GL04380

Subject: **two PPs for THE ms......**
Date: Wed, 29 Mar 2000 10:39:21 -0700
From: "denis l norton" <denis@ruralnetwork.net>
To: "Jeff Hulen" <jhulen@egi.utah.edu>

Jeff:

Hope yous folks had a great trip back to Zi
We really enjoyed you being here.
Please post me Brians phone number.
Edits follow::::::::

Page 10 replacment PP:::::
Edit as to your desire.
****

>From the previous section it was shown tha
the total heat added by the felsite to the
heat the reservoir, fluid plus rock, to its
If the balance, ~91 percent,of the
felsite heat was transferred directly to ci
730 km3 of fluid would have been heated to
This is more than seven times the current
steam-reservoir volume, and using a reserv
2% (Williamson, 1992)
this 730 km3 of fluid would be equivalent t
pore space 365 times.

****

(Jeff: well this seemed intuitively large to me but I redid the calc about 5 times, EACH of these 5 times I misused a conversion from kcal to cal....duahshudaaaaa!) But, the preceding values are correct I managed to edit out some critical words. First we use nine percent of the heat to get the reservoir up to its current state.......then we say how many times can we fill that reservoir with fluid at 235C from the heat left(91percent) in the pluton. three hundred and sixty five times, eg 365. still quite interesting AND reasonable. Cant understand why the reviewers didnt catch the error.)

Page 12 PP that begins with.....These results conflict with....

Add to PP

Although extreme choices of transport parameters used in the calculations could increase the thermal life of the numerical felsite body by 75,000 yr, the values chosen are consistent with laboratory and field values. Alternatively, a more complex intrusive sequence with continuing magma supply into portions of the crust below 5.4 km subsequent to
1.2my ago might prolong the numerical systems life in ways that would be consistent with the extent and style of alteration. Recall that the shift in oxygen isotopic values, Brikowski, this volume, is explained reasonably well with a 305km3 felsite, as does the apparently single pulse vein patterns.
We strongly suggest that the geochronological data sets be reevalutated in the
context of the type of events dated and intrinsic errors in those methods. Our guess is that the numerical and chronological and alteration data sets are actually in quite good agreement if all errors are explicitly included. yaty tyayyatyayya unhyui.

Denis Norton

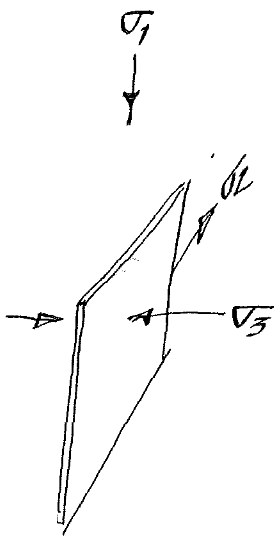
ps-keep this copy I have others.

Jeff

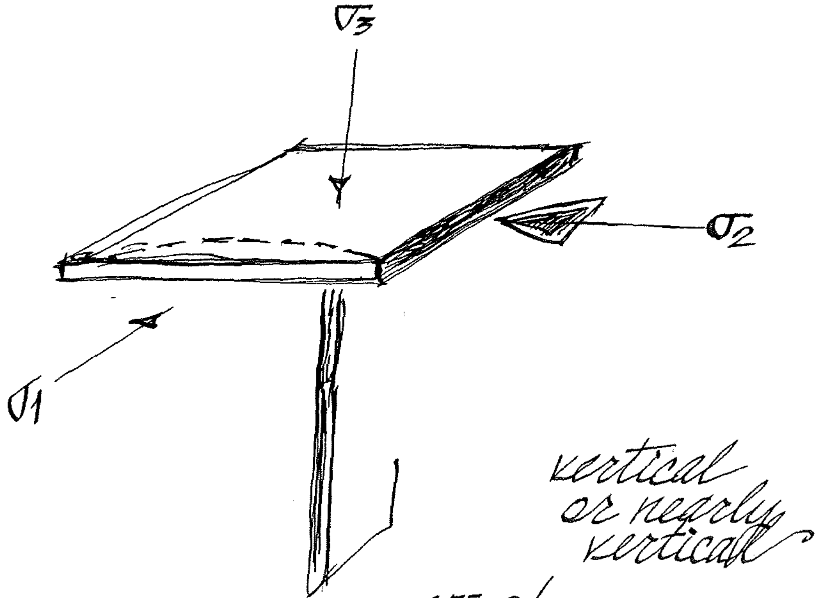
LOOK at
P 66 & beyond.
in particular note that
$X_{Ca_2Fe_3Si_3O_{12}(OH)}$ for Sacrams < 0.3,
& of the geothermals
but also that Xepidote may
be a diagnostic of the history of fluid comps. D

Bending the crust, not really lifting it

Dike σ_1 vertical or nearly vertical



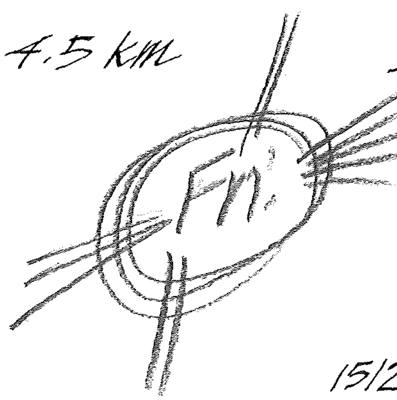
~~σ_2~~



2.75 g/cc

(−) 4.5 km

5.5 km



1,512,500 g/cm²

1512 kg/cm²

1 kg/cm

$\frac{1512\ kg}{cm^2} \cdot 0.98$

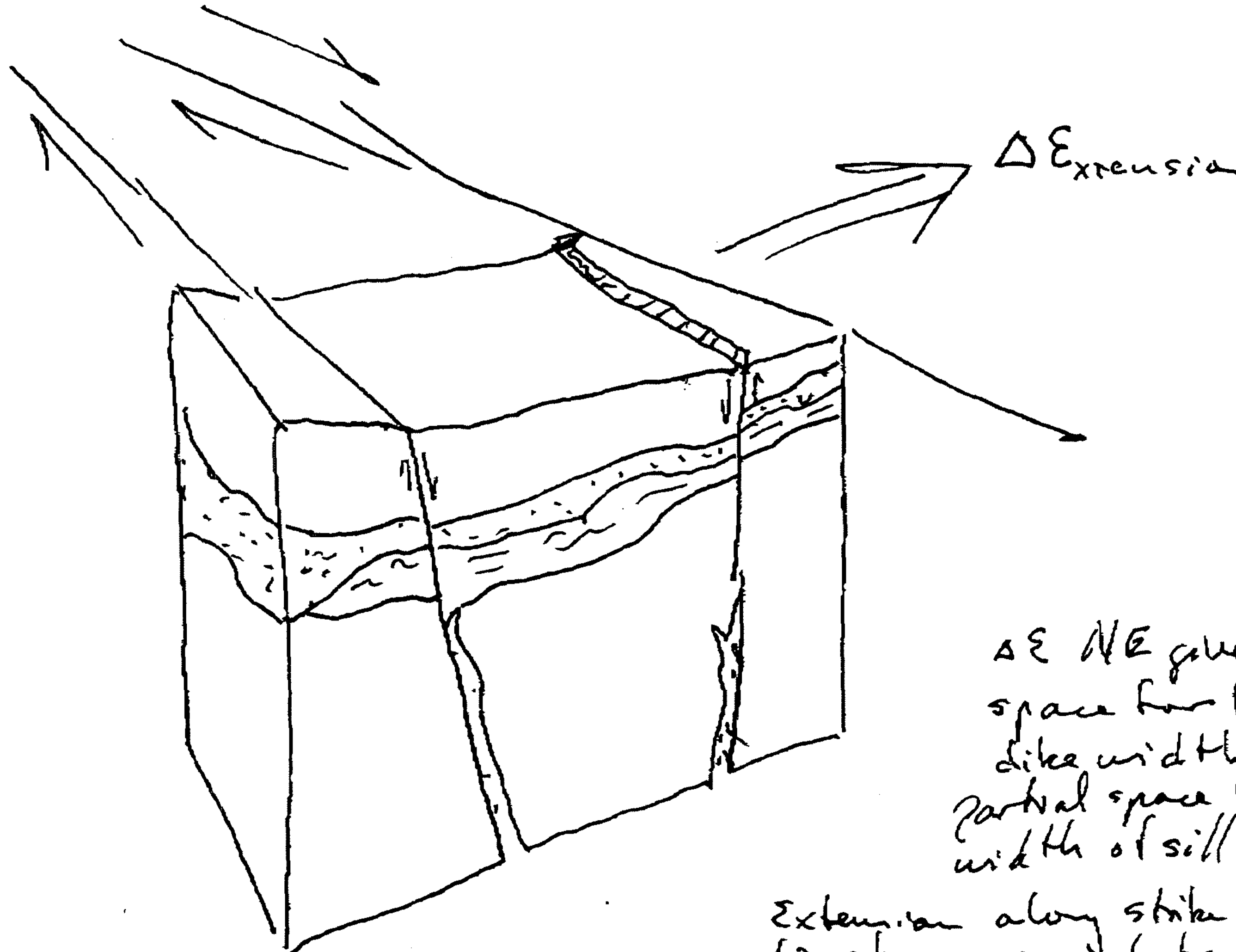
$\frac{1512\ kg}{cm^2} \times \frac{1\ kg/cm^2}{0.9804\ bars}$

