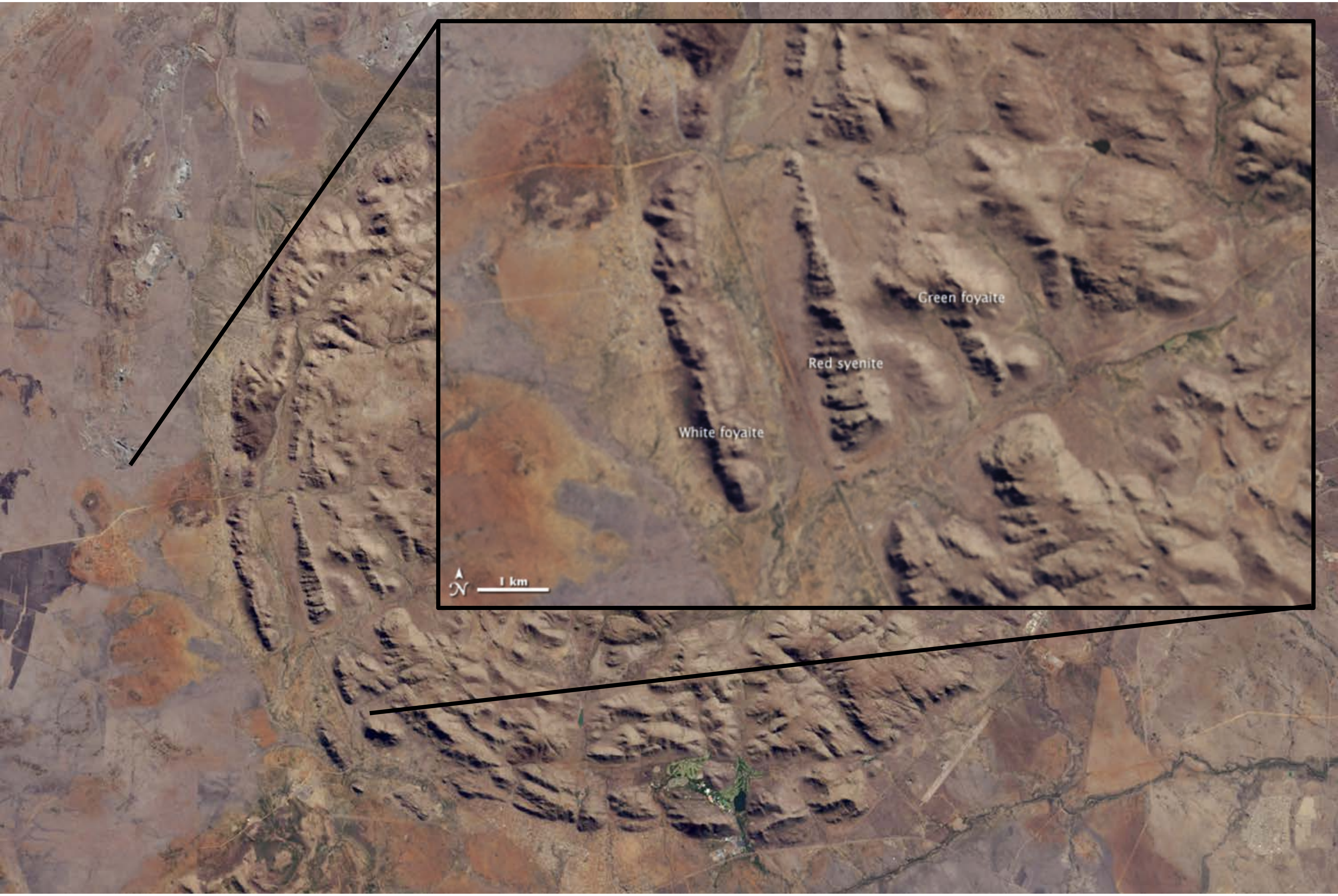
Pilanesberg National Park

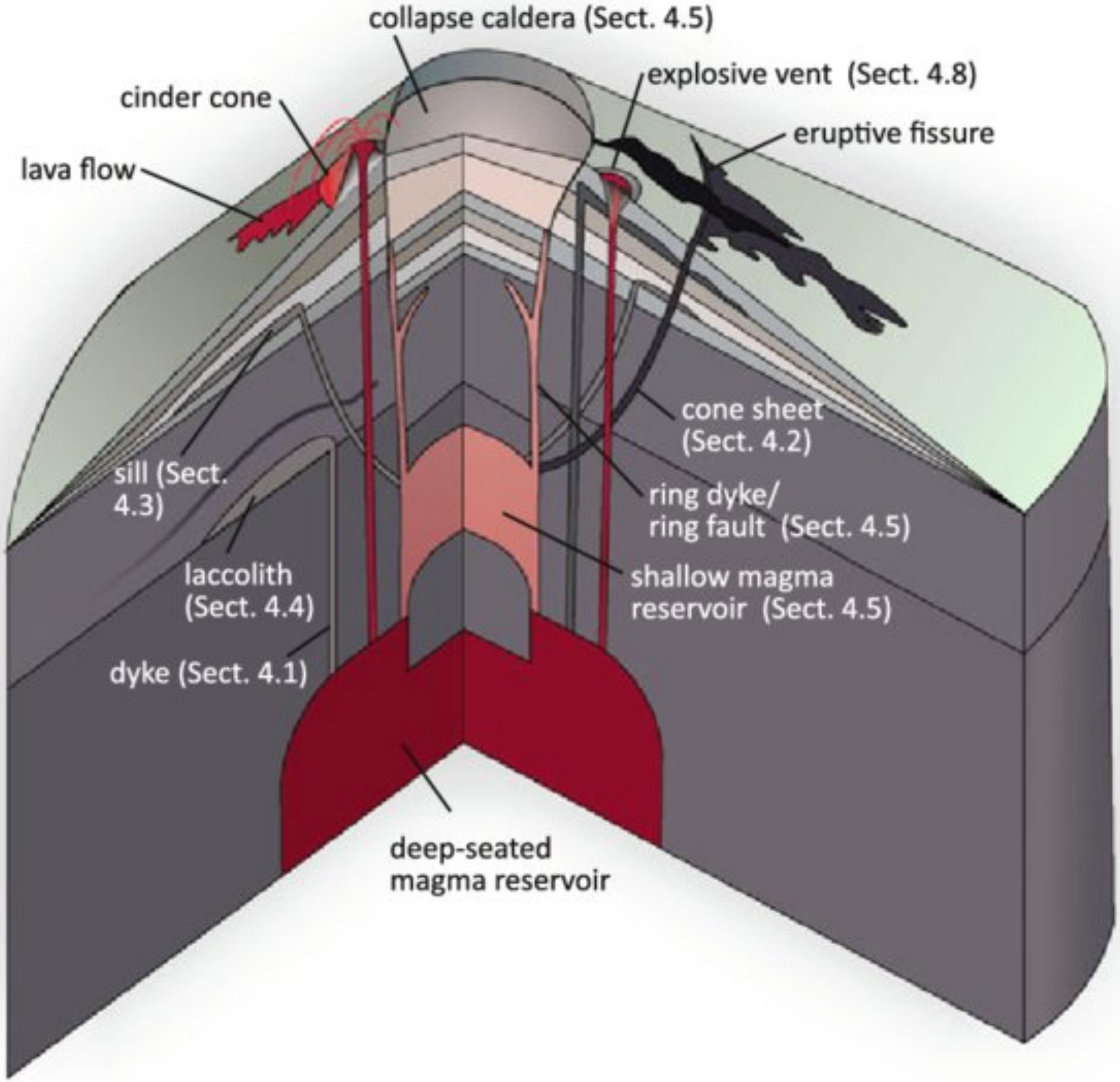


https://pilanesberggamereserve.com/geology.html

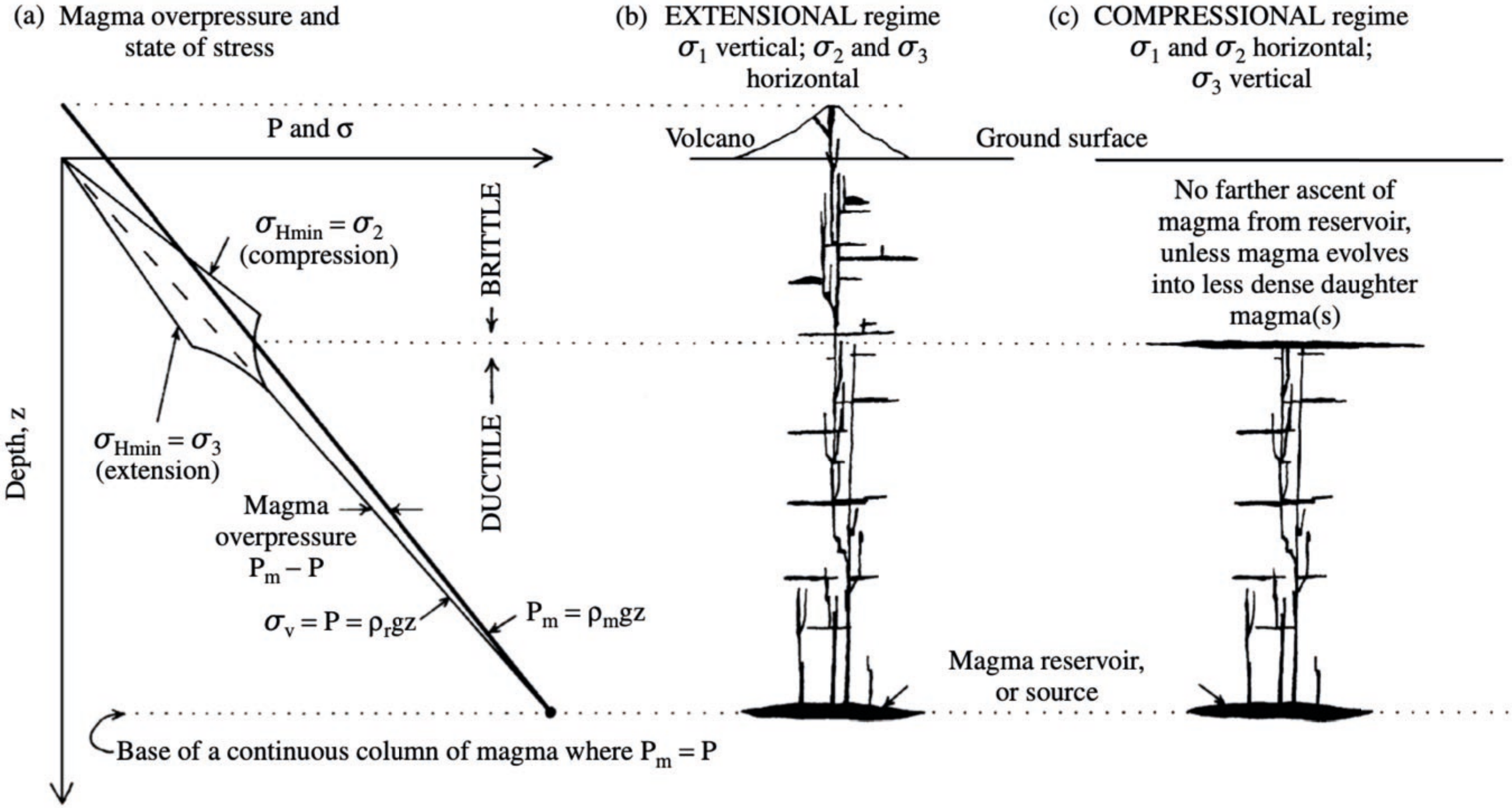
Pilanesberg Caldera

Pilanesberg Caldera





Galland et al (2015)