$1512 \times \frac{1}{0.9804}$

$1482.4\ bars \times \frac{1\ MPa}{10\ bar} =$

148 MPa lith load

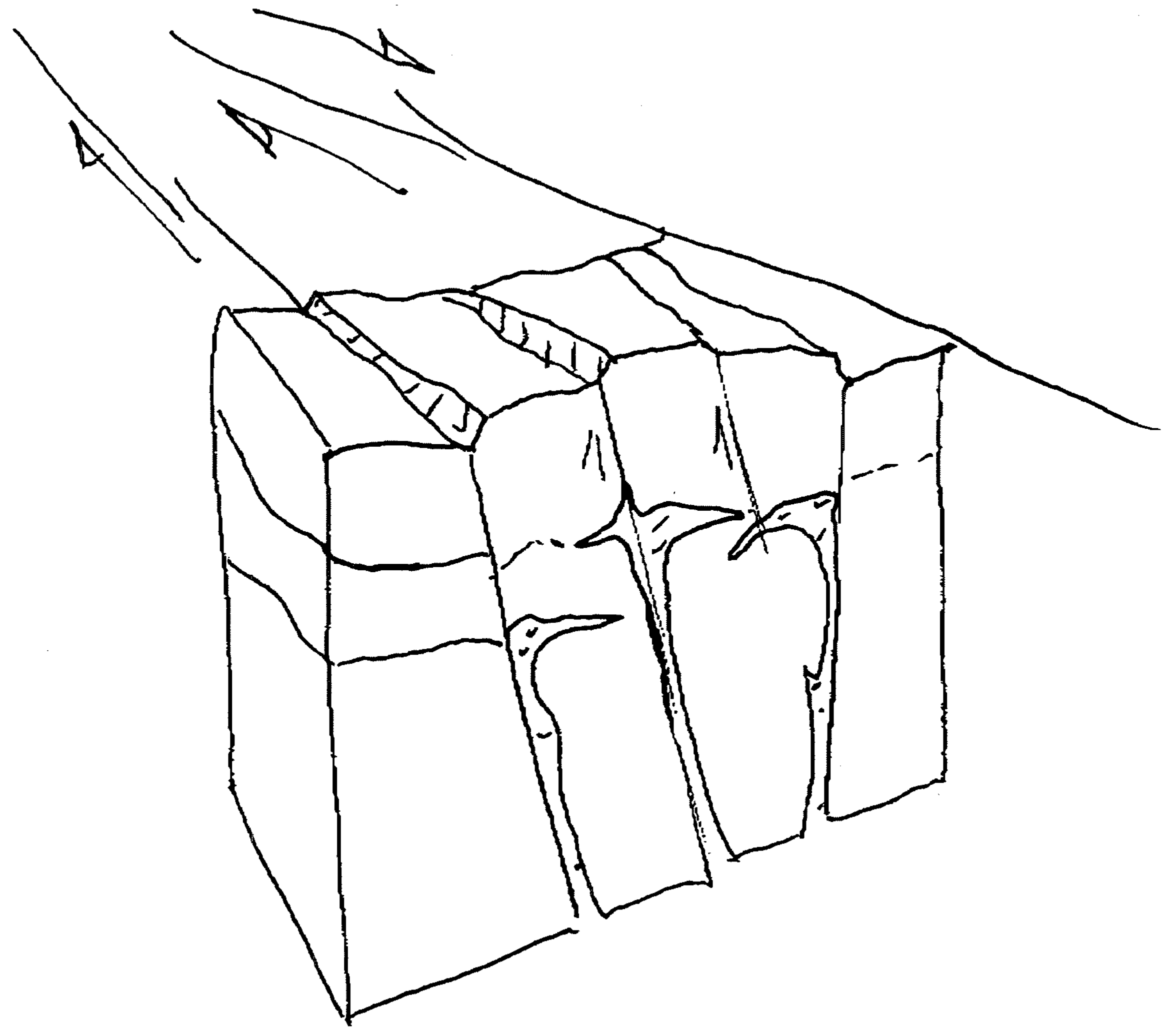
(A) t = 0

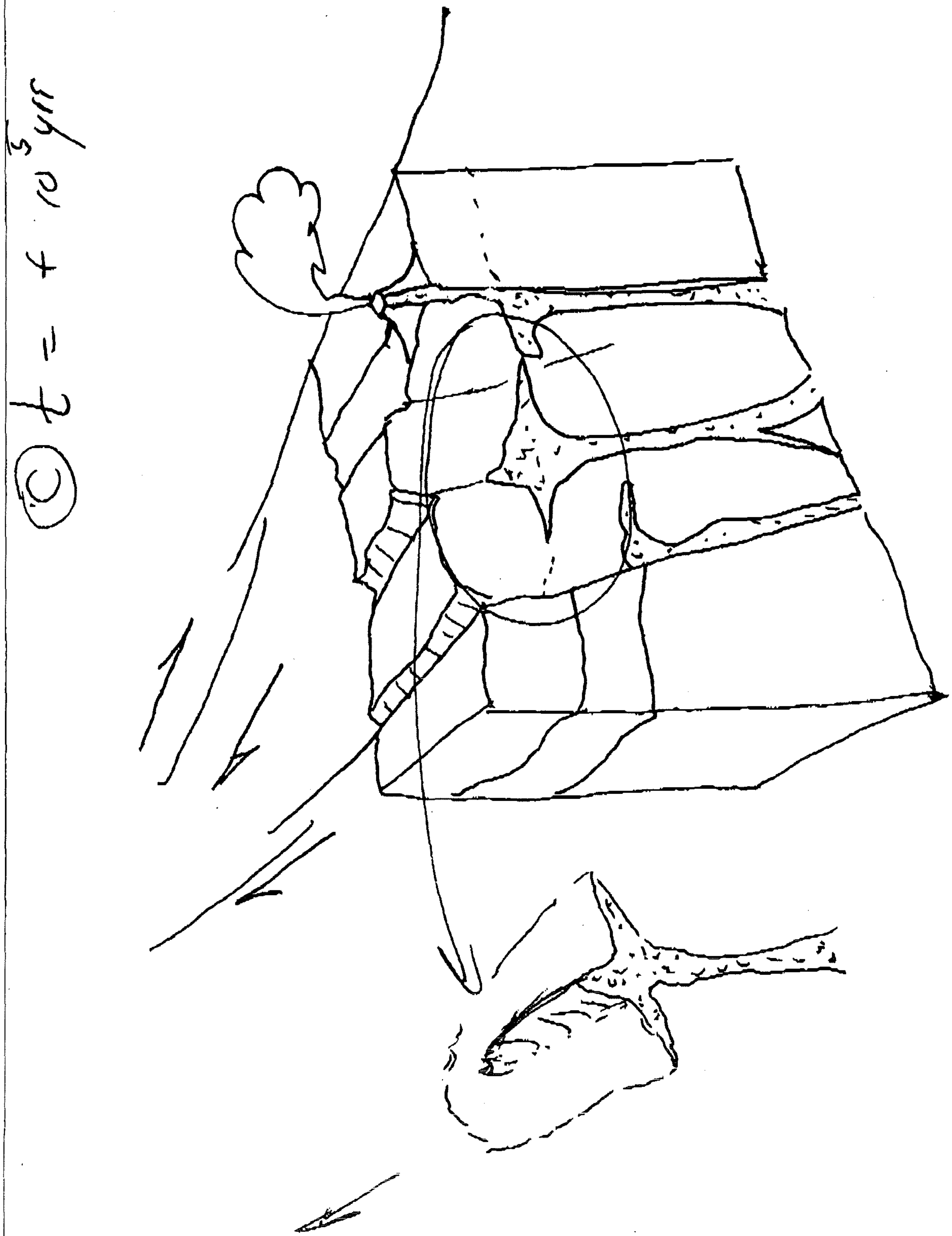


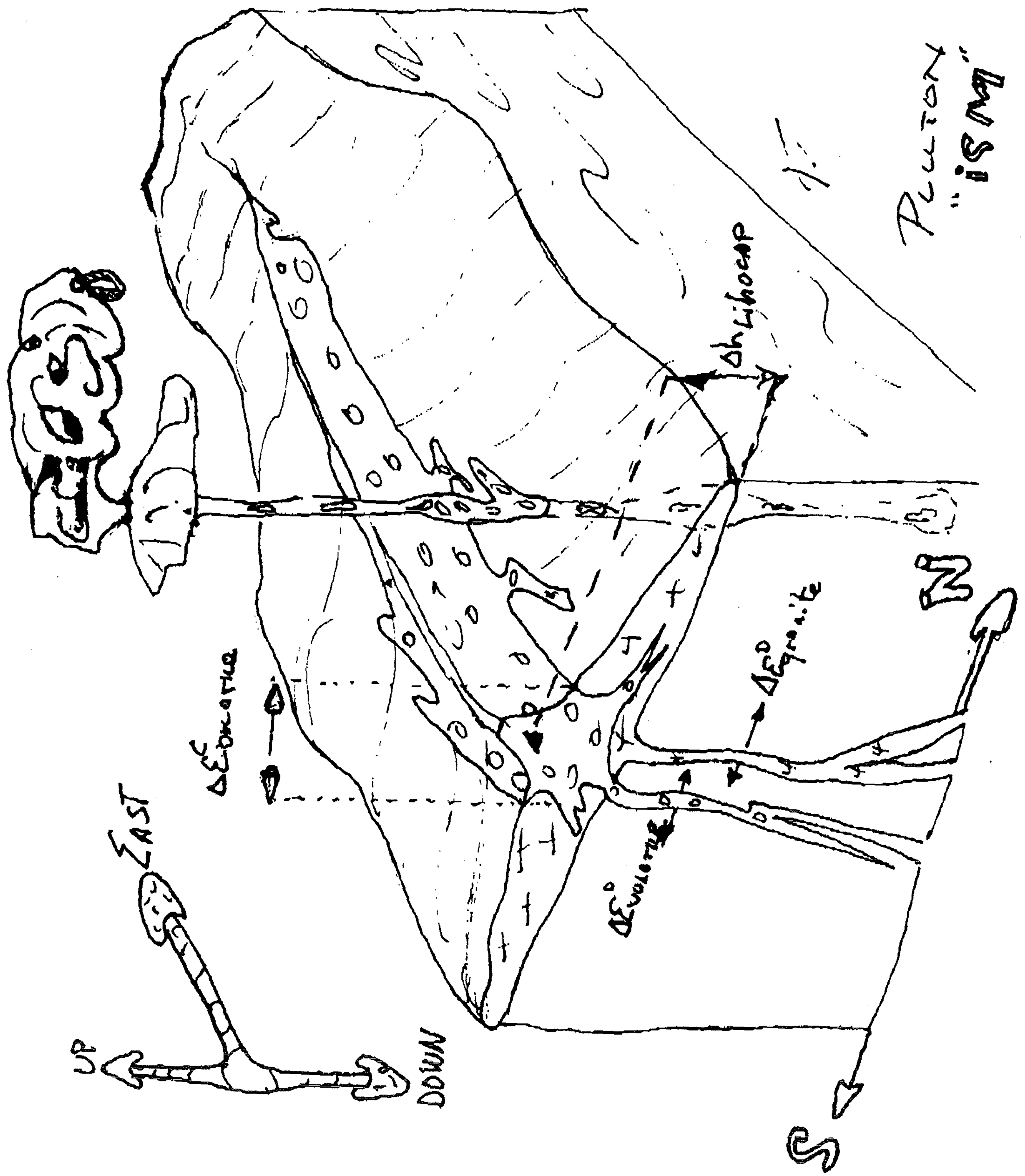
ΔE NE gives space for feeder dike width & partial space for width of sill -

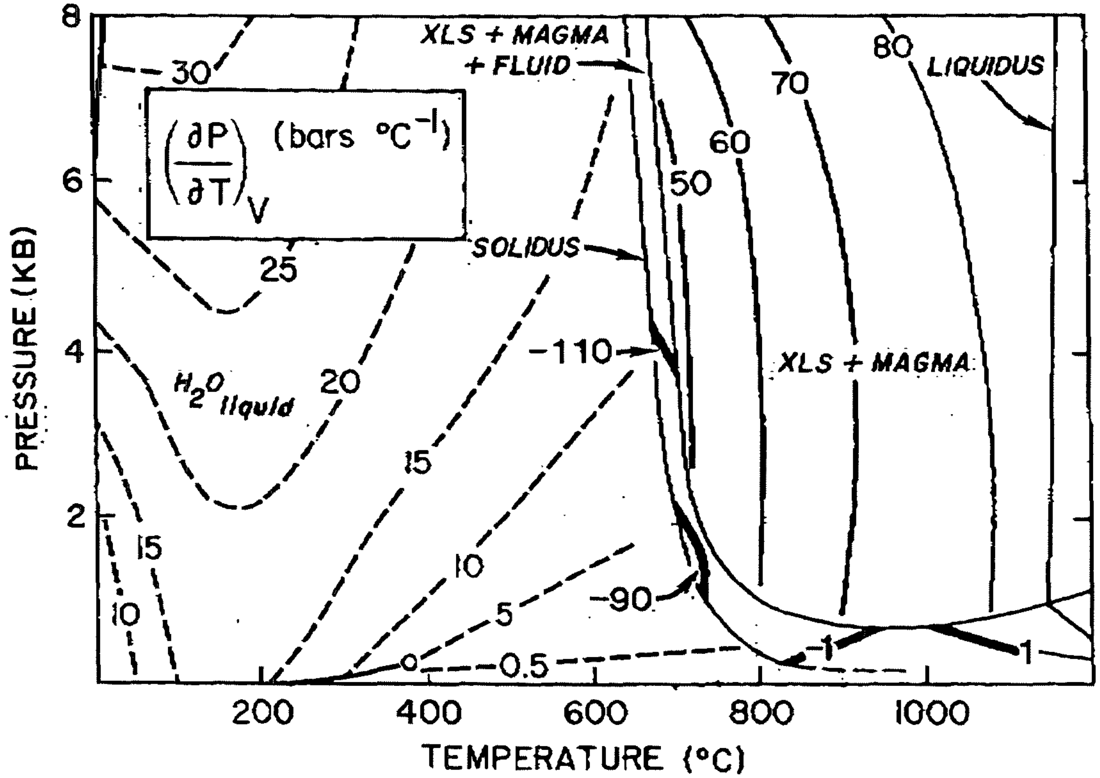
Extension along strike slip direction accomodates sill length in port to

(B) $t = 4\ 5 \cdot 10^4$ yr

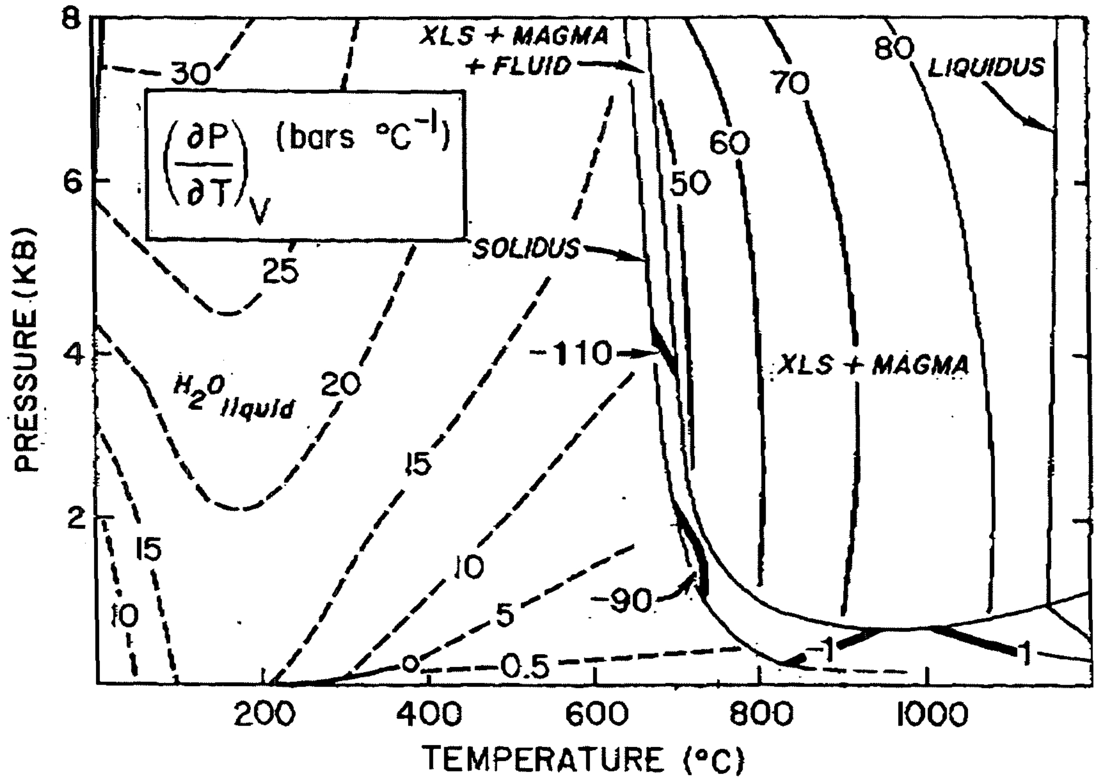



(c) t = t + 10^5 yrs


EAST
UP
DOWN
N
S



(∂P/∂T)V (bars °C⁻¹)
XLS + MAGMA
+ FLUID
LIQUIDUS
SOLIDUS
XLS + MAGMA
H2O liquid
PRESSURE (KB)
TEMPERATURE (°C)
30
25
20
15
10
5
0
−0.5
−110
−90
50
60
70
80
−1
1
8
6
4
2
200
400
600
800
1000