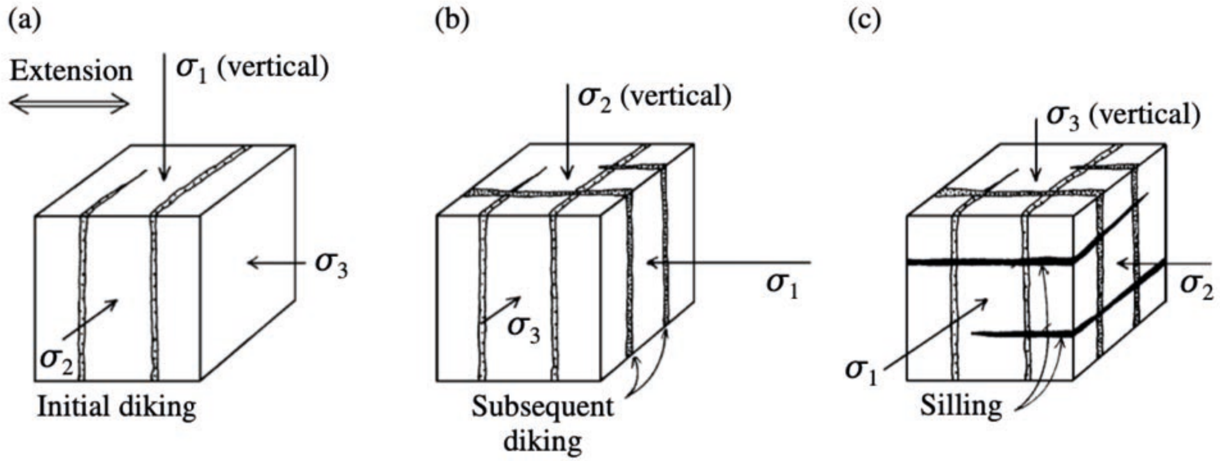
(a) Magma overpressure and state of stress

(b) EXTENSIONAL regime σ_1 vertical; σ_2 and σ_3 horizontal

(c) COMPRESSIONAL regime σ_1 and σ_2 horizontal; σ_3 vertical

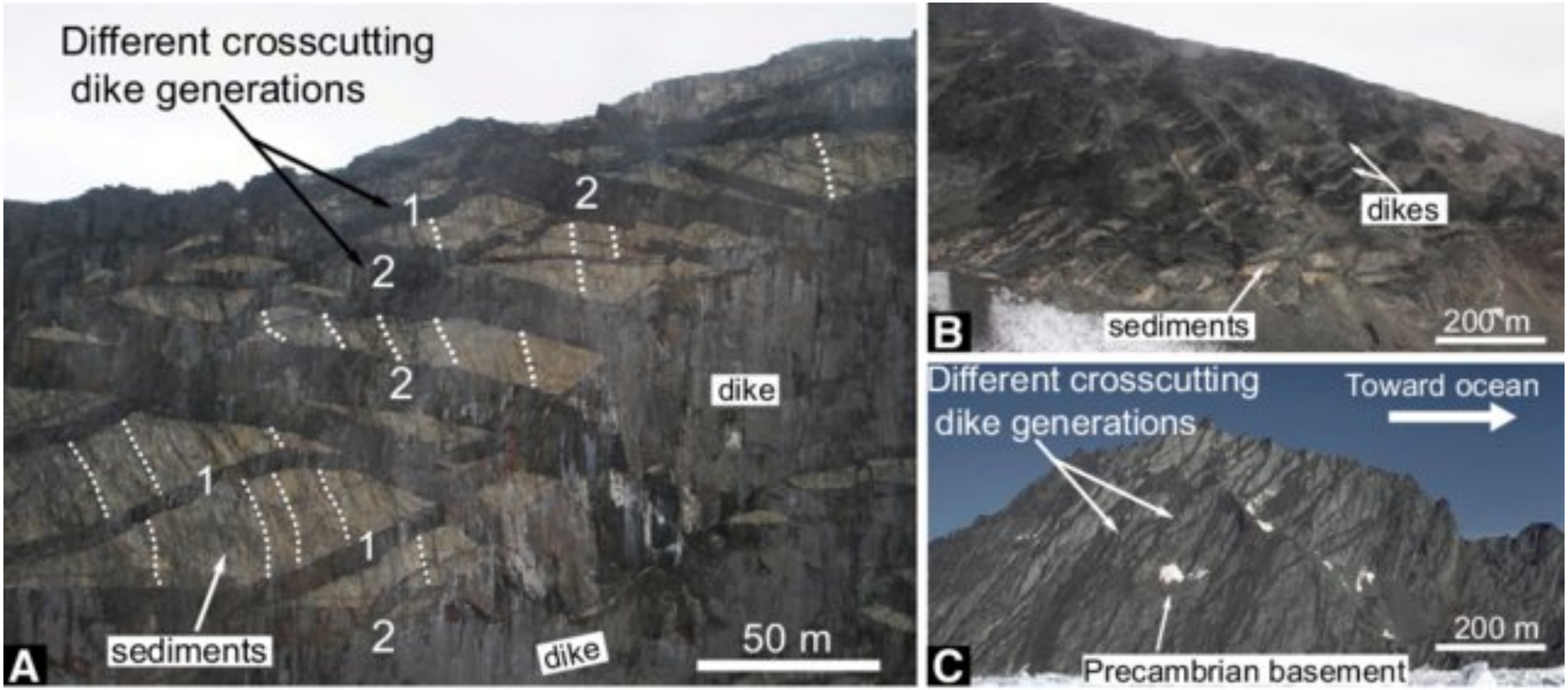
9.12 Schematic relations between static magma pressure and state of stress in the lithosphere that govern magma ascent and stagnation. See also Marrett and Emerman (1992). It is assumed for simplicity that there is no reduction in magma pressure due to viscous loss that occurs during upward flow in a dynamic system and that the tensile strength of rock is nil.

Best (2003)



Best (2003)

9.13 Intrusion of horizontal sills in an extensional tectonic setting after vertical diking. (a) Initial intrusions are vertical dikes perpendicular to horizontal least compressive principal stress, σ_3. Wedging of magma reinforced by thermal expansion of heated wall rocks increases the stress perpendicular to dikes so that σ_3 becomes σ_1 in (b). Relative magnitude of other two principal stresses remains the same: Vertical σ_1 becomes σ_2 and horizontal σ_2 becomes σ_3. In this new state of stress, additional magma is emplaced in vertical dikes perpendicular to initial ones. After this subsequent diking, magnitudes of principal stresses are again interchanged to yield a third state of stress in (c) where σ_3 is now vertical, allowing horizontal sills to develop as more magma is introduced. The sills lift the overlying crust against gravity. (Redrawn from McCarthy and Thompson, 1988.)



Abdelmalak et al (2015; Geology)

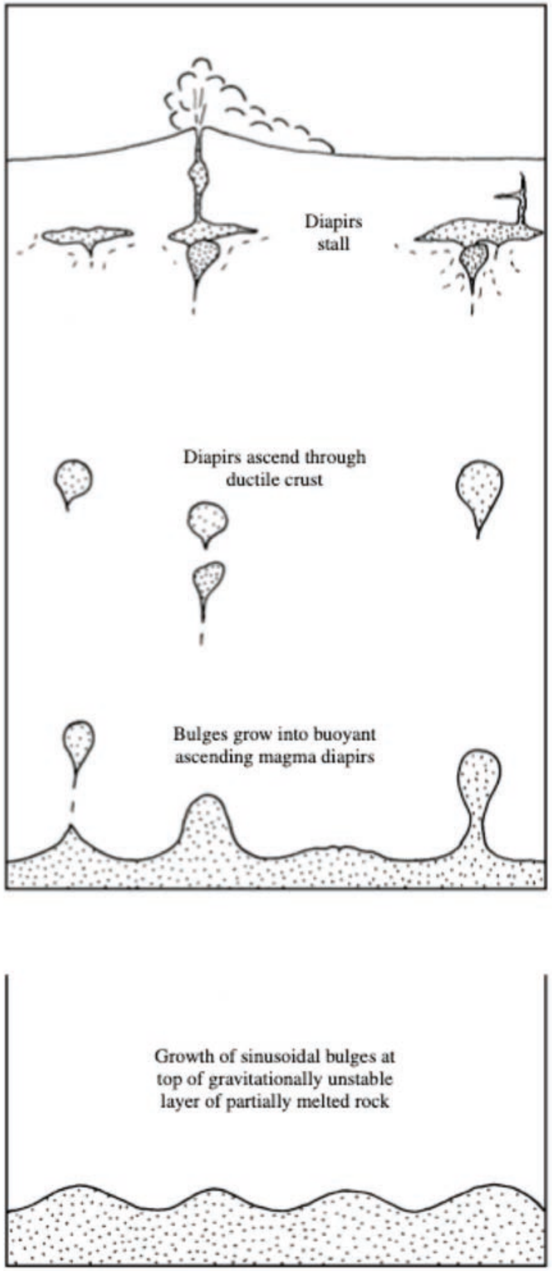
Varie risorse online

https://app.visiblegeology.com/profile.html

(Modelli geologici in 3D)

Diapiri

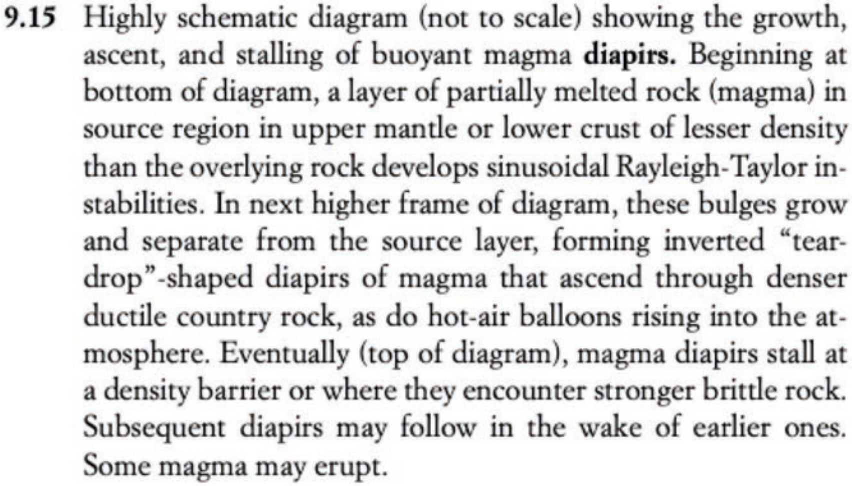
Formazione di diapiri:



Best (2003)

I termini diapiri e *plumes* sono usati per indicare volumi di materiale che risalgono per effetto di un contrasto di densità con il materiale circostante, ovvero per «galleggiamento» (*buoyancy*).

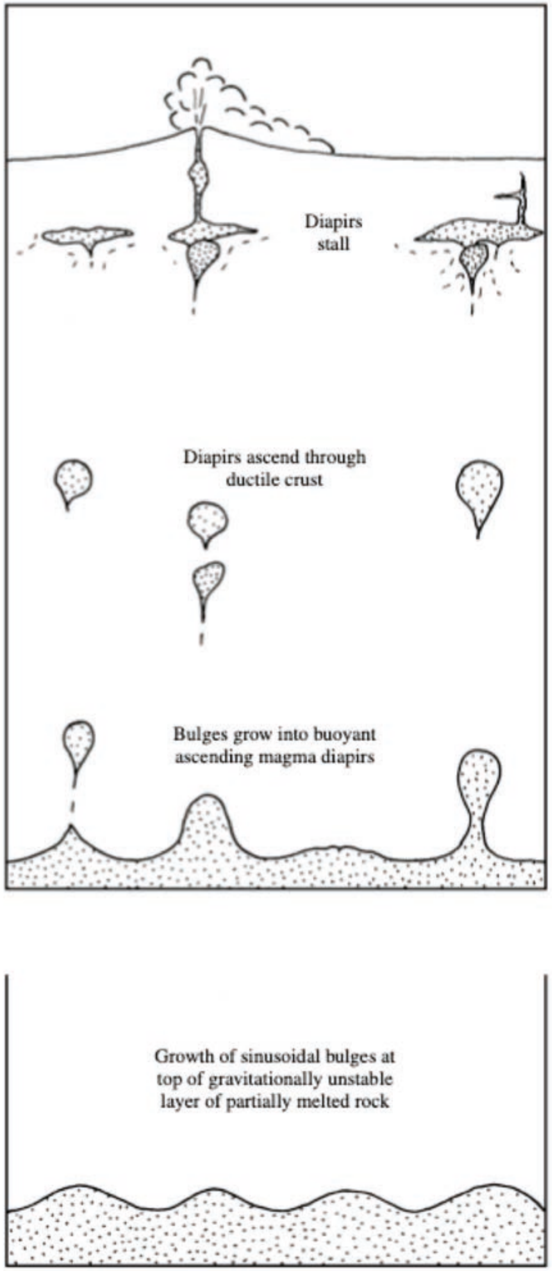
Il termine plume è più utilizzato per volumi di mantello (*mantle plumes*), mentre il termine diapiro è utilizzato per contesti crostali o comunque litosferici (e.g. diapiri salini, diapiri di magma).