$\left(\frac{\partial P}{\partial T}\right)_V$ (bars °C^{-1})
XLS + MAGMA + FLUID
SOLIDUS
LIQUIDUS
XLS + MAGMA
H_2O liquid
30
25
20
15
10
5
0
0.5
−110
−90
−1
1
50
60
70
80
PRESSURE (KB)
TEMPERATURE (°C)
8
6
4
2
200
400
600
800
1000

The general hydrothermal system evolution during early stages is rich in complex behavior because of the intricate coupling among transport processes and the non-linearity of the fluid equation of state. A progressive thermal field early in the magmas cooling history generates fluid pressures sufficient for the formation of extensive networks of hydraulic fractures. The percolation paths through these fracture networks are probably most extensive near steep pluton-lithocap contacts where the mechanical energy dispersed early in the cooling history is less likely to be mitigated by fracture filling, and where the contact geometry focuses stress, Lantz, 1984, Marder, 1998, Norton, Taylor, and Bird, 1985. These prograde thermal conditions develop within the first few thousand years it takes the magma to reach its apogee in the crust, then evolve upward into the lithocap through a mechanism of complex process interaction that features alternating chemical and mechanical events. This stage of hydrothermal activity is confined to within crystalline portions of the pluton and contiguous rocks in its lithocap. Consequently, the geometric form of the chamber, rate of emplacement, and state-of-stress strongly control the style of evolution.

Geometric Form of Chamber

The geometric form of the magma chamber and extent of stress interaction with regional stresses can be reconstructed by considering the combined processes of magma infiltration into a middle to upper crust regime where strike-slip tectonics was actively forming extension openings between the Coll and Mercuryville faults. If we presume that the lateral margins of steam extend laterally beyond the present margins of the felsite by a couple of kilometers, then the girth of the felsite is roughly elliptical in plan with a(major axis)= 16km and the b(minor axis) = 6 km; the a axis is oriented N?W. This asymetry in plam view implies that during emplacement of the main mass of magma the horizontal stresses were unequal as magma inflated its chamber and deflected its roof. Given this extent of magma in plan, and modest magma pressures, but weak overburden strengths one can account for a 5-10 km maximum thickness of the magma, Pollard and Johnson , 1973, and Norton, Taylor, and Bird, 1984. However, the regional state of stress in the magma hosts during intrusion is demonstrably one of strike-slip tectonics. We suggest an interaction among deflection of the magmas lithocap and extensional opening along fracture sets associated with the coupling of stress between the Mercuryville and Colliomyi faults attended the flow of magma. The sharp keel and apparent offset of the southern end of the intrusion into geometric patterns similar to the nearby strike-slip basins we attribute to the ongoing regional tectonics but the overall form and aggregate thickness of the felsite appears to be explicable by simple deformation of the lithocap by magma pressure followed by sill like emplacemnet of the main granitic mass.

As magma was intruded fractional crystallization produced a volatile-rich phase as evident from the presence of mirialotic cavities??, biotite and hornblende, and tourmaline rich regions of the carapace. This phase of the magma on cooling would augment the emplacement magma pressure with locally enormous overpressures that were relieved in part by eruption, augmented motion on local strands of the strike slip fault arrary, and or dike emplacement??.

Concommitant transfer of thermal energy to the lithocap during intrusion caused further deformation of the lithocap as a consequence of increased fluid pressures in the wet Franciscan series sediments. These fluid pressure increases tend to be localized around isolated porous zones in matrix blocks or otherwise sealed fault segments, consequently, they may either augment additional opening of extension zones and/or intiate the generation of fracture networks along which embryonic hydrothermal convective flow occurs.

References

Pollard, David, D. and Arvid M. Johnson, 1973. Mechanics of Growth of some Laccolithis intrusions in the Henry Mountains, Utah, II. Tectonophysics, 18, p 311-354.

Norton, Denis, H.P. Taylor Jr., Dennis K. Bird, 1984. The geometry and high-temperature brittle deformation of the Skaergaard Intrusion, Journal of Geophysical Research. v 89. p 10178-10192.

Comments

1) Not sure I like making the edge of steam the delineation of the edge of magma. This edge also coincides with the Hg-ville and Collyami structures, particularly the former. I can envision good convective upflow along these structures driven by the margin of lateral heat dispersed from the magma, if edge of magma is within a couple of kms of the structure.......so lets shrink the magma margin by about 4km in length and width.

2) the emphasis of Pollards work relates to "laccoliths" but I see it as a general quantitative description of the deformation processes that occur in ALL magma lithocaps where magma is emplaced in regionally quiescent tectonics.

- the Pollard lithocap deflection analysis actually pertains to all magmas emplaced into the mid-upper crust. A combination of deflection of the roof, mass wasting of rocks from overstepened surfaces, apropos normal and strike slip deformation to provide additional room, and some degree of wall and roof block stoping accompany all such mass transfer of melts into the crust. I suggest that the Pollard roof deflection principles definitely pertain to the Geysers felsite,,,, but it is clearly modified by concurrent strike-slip/extensional mechanics.

The overall elliptical plan view and roof profile of the felsite from 5-6000ft below sea level to depth X to the Pollard lithocap deflection process, as this occurs fractionation of the magma to a volatile rich phase about the same volume that we would get for the keel from the top to -5or6000 ft or about 5 percent of the total mass as drawn in your color figs. this volume is the filler of extensional strike slip features. (NB: this fraction is in the general range of volatile rich fractions I have noted in high-level plutonic bodies.

-as the lithocap is deflected, eg domed up, the rocks are subject to tensional stress, this helps a pre-existing extensional feature in the already deforming lithocap, AND also sets up a very convenient stress situation for the dissipation of magma fluid pressures in the chamber and isolated pore pressures in the lithocap.

The rate of chamber filling for granitic family magma is more problematic. The mechanism of aggradation of a granitic affinity batholith/pluton is through a sequence of magma dikes ranging in thickness from a few meters to 50 meters and upto several hundred meters in width. Each magma dike flows along the prior body in relatively rapid sequence utilizing the exsolving fluids to augment magma pressure and decrease viscose resistance. In effect a continuous dike swarm(one can see these in outcrops of all granitic affinity plutons.

The rate of this process seems fast because the plutons retain their thermal mass as if they were emplaced during a time interval that is but a small fraction(<1 percent) of their total thermal lives. A slower emplacement time would result in a thermal lag such as we note along the spreading ridge environment where each dike event degrades prior to the next dike.

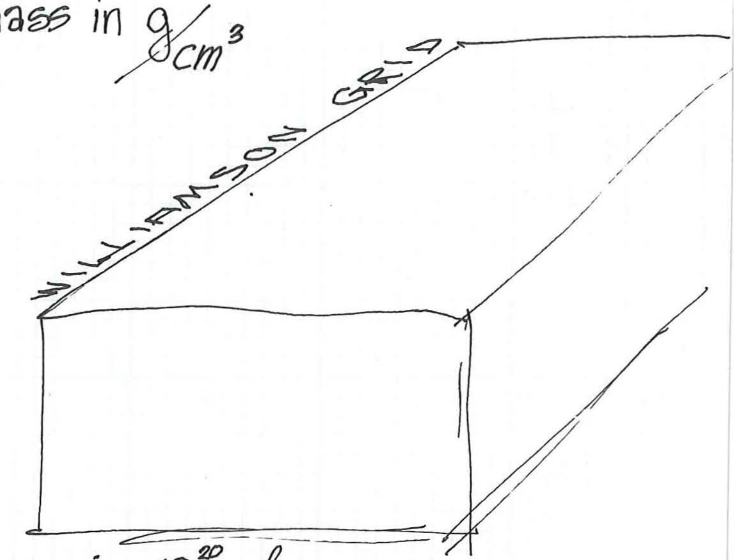
Notes on deviations from the ideal Pollard sill-laccolith.

Geologists have proposed that plug like shapes of plutons arise because of heat loss from the extreme tips of the initial sill, viscosity increases and pressure is directed toward the roof over a smaller area. HOWEVER, the roof is raised by a force, Fz, that relates to magma pressure, P, through the area over which it is distributed, A. Consequently, any decrease in area over which the magma pressure acts Acutally decreases the force. Therefore the more plug like shape requires an increase in magma pressure during the intrusion process, something that is indeed possible IF a volatile rich phase is fractionated from the magma batch and causes increase in magma pressure !!!!!!!

φ = heat content in cal/g

M = mass in g/cm^3

C_p = heat capacity in (cal/g)/°C



$$\varphi = C_p \times \Delta T \times M$$

present-day total heat content of Geysers reservoir 10^{20} cal

Est. vol. of steam reservoir in graywacke

1.2 km thick
~~10.0~~ km l
11.6 km W
19.5 km long

27~~1~~0 km^3 in GW

steam reservoir

9.5×10^9 ft^3 in Graywacke
3.5×10^{10} ft^3/km^3

2.71×10^{-1} km^3

27.1×10^0 km^3

Total steam-reservoir volume (Williamson, 1992)
660 km^3

∴ vol. of steam reservoir in felsite ≅ 390 km^3

Avg. depth to steam = 1.7~~4~~0 km
10° ambient to 230° Top of res
120°C mid-point

Assume 40°C/km pre-pluton

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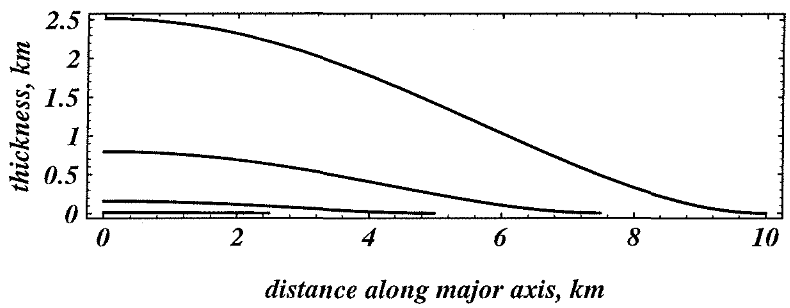
06101
203-644-1551

Geometry and state of stress for Geysers Plutons
May 26, 2000

Jeff:

Follows a simple diagram of about the proportions for the Entire Geysers pluton. It can be viewed as a time series, starting with a very thin sill of 2.2 km half-width then increasing in length and thickness proportionate to equation 3 in Skaergaard paper number 2.. Note: A 25 percent increase in sill major axis from approx 8-10km produces a factor of 3 increase in maximum thickness. So as one trims the ellipitical plan view dimensions pluton thickness is less.

Deflection of Lithocap for a/b=2.5

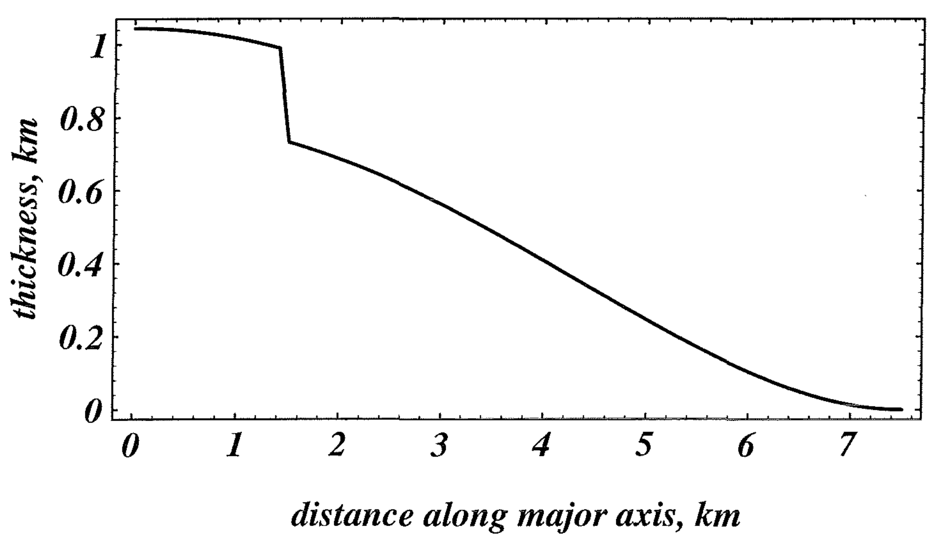


Now if one increases the magma pressure by a factor of 1.5 in the central 1.5 km region of the sill; this would be like having the outer margins mostly crystalline and resistant to further flow, perhaps with synchronous extensional tectonics in this same region, we get a pseudo-keel form.

Okay want to get this to you so will quit here.

denis

Deflection by a = 7.5km Intrusion; a/b =2.5



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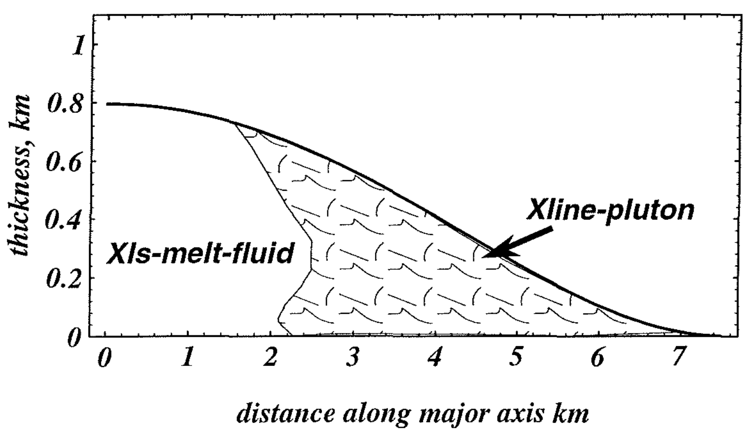

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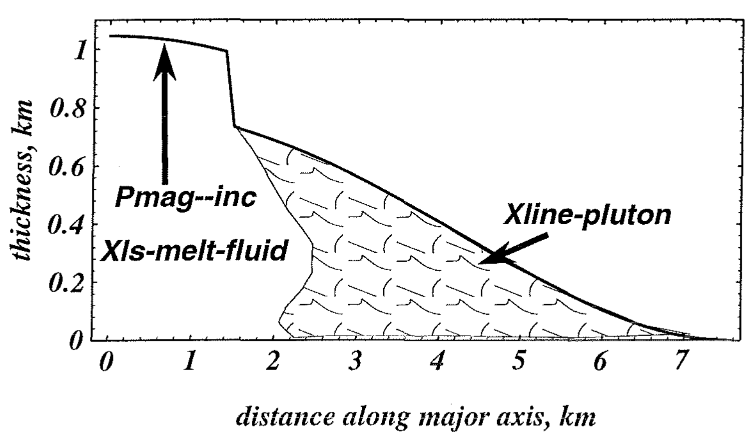
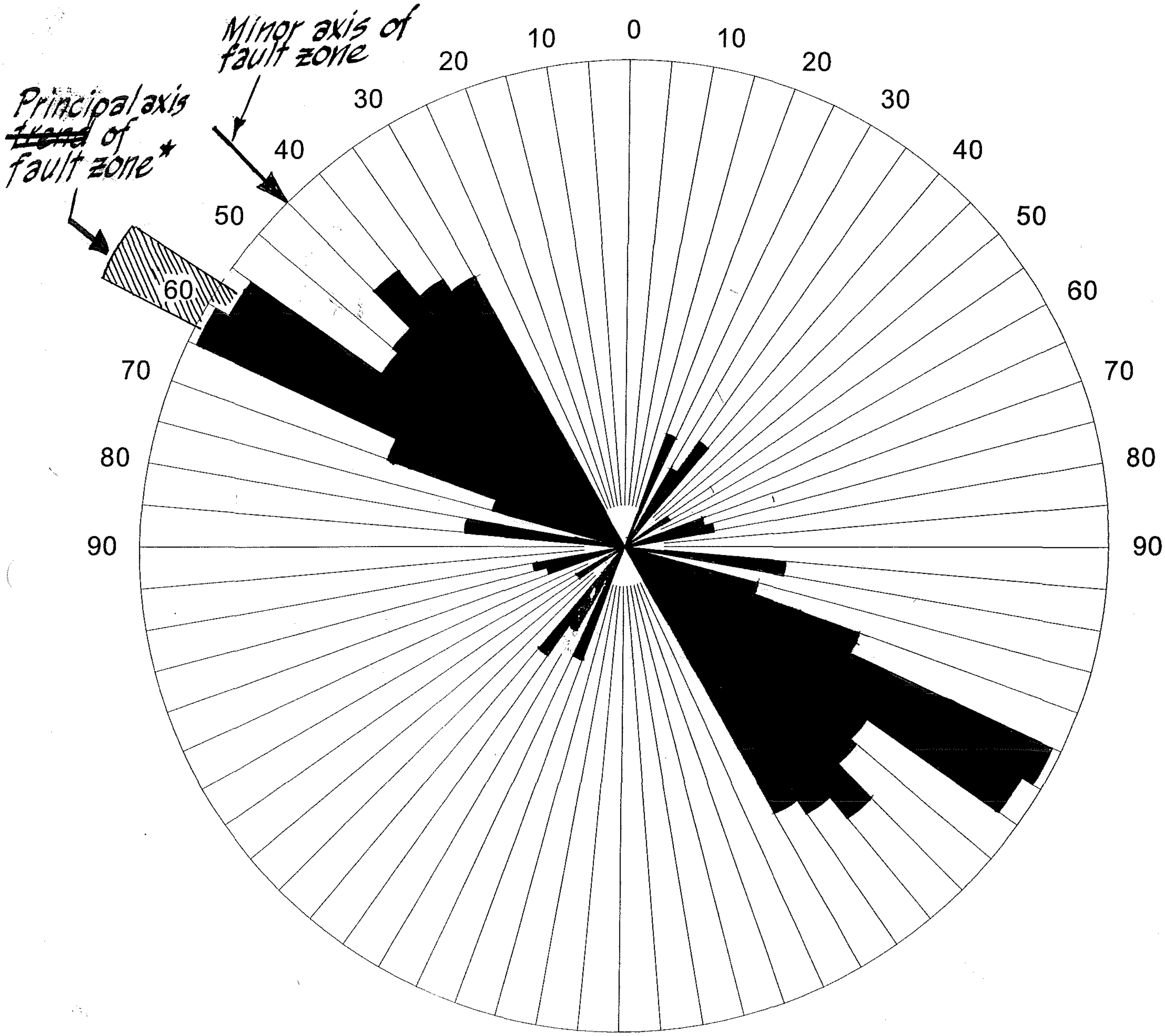
Margin xllzation Pmagma inc. by x 1.5