9.15 Highly schematic diagram (not to scale) showing the growth, ascent, and stalling of buoyant magma **diapirs.** Beginning at bottom of diagram, a layer of partially melted rock (magma) in source region in upper mantle or lower crust of lesser density than the overlying rock develops sinusoidal Rayleigh-Taylor instabilities. In next higher frame of diagram, these bulges grow and separate from the source layer, forming inverted "teardrop"-shaped diapirs of magma that ascend through denser ductile country rock, as do hot-air balloons rising into the atmosphere. Eventually (top of diagram), magma diapirs stall at a density barrier or where they encounter stronger brittle rock. Subsequent diapirs may follow in the wake of earlier ones. Some magma may erupt.

Diapiri

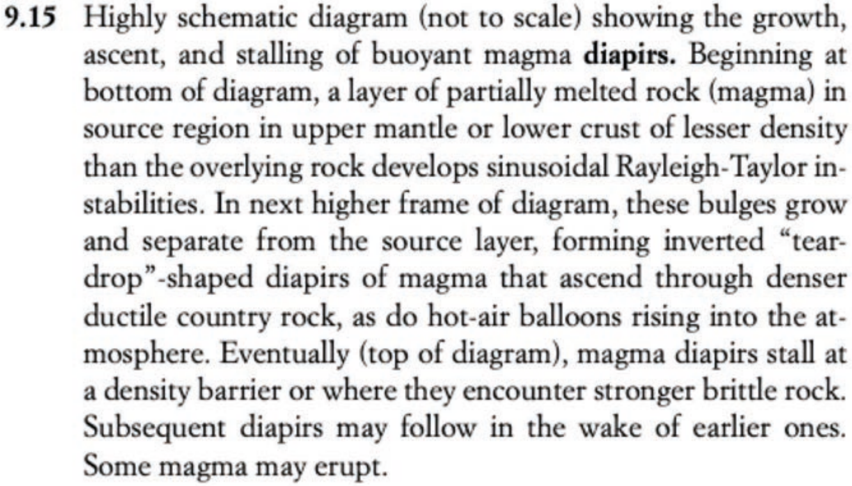
Formazione di diapiri:



Best (2003)

Il principio della formazione dei diapiri è basato sul fatto che qualsiasi corpo di materiale poco denso che sta al di sotto di un corpo più denso è instabile dal punto di vista gravitazionale.

Nel caso i corpi siano tabulari e stratificati, la parte superiore del corpo meno denso tenderà a formare delle protuberanze sinusoidali, chiamate instabilità di Rayleight-Taylor, che cresceranno fino a quando l'inversione di densità viene stabilizzata.



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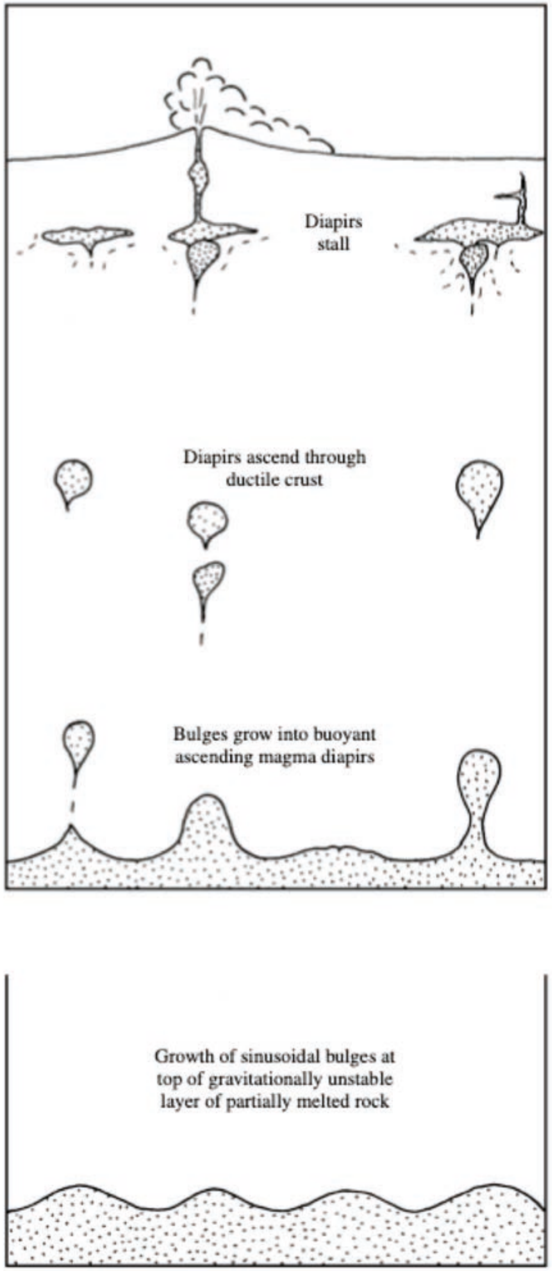
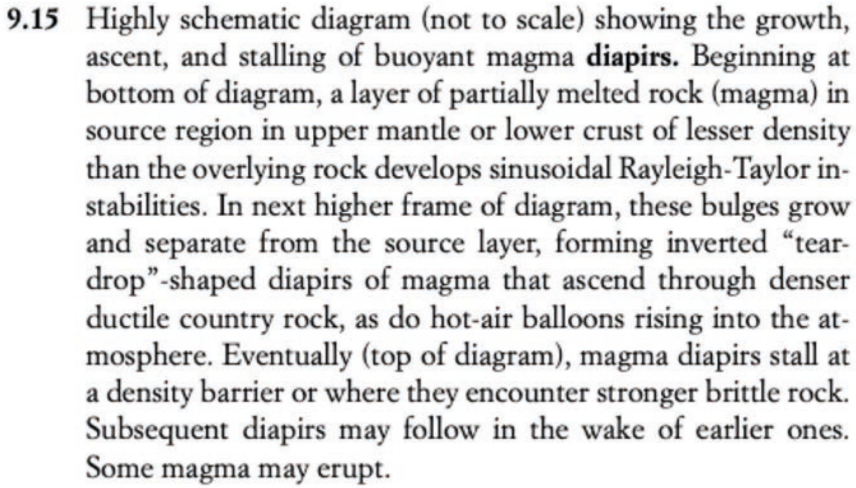


Best (2003)

La velocità di risalita dei diapiri e la loro durata sono funzione di molti parametri, tra i quali le dimensioni e la forma dei diapiri stessi.

Maggiore sarà il rapporto tra volume e area del diapiro, maggiore sarà la forza di galleggiamento e minore sarà la resistenza alla trazione.

Quindi, la forma ottimale per un diapiro sarà quella di una sfera, che tra le altre cose, è anche quella che permette di avere una perdita di calore per conduzione inferiore.



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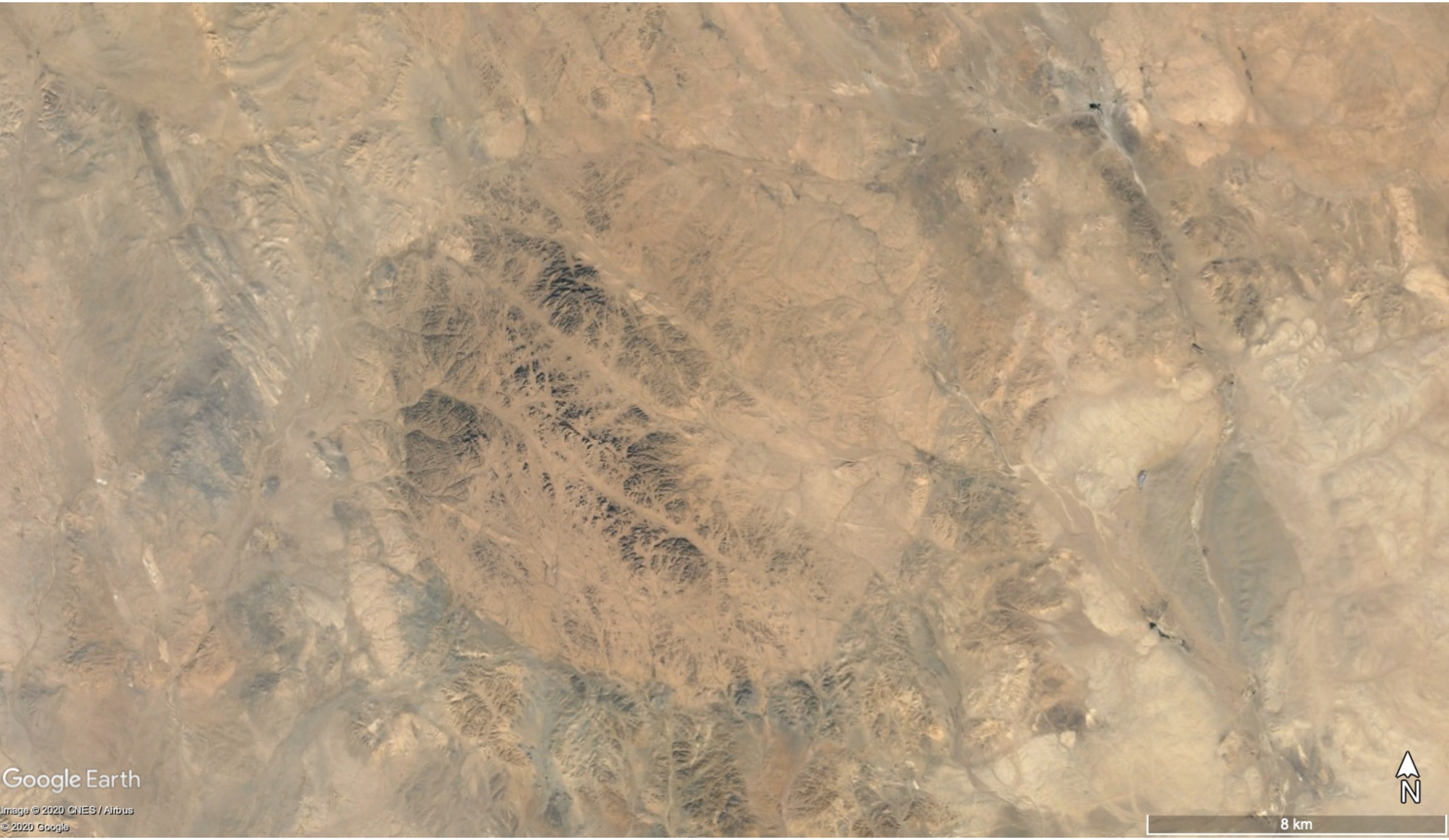
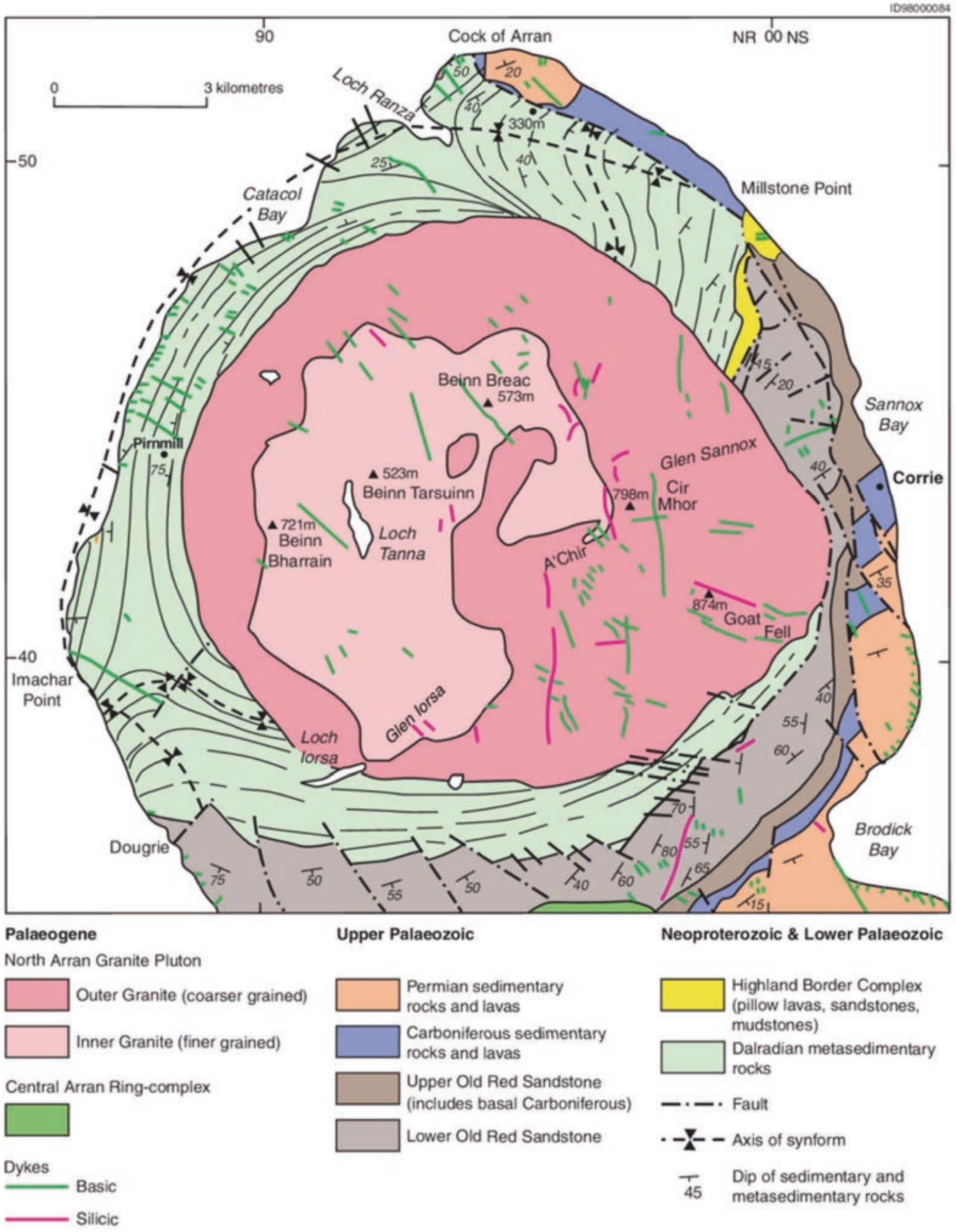
I grandi corpi granitici affioranti oggi sulla superficie erano dei diapiri?