Big Sulphur Creek fault zone
strikes of major (>1 km long) high-angle faults & fault segments



*67% of total strike length

Big Sulphur Creek fault zone
strikes of major faults & fault segments

N5 – N5W			N5 – N5E	
N5-10W	~~0.0,~~		N5-10E	
N10-15W			N10-15E	
N15-20W	0.7,		N15-20E	
N20-25W	2.0, 0.7	(2.7)	N20-25E	1.5,
N25-30W	0.7		N25-30E	
N30-35W	2.8, 1.0	(3.8)	N30-35E	1.1
N35-40W	0.7, 1.6, 1.7,	(4.0)	N35-40E	1.6
N40-45W	1.7, 1.0, 0.7, 1.0,	(4.4)	N40-45E	
N45-50W	1.7, 1.3, 0.8	(3.8)	N45-50E	
N50-55W	1.7, 1.4, 0.6,	(3.7)	N50-55E	
N55-60W	3.9, 1.1, 0.7	(5.7)	N55-60E	0.8 (ACFZ)
N60-65W	1.2, 1.9, 1.5, 1.3	(5.9)	N60-65E	(ACFZ)
N65-70W	0.3, 2.8	(3.1)	N65-70E	(ACFZ)
N70-75W	1.7,		N70-75E	1.0 (ACFZ)
N75-80W			N75-80E	1.1 (ACFZ)
N80-85W	1.2, 0.8	(2.0)	N80-85E	
N85-90W			N85-90E	

ACFZ

65
158
165
77

25.7 = 1km

3.8 km @ N52°W
6.6 km @ N43°W
7.5 km @ N53°W
3.7 km @ N60°W

NOTES ON EVOLUTION OF THE GEYSERS FIELD.

Rick Allis, 30 September, 1998

In natural state, there was evidence for:

- Vapor-dominated, largely between cap rock and underlying felsite intrusive; vapor-static pressure gradient implies considerable under-pressures at depth (~ 1kbar/km relative to hydrostatic gradient) and low permeability around reservoir boundaries (White et al., 1971)
- Productive reservoir area is about 50 km^2, elongate to the NW (~10 km x 5 km)
- Productive thickness greater in SE than NW, but assume here 2 km average
- Matrix and fracture porosities are low; (0.01 – 0.05 Williamson, 1992; Gunderson, 1992). Matrix porosity decreases downwards. Assume average fracture porosity in reservoir is 0.02
- Heat flow through cap rock is conductive in most places, and averages 0.4 W/m^2 (10 HFU) over 50 km^2 reservoir. The cap rock is thinnest (and heat flow highest) over the high point of the felsite in the SE Geysers
- Lateral gradient in oxygen isotopes (heavier to northwest) implies some natural recharge of meteoric water in SE – perhaps down through Cobb Mtn rhyolite (Truesdell et al., 1993)
- High temperatures (350 °C) and the presence of chloride (as HCl) in steam exist in the NW Geysers at depth (Walters et al., 1988). Fluid inclusions here record a fossil cooling gradient from magmatic fluids (> 400 °C; 44wt% NaCl equivalent; lithostatic pressure) near the pluton to modified connate waters (325°C, 5 wt% NaCl equivalent, hydrostatic pressure) 1500 m from the pluton (Moore and Gunderson, 1995)
- There is no evidence for an earlier high temperature history in the SE Geysers (Moore and Gunderson, 1995)
- Magmatic intrusion, volcanism and hydrothermal alteration evidence suggest that the system could be at least 1 m.y. old, with it being liquid dominated for much of this time. (adularia dates 600 - 300 k.y.; perhaps vapor-dominated for last few hundred thousand years; Hulen and Moore, in prep...check dates)
- All models for evolution of system invoke "boil-down" of liquid system, at some critical moment. Large-scale venting of excess fluids, perhaps hydrothermal eruptions; the bottom line is net discharge exceeds recharge. Numerical models simulate this by having a well drawdown the reservoir during short period of time until a small liquid mass fraction remains in fractures. The system is then assumed to be sealed (Pruess, 1985; Shook, 1995). The vapor-dominated system is then stable.

Comments

The transition from a liquid-dominated to a vapor-dominated system is poorly constrained. What circumstances caused the discharge event and the "boil-down"? If it was some tectonic event like a major earthquake causing rupturing of the reservoir, why should this be unique? Why shouldn't it recur and cause later flooding of the reservoir? Could there be alternative explanations for the "boil-down"? Isotopic evidence indicates that the vapor-dominated system was not totally sealed – any model should allow for this.

The model proposed here is that the fracture volume of the reservoir has been enhanced by extension resulting from ongoing tectonism and magmatic intrusions into the upper crust beneath the reservoir. There is no need for a major discharge event, although it is not precluded. Increased fracture volume in a reservoir with low permeability boundaries will cause and sustain a vapor-dominated system.

Constraints from the natural heat flow

The average heat flow of 0.4 W/m^2 over a 50 km^2 reservoir area implies a conductive heat loss of 20 MW_{th}. This is sustained by the upward flux of steam condensing near the top of the reservoir, and condensate draining back down into the reservoir. Some steam leaks to the surface as steaming ground and fumaroles. This has apparently increased with time. Early descriptions and photographs (Koenig, 1992; Hodgson, 1992) suggest that the steaming ground was largely limited to the Big Sulfur Creek area. It is likely to have been more than 10 MW_{th} but less than 100 MW_{th}. Here we conservatively assume it was about 30 MW_{th}. The sum of the conductive and convective heat losses from the reservoir is therefore inferred to be about 50 MW_{th}.

The natural convective heat loss has implications for both the rate of mass discharge from the vapor-dominated reservoir and the magmatic heat input beneath the reservoir necessary to sustain the reservoir. A natural steam discharge of about 30 MW_{th} implies a mass loss of 10 kg/s. This could have been the same order of magnitude as the natural meteoric recharge to the reservoir if the Geysers reservoir was close to steady state prior to development. If the natural mass recharge was as high as 100 kg/s, for example, the fracture volume of the reservoir (0.02 x 50 km^2 x 2 km) of 2 km^3, would become liquid-dominated within 700 years (unless steam discharge rate was also significantly higher). Since the time-scale for the vapor-dominated reservoir is apparently the order of 10^5 years, an approximate mass balance may be implied.

If the heat output has been at least 50 MW_{th} for most of the reservoir's existence, some minimum order of magnitude estimates of magmatic heat and mass input to the crust beneath the Geysers can be derived. (refer to ?? papers by Cathles, Norton, etc for more elaborate models of the heat lost from cooling intrusions). If the heat originates from cooling magma, and the amount of cooling is 500°C (750 to 250°C), then 50 MW_{th} requires 1 x 10^6 m^3/y of continuously cooling magma. Considering the latent heat of fusion may decrease this by a small fraction (20 – 30% ref.?). If sustained for 10^5 years, this amounts to 100 km^3 of total intrusion. It could be viewed as the equivalent of a 2 km slab (dike) 5 km wide by 10 km deep beneath the reservoir, or a 2 km thick slab (sill) in the upper crust beneath the entire reservoir. Irrespective of whether this is new crustal material (basaltic) or largely remobilised lower crustal material, its intrusion into the upper crust is likely to be associated with doming and extension. Movement on low angle faults and ductile deformation may have accommodated much of the extension, but some enhanced fracture volume is also likely. It is argued here that this could have been the main factor causing a substantial pressure decline in the fractures (and hence the "boil-down").

Other evidence for reservoir extension

Stanley et al. (1998) review the evidence for a NE-SW extension zone extending between the Geysers reservoir and Clear Lake, where Quaternary north-northeast and northeast trending faults, fractures, lineaments and mineralised veins are common. These are consistent with fault plane solutions from seismicity in the Geysers region which indicate uniaxial extension in a 105° azimuth below 1 km depth (Openheimer, 1986). Although evidence from steam-bearing fractures suggests an effectively randomly oriented fracture network within the reservoir, the results of tracer studies indicate preferential permeability in a north-northeast direction (Beall and Box, 1992). Thompson and Gunderson (1992) suggest that low angle fractures may be important in the greywacke, whereas in the felsite, fractures are more commonly encountered in north-northwest and southwest-northeast wellbore directions. The overall domed shape of the reservoir coinciding with and over-lying the felsite suggests a close structural relationship (Thompson, 1992).