La formazione di un granito per diapirismo può essere provata solamente quando si può dimostrare che vi sia stata una risalita verticale del corpo viscoso

Mongolia centrale



North Arran Granite Pluton (Scozia)



Emeleus & Bell (2005)

Isola d’Elba

Isola d’Elba

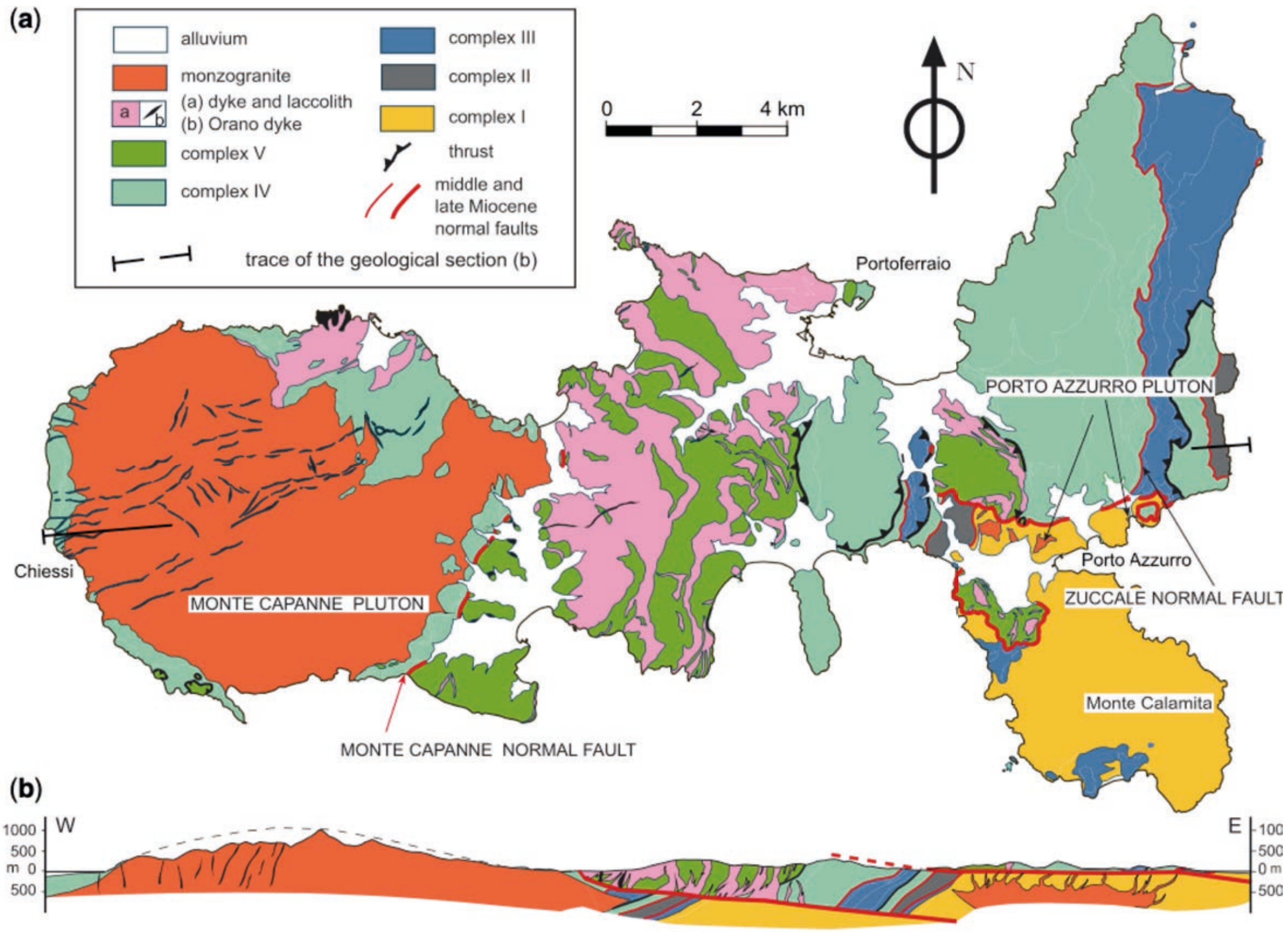


Fig. 2. Elba Island: (**a**) schematic geological map and (**b**) cross-section. The Monte Capanne pluton is exposed for *c.* 67 km^2.

Caggianelli et al (2015; Geol. Soc. London Spec. Publ.)

La messa in posto dei magmi nella crosta
(la formazione dei plutoni)

La messa in posto di un corpo magmatico al di sotto della superficie implica che un certo volume di crosta deve essere spostato.

Per quanto riguarda i magmi derivanti dal mantello, due sono i modi possibili tramite i quali un magma si fa spazio nella crosta per poter formare dei corpi plutonici:

1) tramite sollevamento della superficie
2) tramite inspessimento crostale, ossia il limite crosta-mantello (Moho) si abbassa, compensando il volume di mantello che ha fuso per creare il magma stesso

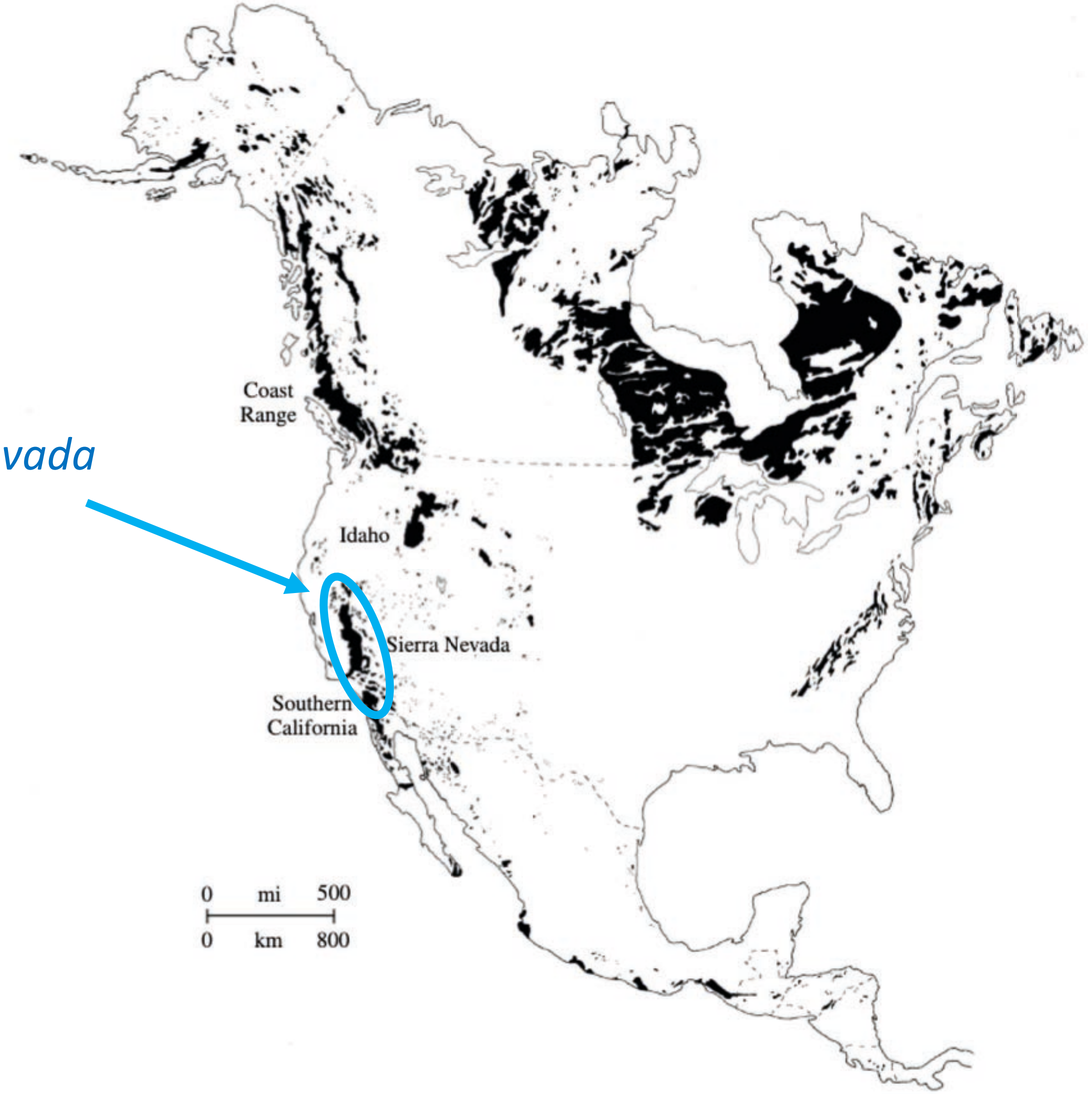
Lo spazio necessario per i magmi generati o derivanti dalla crosta inferiore può d'altra parte essere creato anche tramite movimento della porzione di crosta verso il basso.

La maggior parte delle intrusioni esposte oggi sulla superficie sono composizionalmente e tessituralmente eterogenei.

In base al tipo di eterogeneità, possiamo dividere le intrusioni in due tipi principali:

- **Intrusioni composite.** Sono composte da volumi composizionalmente e/o tessituralmente diverse che riflettono la messa in posto di due o più magmi ben distinti.

Sierra Nevada Batholith



Best (2003)

9.16 Distribution of exposed granitic rocks in North America. Granitic rocks in Precambrian Canadian shield are generalized and include some metamorphic rocks. Rocks in the Appalachian orogen along the U.S. East Coast are mostly Paleozoic. Labeled **batholiths** along the west coast in the Cordilleran orogen are mostly Mesozoic. (Redrawn from the Tectonic Map of North America, U.S. Geological Survey.)

Sierra Nevada Batholith

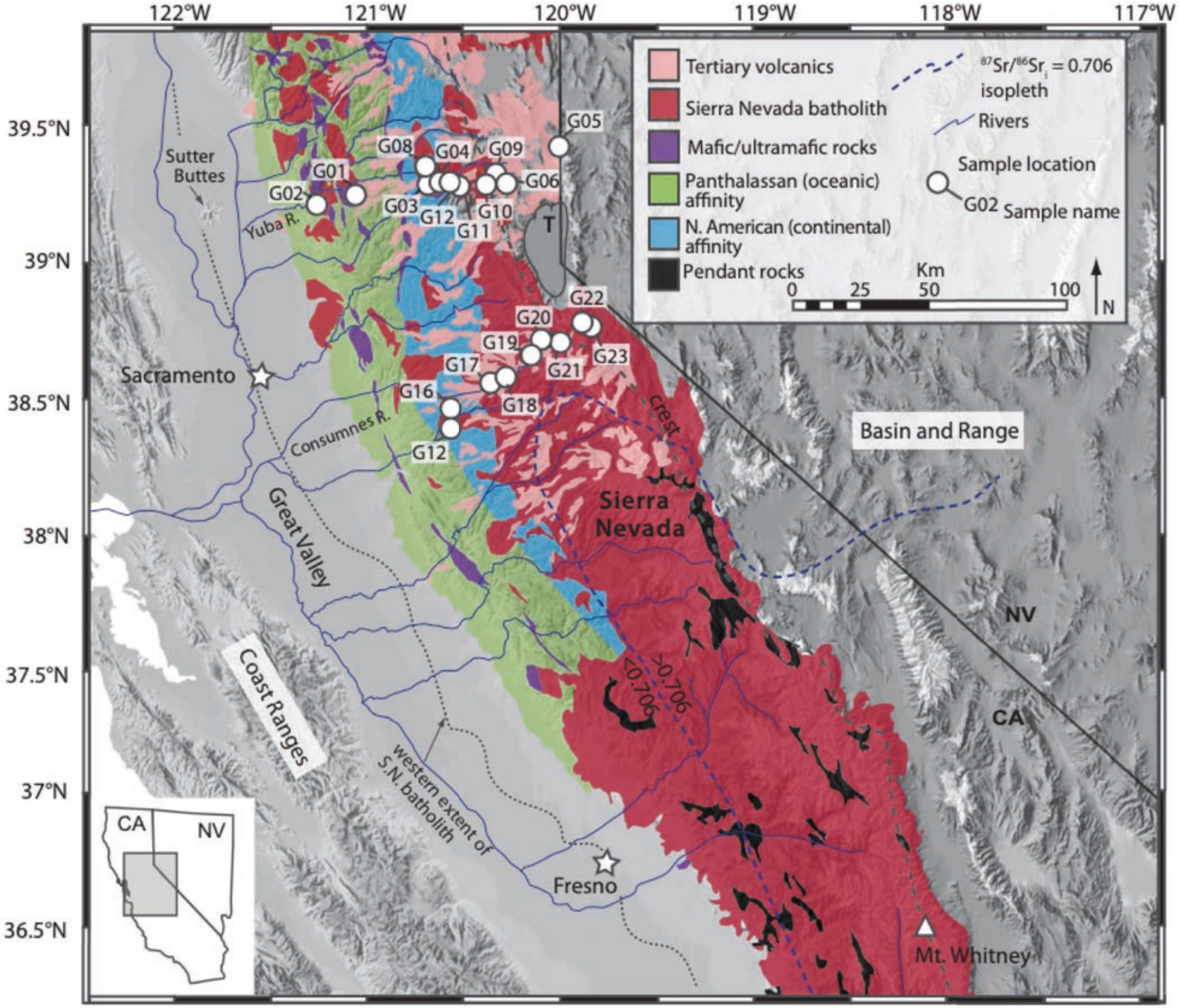


Figure 1. Generalized geologic map of the central and northern Sierra Nevada, modified after Irwin and Wooden (2001), Saucedo and Wagner (1992), and Wagner et al. (1987). Sample locations (and their corresponding names) are shown in white. The Sr_i 0.706 line is modified after Kistler and Peterman (1978) and Kistler (1990). Belts of metamorphic rocks in the northern Sierra foothills have been grouped according to the two different interpreted lithosphere types (Panthalassan and North American) of Kistler (1990). The western extent of the Great Valley is based on the presence of tonalitic and gabbroic arc-related basement sampled in well cores (Williams and Curtis, 1977; Saleeby, 2007).

Cecil et al. (2011; Geosphere)

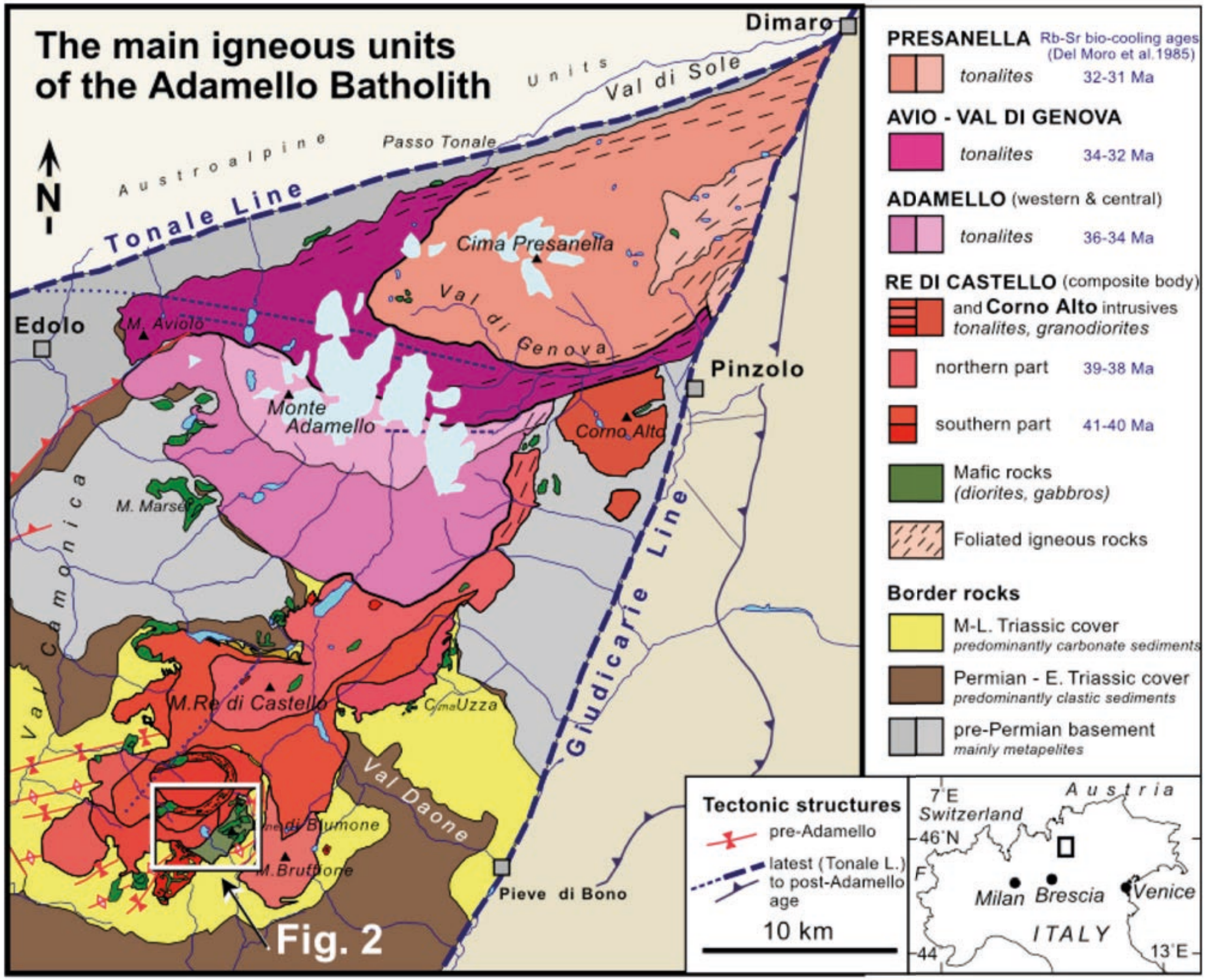


Fig. 1. Simplified geologic map of the Adamello batholith after Schaltegger et al. (2009), illustrating the approximate ages, lithologic characteristics, and designations of the main igneous units. See Schaltegger et al. (2009) for more detailed map and geochronology of the Re di Castello pluton. Location of the field site and Fig. 2 is outlined by the white box.

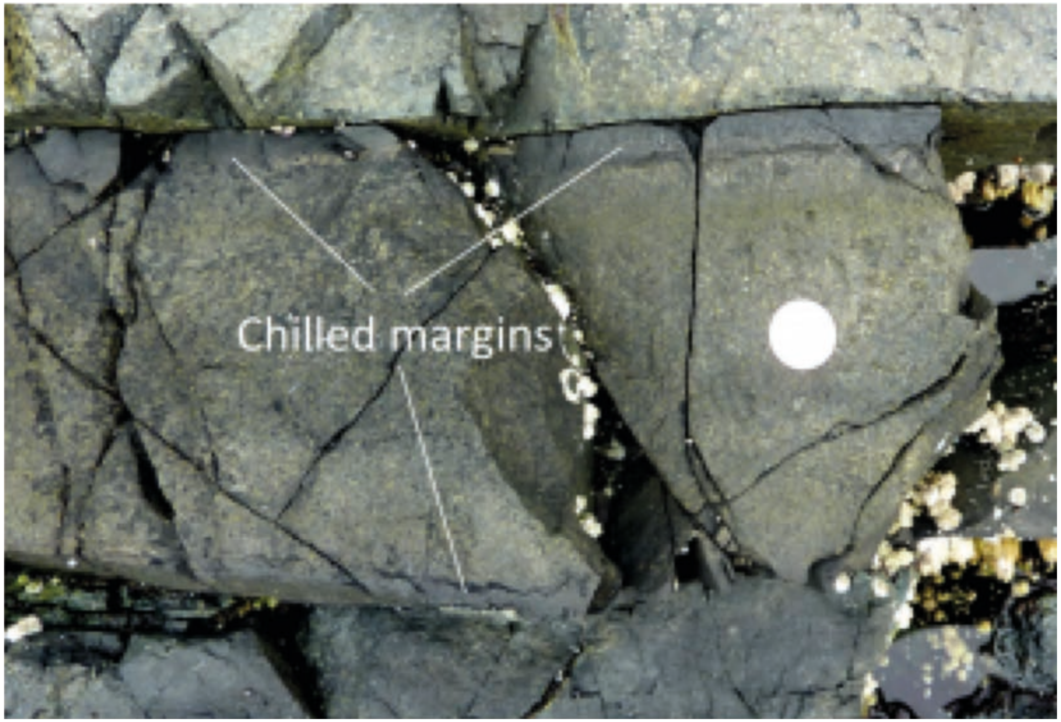
Schoene et al. (2012; EPSL)

La maggior parte delle intrusioni esposte oggi sulla superficie sono composizionalmente e tessituralmente eterogenei.