The rate of extension is poorly constrained. The present day west-northwest extension derived from geodetic measurements in the Geysers-Clear lake area is 0.2 μstrain/y (Prescott and Yu, 1986). However there was no significant dilatation. This does not preclude dilatation in the Geysers reservoir area because it is a small part of the geodetic network. More rapid extension is likely to occur at the time of magmatic intrusions. This is likely to be periodic over geologic time, but as discussed above, must be able to accommodate of the order of 1×10^6 m^3/y intruded beneath the reservoir area in order to sustain the heat output. Depending on how the intrusion occurs, the extensional strain could range up to $2 \times 10^{-6}/y$. The actual extension history could be several orders of magnitude higher than this during intrusion events, which are separated by long periods of quiescence, or even slight contraction due to the effects of cooling of the newly intruded material. If the reservoir fracture porosity at the Geysers is only 2% on average, and there is little evidence for healed fractures, much of the reservoir deformation at the time of intrusion could be on low angle faults. Alternatively, a large component of the intrusion could be contributing to increased upper crustal thickness (and uplift) rather than extension. Increased uplift increases average ground elevation, and has probably also increased erosion of the area. Although the overall component of extension that has created new fracture volume at the Geysers may be small, it could still be important if original fracture volume was low.

Proposed mechanism for the formation of the vapor-dominated reservoir

Most high temperature geothermal systems are situated in extensional tectonic regimes. This is often a consequence of the coincidence between active volcanism providing an upper crustal heat source, and arc or rift tectonism. Most geothermal systems are liquid-dominated. The small percentage of developed fields that have vapor-dominated reservoirs are The Geysers, Lardarello, Matsukawa, Kamojang and Darajat. This list excludes shallow vapor-dominated zones in structural highs overlying liquid reservoirs. The latter are have limited vertical extent and are readily explained by natural drainage above the hot liquid reservoir. Often liquid pressures are controlled by the nature and elevation of the main outflow zone of the reservoir, and the permeability regime connecting with the main liquid recharge zone.

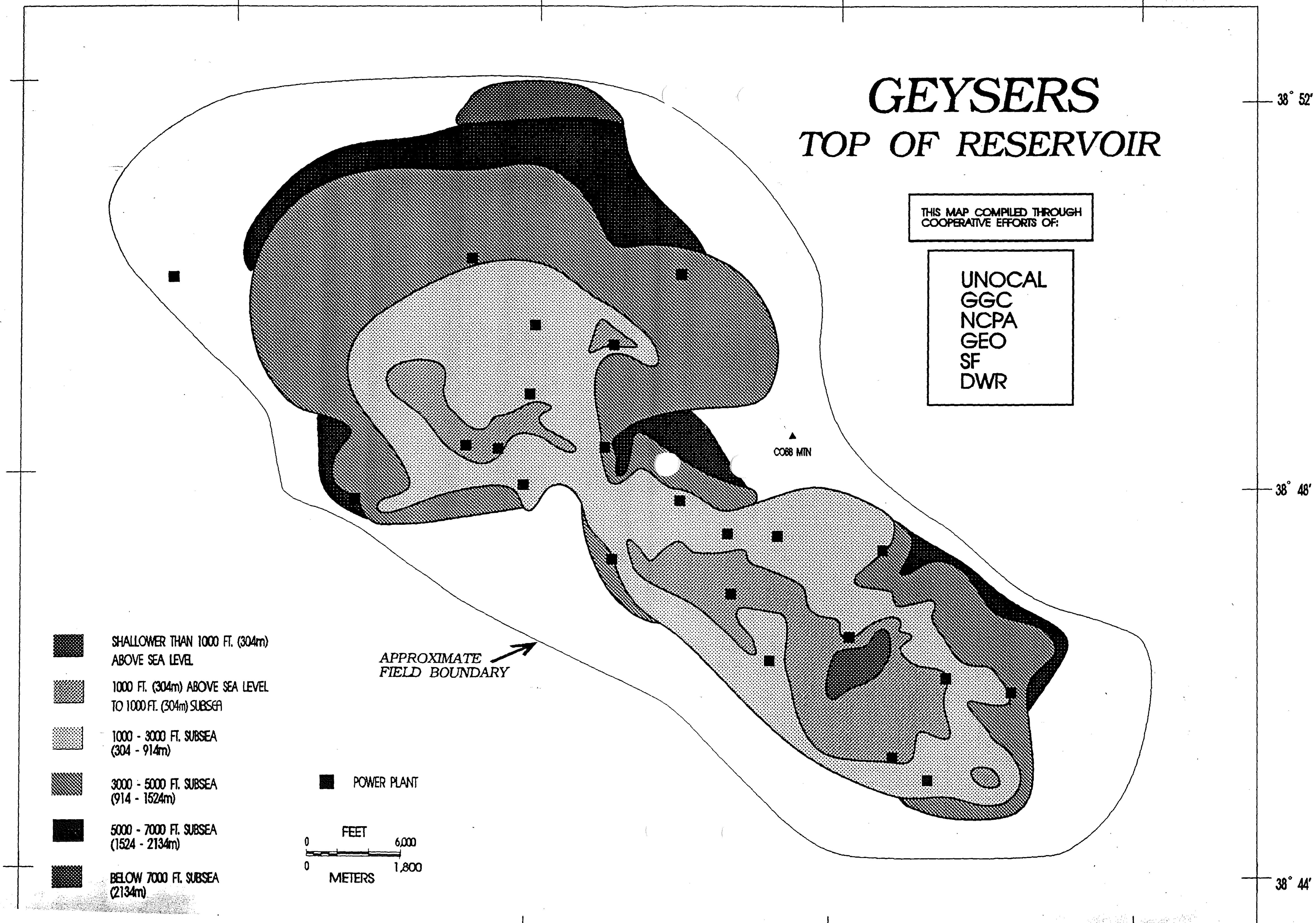
In the case of vapor dominated reservoirs, low permeability boundaries and little recharge are essential for their survival. The under-pressuring means that any potential flow is inwards to the reservoir, with the exception of steam loss to the surface. In most fields the extensional tectonism probably ensures that both reservoir permeability is sustained (new fractures replace healed fractures) and liquid recharge keeps the reservoir liquid-dominated. The question is therefore why the few reservoirs that have, or develop, low permeability boundaries also develop an under-pressured, vapor dominated state.

Once the mass flux through a liquid dominated reservoir is reduced to low levels due to low permeability boundaries, the reservoir becomes sensitive to fracture volume changes. If the initial fracture volume is low (e.g. 1% if the 'reservoir" is hosted in basement rocks), then even small amounts of new fracturing due to extension could cause large pressure changes. If the enhanced fracturing occurs at the time of an intrusive event, or is coseismic, then it is less likely that mass inflows can compensate for the fracture volume increase. The relatively sudden pressure decline causes increased boiling, and further pressure declines are possible if the steam is able to leak to the surface.

Extension at the time of upper crustal intrusion(s) is more appealing than coseismic extension for the Geysers reservoir because of the close relationship between the fracture permeability and the felsite. The Geysers-Clear Lake tectonic extension zone is much larger in area, and relatively high temperatures (albeit with lower conductive heat flows) have been observed in exploration wells (Stanley et al., 1998). Both magmatic intrusions and volcanism have also occurred across much of this extension zone, but the coincidence of high temperatures and high permeability have yet to found outside The Geysers reservoir. The difference may that the geothermal system at the Geysers appears to have been sustained for most of the last 1 m.y. implying sustained magmatic intrusion into the upper crust in that area, and arguably, enhanced fracture permeability in and overlying the intrusion zone. Relatively ductile capping rocks at The Geysers may have restricted the enhanced permeability vertically, and minimized downflows of meteoric water into the reservoir.

Comments on other vapo-dominated reservoirs....

Modeling evidence supporting mechanism?