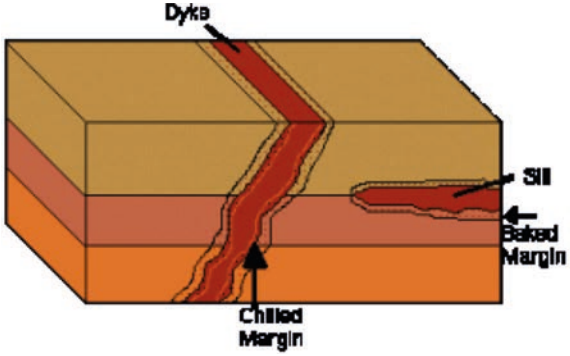
In base al tipo di eterogeneità, possiamo dividere le intrusioni in due tipi principali:

- **Intrusioni composite.** Sono composte da volumi composizionalmente e/o tessituralmente diverse che riflettono la messa in posto di due o più magmi ben distinti.

In molti casi, l'intervallo temporale tra la messa in posto dei vari magmi può essere anche grande, tale ad esempio da permettere la formazione di ***chilled margin*** in corrispondenza del contatto tra i due corpi. In altri casi, l'intervallo temporale è più piccolo e il magma successivo si può intrudere prima ancora che il magma precedente si sia raffreddato sotto la sua T di *solidus*, formando contatti tra i corpi che mostrano evidenze di contrasto termico meno accentuato.



https://courses.lumenlearning.com/physicalgeology/chapter/3-5-intrusive-igneous-bodies/



https://geologymike.wordpress.com/2013/10/21/rocks-made-by-fire/

La maggior parte delle intrusioni esposte oggi sulla superficie sono composizionalmente e tessituralmente eterogenei.

In base al tipo di eterogeneità, possiamo dividere le intrusioni in due tipi principali:

- **Intrusioni composite.** Sono composte da volumi composizionalmente e/o tessituralmente diverse che riflettono la messa in posto di due o più magmi ben distinti.
In molti casi, l'intervallo temporale tra la messa in posto dei vari magmi può essere anche grande, tale ad esempio da permettere la formazione di ***chilled margin*** in corrispondenza del contatto tra i due corpi. In altri casi, l'intervallo temporale è più piccolo e il magma successivo si può intrudere prima ancora che il magma precedente si sia raffreddato sotto la sua T di *solidus*, formando contatti tra i corpi che mostrano evidenze di contrasto termico meno accentuato.

- **Intrusioni zonate.** Esse sono invece composte da parti composizionalmente e tessituralmente diverse disposte in modo più o meno concentrico.
Nei plutoni con zonatura normale, queste parti sono sempre meno mafiche andando verso l'interno. Questo tipo di zonature si può sviluppare, ad esempio, per effetto di un diapiro di magma dioritico che si ferma ad un certo livello crostale e lungo la sua scia termica dei magmi più sialici e viscosi vanno a intrudersi al di sotto, flettendo verso l'alto il corpo dioritico. Alternativamente, una zonatura normale si può formare per assimilazione della rocca mafica incassante o tramite processi di cristallizzazione di un magma inizialmente omogeneo, nel quale i minerali mafici di più alta T cristallizzano preferenzialmente vicino ai margini.

Tuolumne batholith (Sierra Nevada)

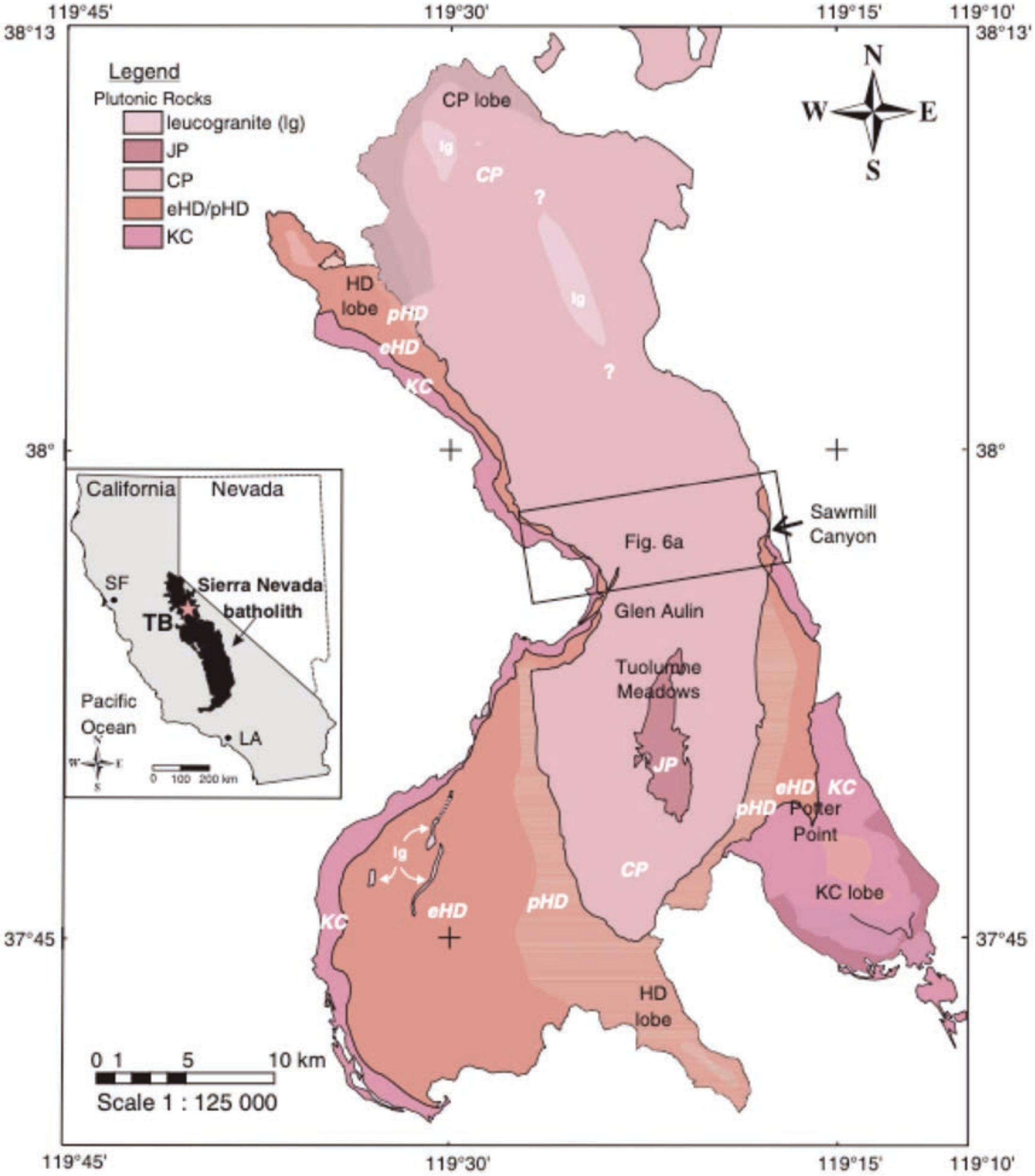
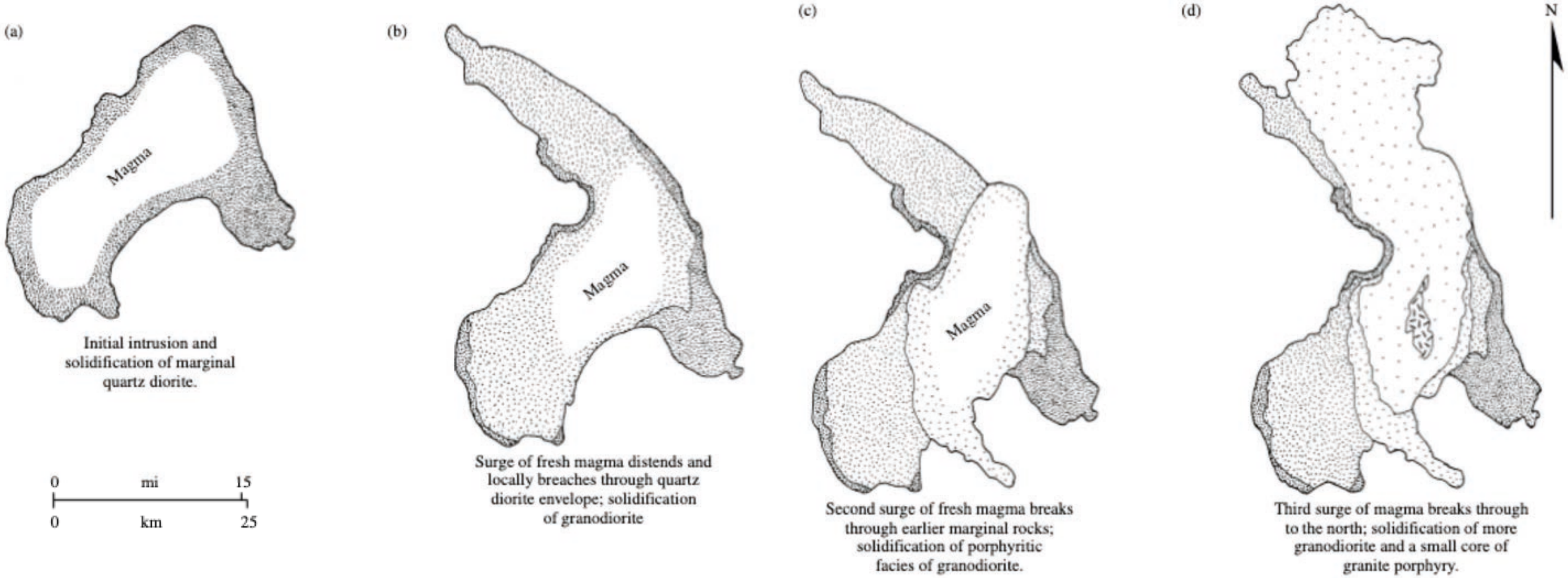


Figure 1. Geologic map of Tuolumne batholith and its host rocks (after Huber et al., 1989). Includes new mapping (by Paterson and colleagues) of much of the batholith at a scale of 1:24,000. Note the five main units in the central batholith and presence of additional internal zoning in the four lobes extending out from the units in the central batholith (after mapping by Memeti and colleagues). The structures discussed in this paper occur in all units and in lobes. Index map shows location of Tuolumne batholith (TB) in California. Box indicates location of Figure 6A. KC—Kuna Crest unit; CP—Cathedral Peak granodiorite; JP—Johnson granite porphyry; HD—Half Dome granodiorite (p is porphyritic, e is equigranular); SF—San Francisco; LA—Los Angeles.

Paterson
(2009; Geosphere)



Initial intrusion and solidification of marginal quartz diorite.

Surge of fresh magma distends and locally breaches through quartz diorite envelope; solidification of granodiorite

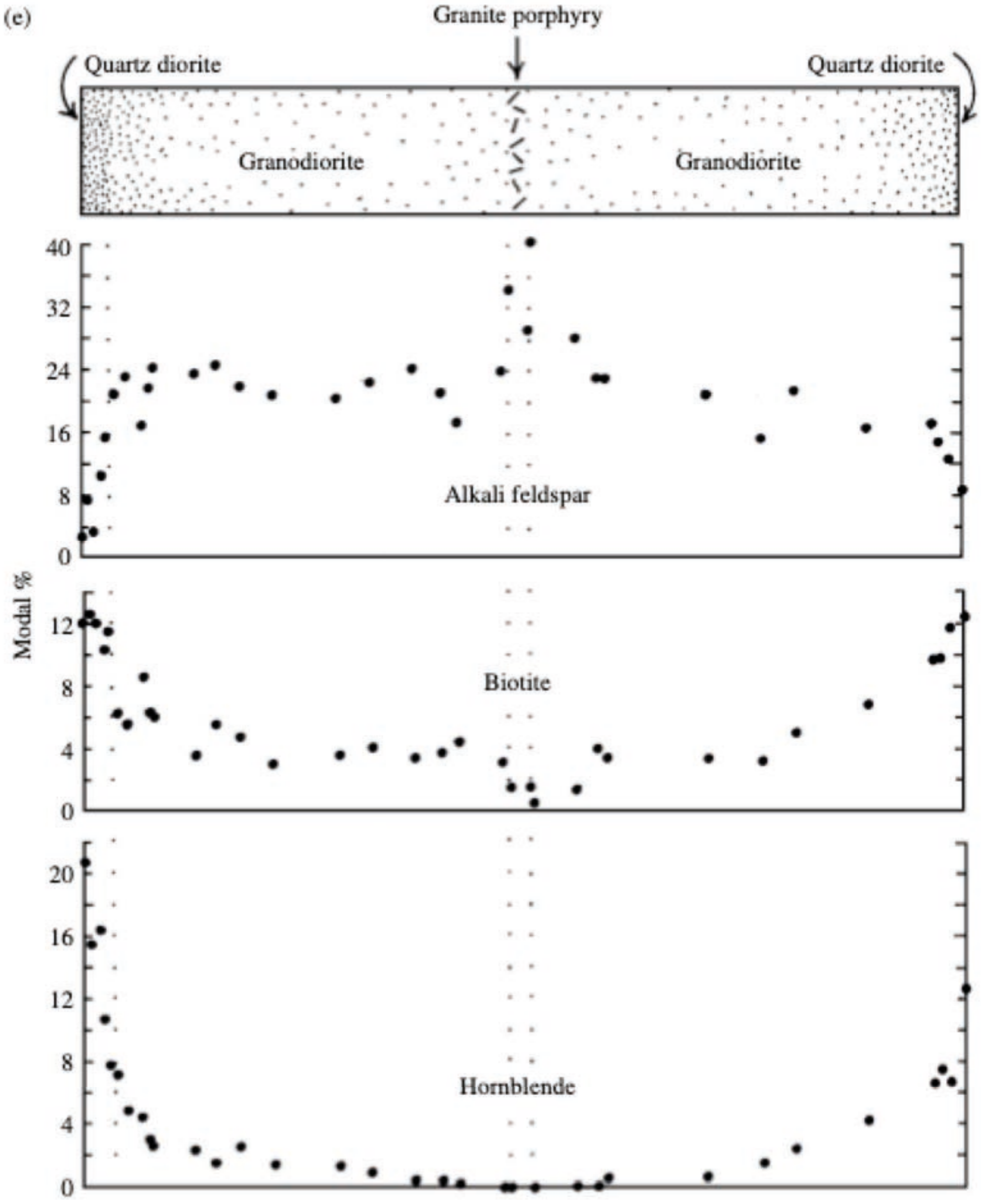
Second surge of fresh magma breaks through earlier marginal rocks; solidification of porphyritic facies of granodiorite.

Third surge of magma breaks through to the north; solidification of more granodiorite and a small core of granite porphyry.

9.18 Evolution of the Tuolumne Intrusive Series, a compositionally **zoned pluton** within the Sierra Nevada batholith, California. Mantle-derived basalt magmas contaminated by increasing amounts of partial melts of the lower continental crust were intruded into the shallower crust over a time span of several million years (Kistler et al., 1986). See also Table 13.8. (a–d) Schematic sequence of events during growth of pluton. (e) Compositional variations along a west-east line across the pluton. (Redrawn from Bateman and Chappell, 1979.)

Best (2003)

Third surge of magma breaks through to the north; solidification of more granodiorite and a small core of granite porphyry.



9.18 (*Continued*).

Best (2003)

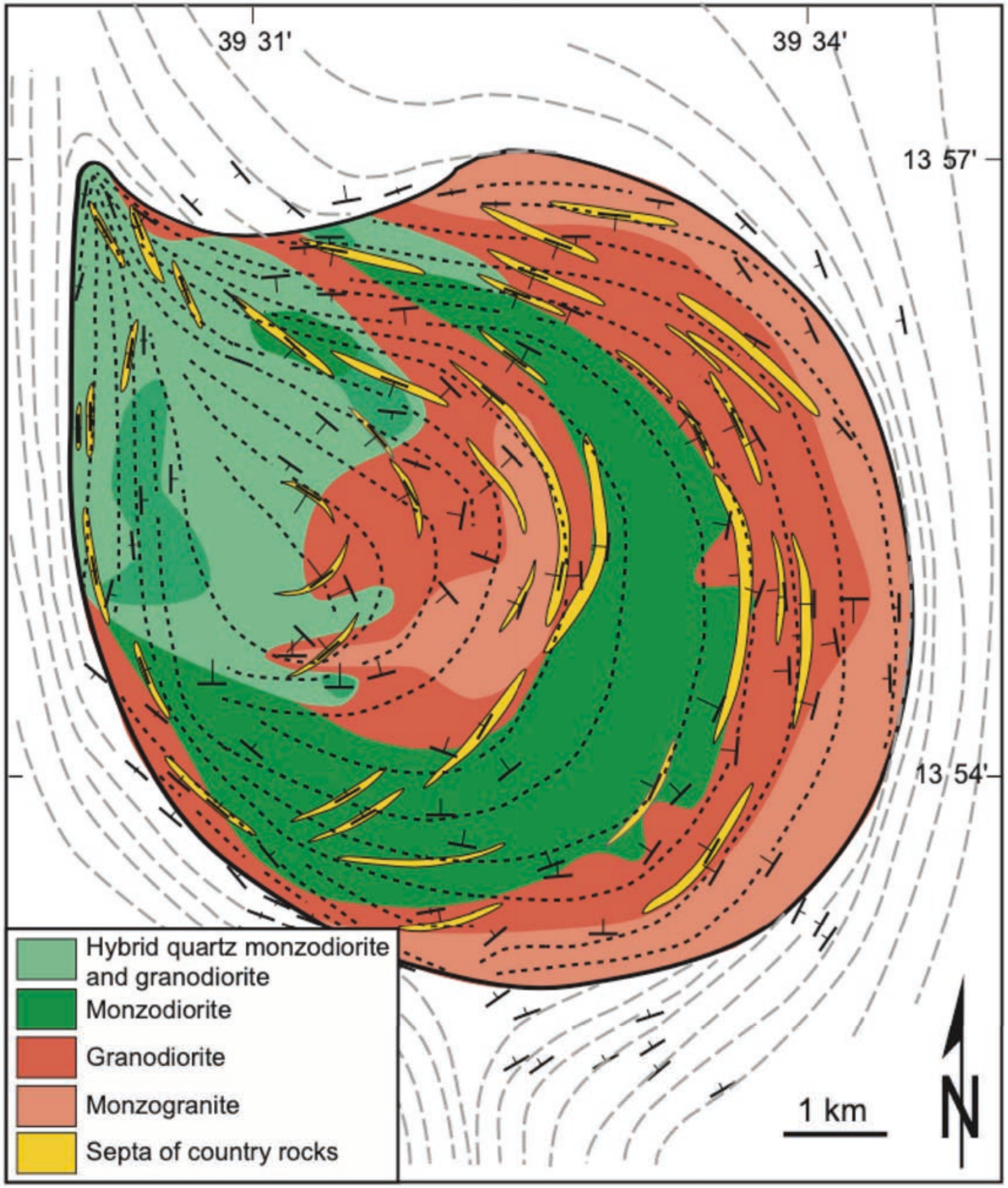
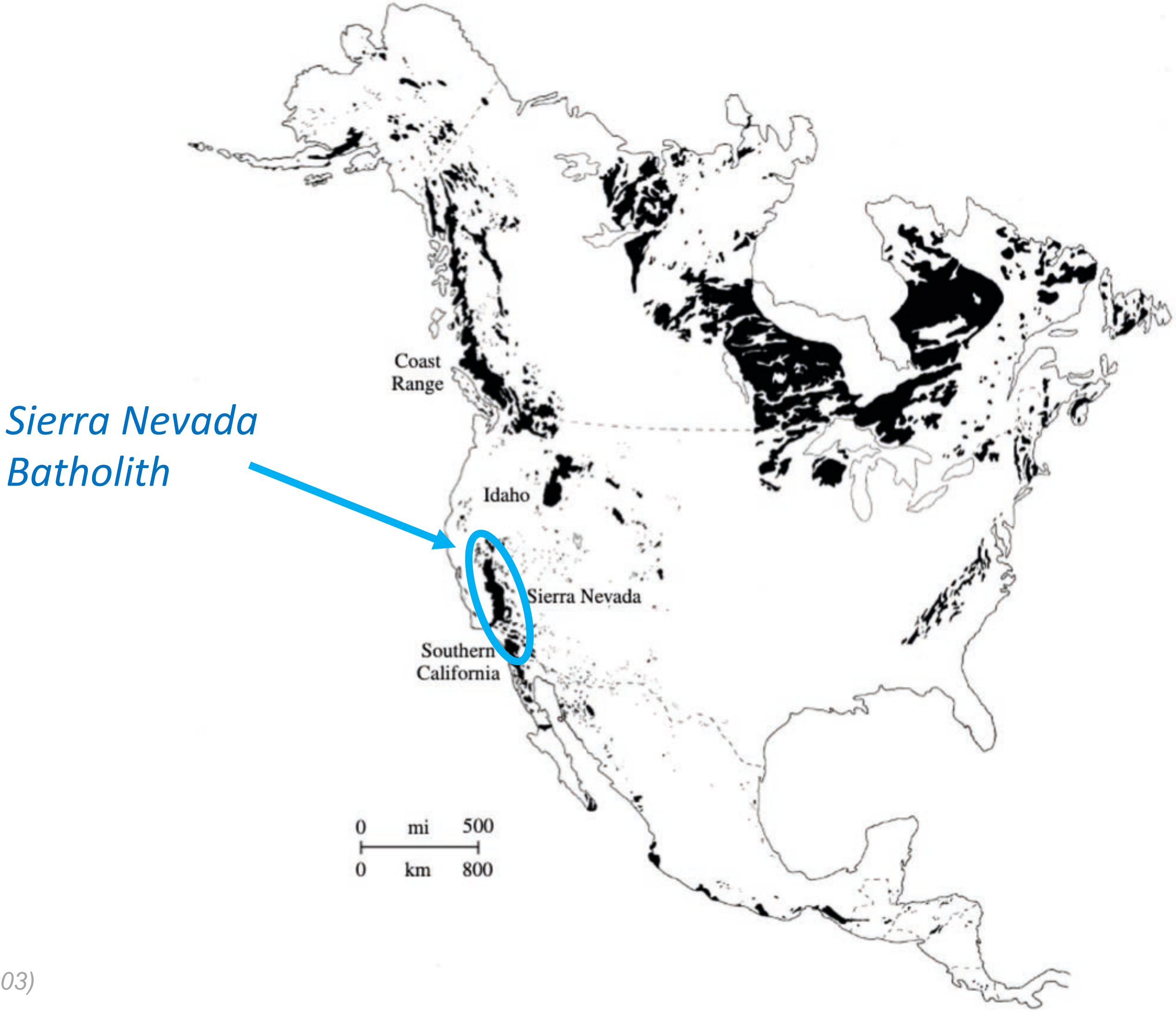


Figure 10. Geological map of the Negash pluton (northern Ethiopia) showing the shape and distribution of the country-rock septa; from Asrat et al. (2004).

Barbey (2009; Geol Belg)

Un **batolite** è un plutone, o più comunemente un gruppo di plutoni, che si estende generalmente dalla decina a molte centinaia di km.



Best (2003)

9.16 Distribution of exposed granitic rocks in North America. Granitic rocks in Precambrian Canadian shield are generalized and include some metamorphic rocks. Rocks in the Appalachian orogen along the U.S. East Coast are mostly Paleozoic. Labeled **batholiths** along the west coast in the Cordilleran orogen are mostly Mesozoic. (Redrawn from the Tectonic Map of North America, U.S. Geological Survey.)

Un **batolite** è un plutone, o più comunemente un gruppo di plutoni, che si estende generalmente dalla decina a molte centinaia di km.

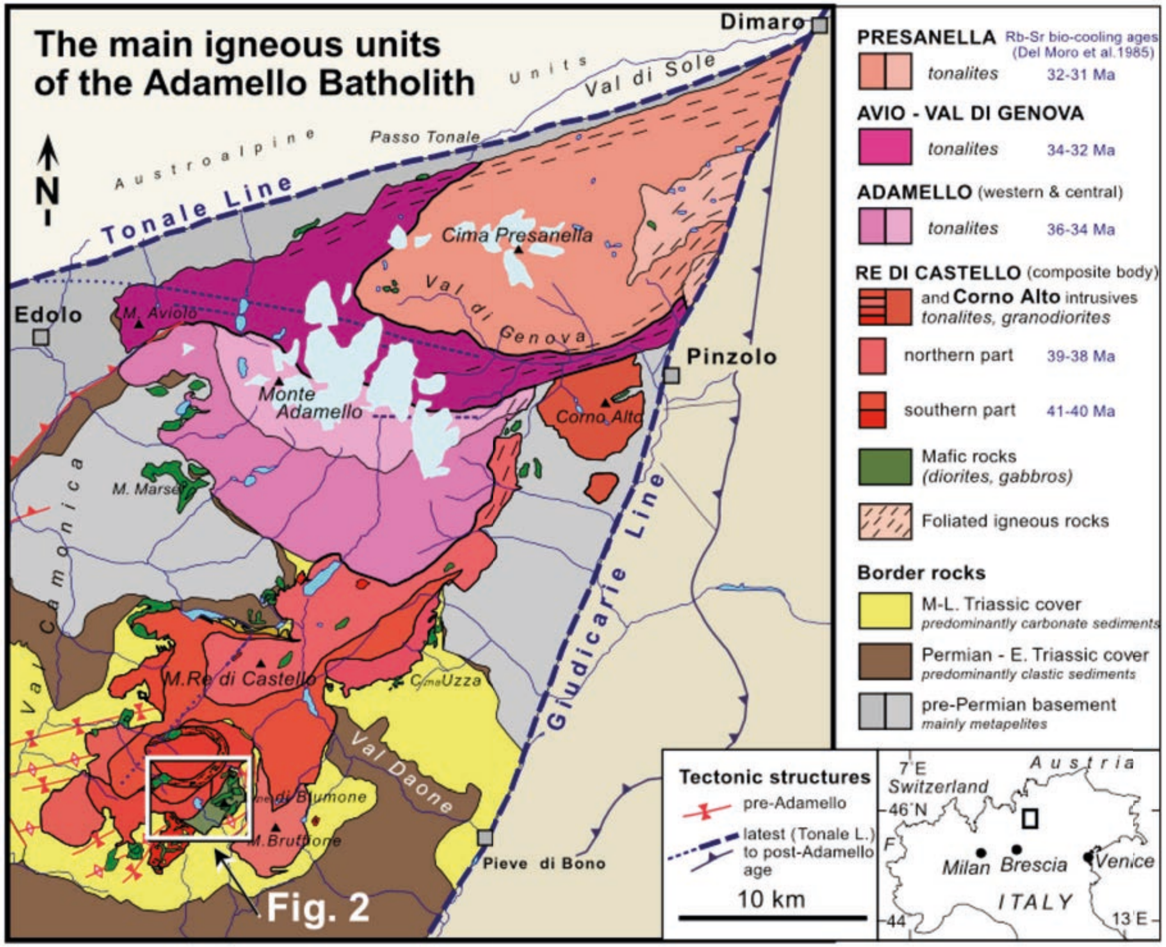
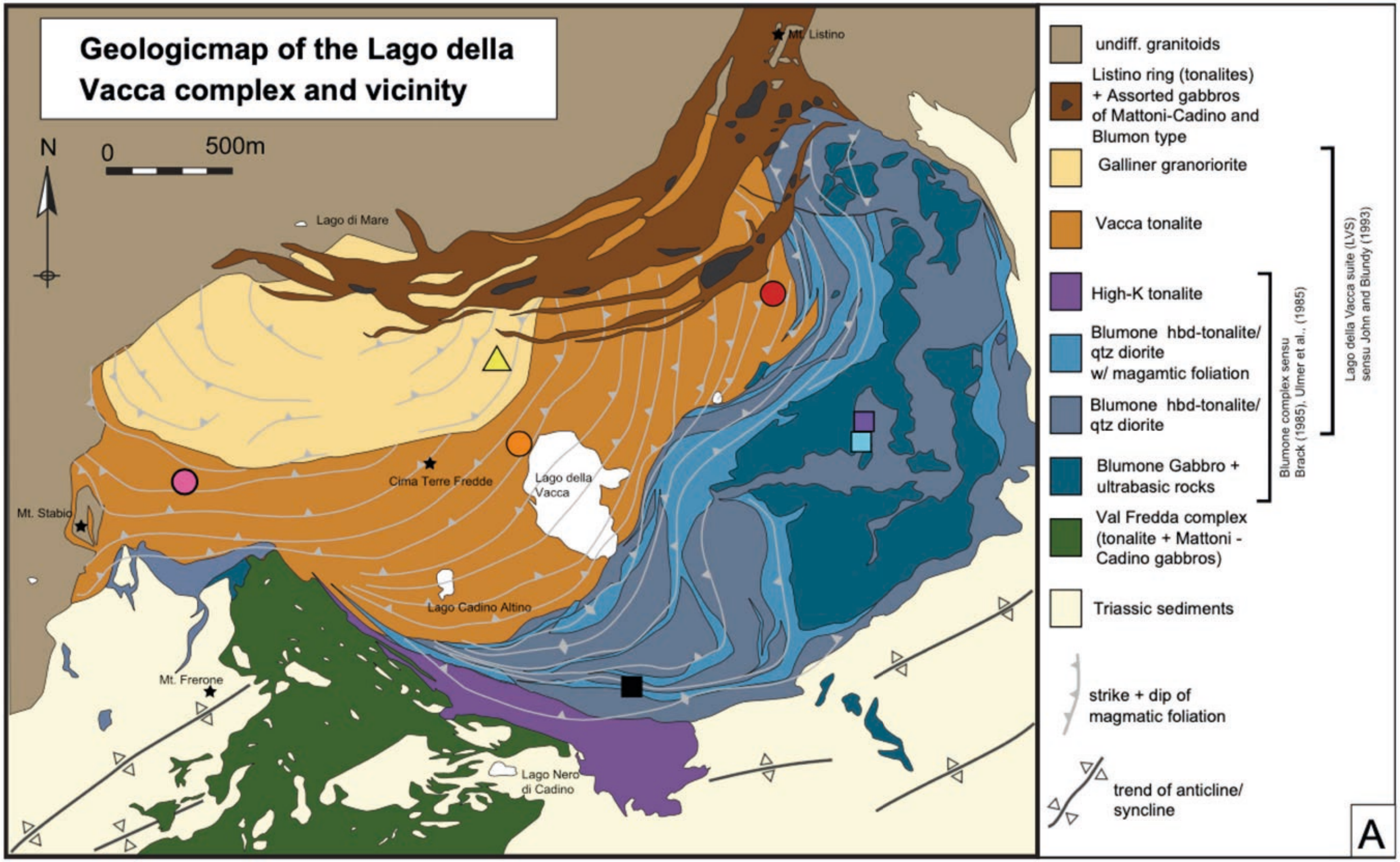


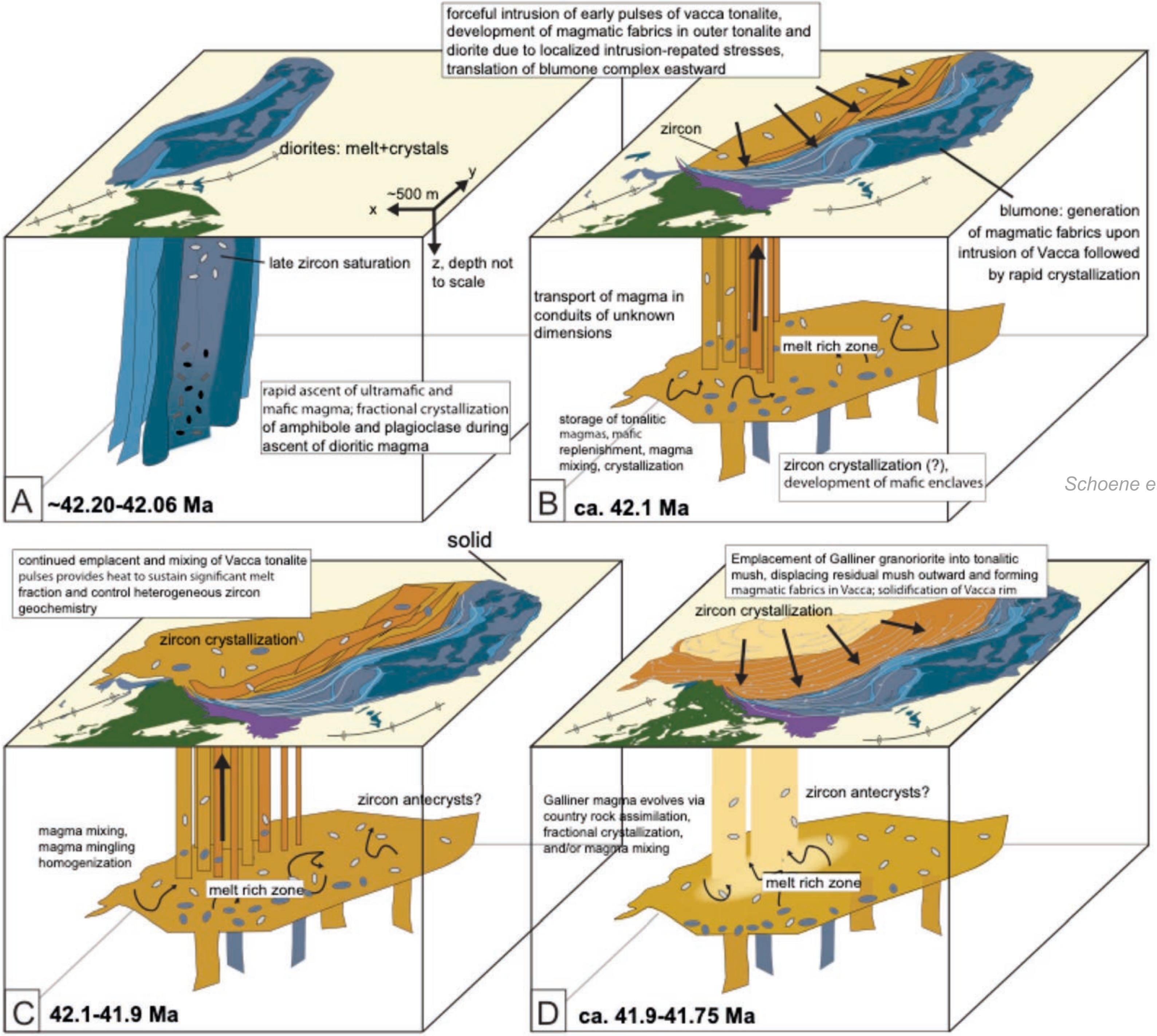
Fig. 1. Simplified geologic map of the Adamello batholith after Schaltegger et al. (2009), illustrating the approximate ages, lithologic characteristics, and designations of the main igneous units. See Schaltegger et al. (2009) for more detailed map and geochronology of the Re di Castello pluton. Location of the field site and Fig. 2 is outlined by the white box.

Schoene et al. (2012; EPSL)

(Adamello)



Schoene et al. (2012; EPSL)



rapid ascent of ultramafic and mafic magma; fractional crystallization of amphibole and plagioclase during ascent of dioritic magma

forceful intrusion of early pulses of vacca tonalite, development of magmatic fabrics in outer tonalite and diorite due to localized intrusion-repated stresses, translation of blumone complex eastward

blumone: generation of magmatic fabrics upon intrusion of Vacca followed by rapid crystallization

transport of magma in conduits of unknown dimensions

storage of tonalitic magmas, mafic replenishment, magma mixing, crystallization

zircon crystallization (?), development of mafic enclaves

continued emplacent and mixing of Vacca tonalite pulses provides heat to sustain significant melt fraction and control heterogeneous zircon geochemistry

magma mixing, magma mingling homogenization

Emplacement of Galliner granoriorite into tonalitic mush, displacing residual mush outward and forming magmatic fabrics in Vacca; solidification of Vacca rim

Galliner magma evolves via country rock assimilation, fractional crystallization, and/or magma mixing

Schoene et al. (2012; EPSL)