GEYSERS
TOP OF RESERVOIR
THIS MAP COMPILED THROUGH COOPERATIVE EFFORTS OF:
UNOCAL
GGC
NCPA
GEO
SF
DWR
COBB MTN
APPROXIMATE FIELD BOUNDARY
SHALLOWER THAN 1000 FT. (304m) ABOVE SEA LEVEL
1000 FT. (304m) ABOVE SEA LEVEL TO 1000 FT. (304m) SUBSEA
1000 - 3000 FT. SUBSEA (304 - 914m)
3000 - 5000 FT. SUBSEA (914 - 1524m)
5000 - 7000 FT. SUBSEA (1524 - 2134m)
BELOW 7000 FT. SUBSEA (2134m)
POWER PLANT
FEET
0
6,000
0
1,800
METERS
38° 52'
38° 48'
38° 44'

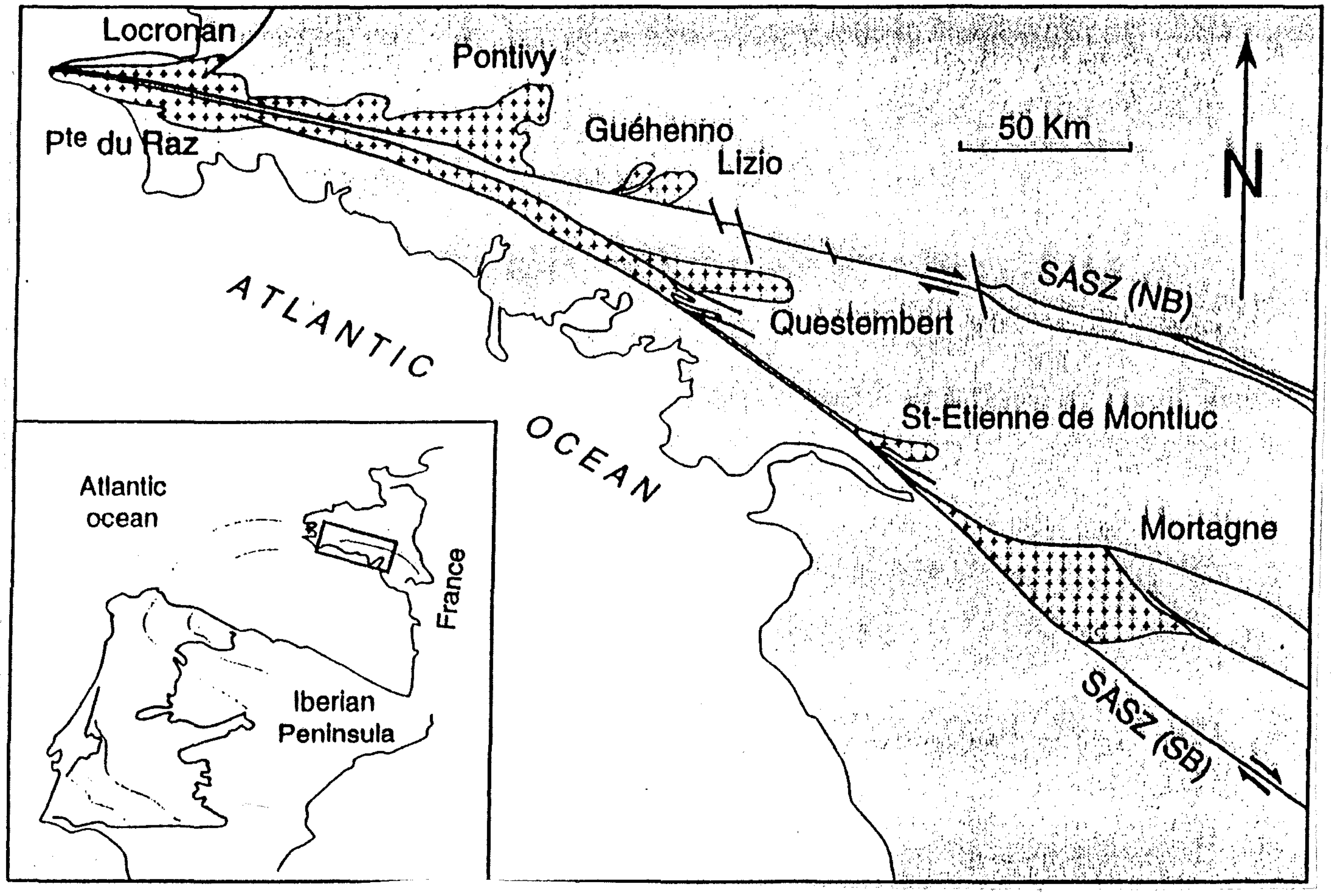
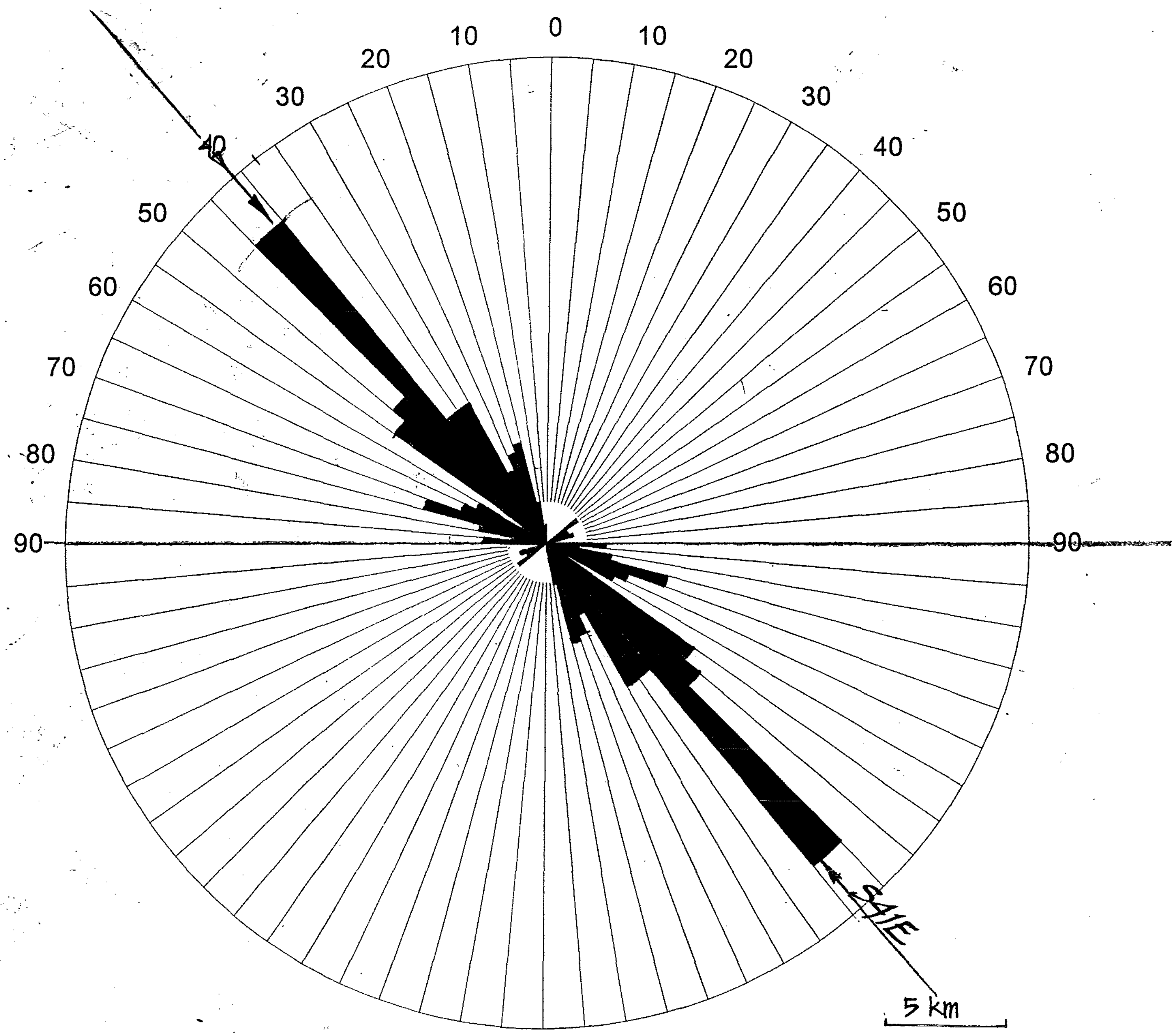


Fig. 3. Sketch map of granite plutons along the South Armorican shear zone.
(R-B et al., 1997)

Collayomi fault zone
major (>1 km long) high-angle fault segments.



What is ~~deviatoric~~ stress?
" " a stress trajectory

2 cm/yr for ~~%~~ 10^5 yr = 2×10^5 ~~cm~~ $\times 10^{-2}$ m/~~cm~~

1 cm = 10^{-2} m

2×10^3 m

Avg. San Andreas
7 cm/year

~~2~~ km opening in 100,000 yr
(14) ~~4~~ km opening in 200,000 yr.

10 ≡ 10 km opening

Dal Stanley!

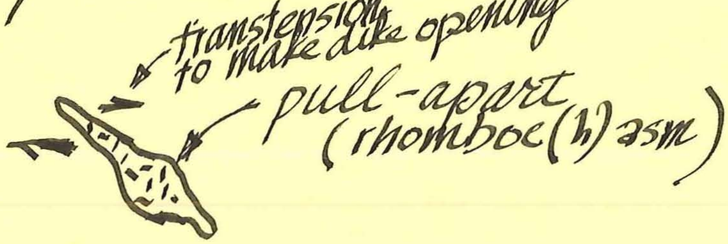
likely → multiple intrusive mechanisms

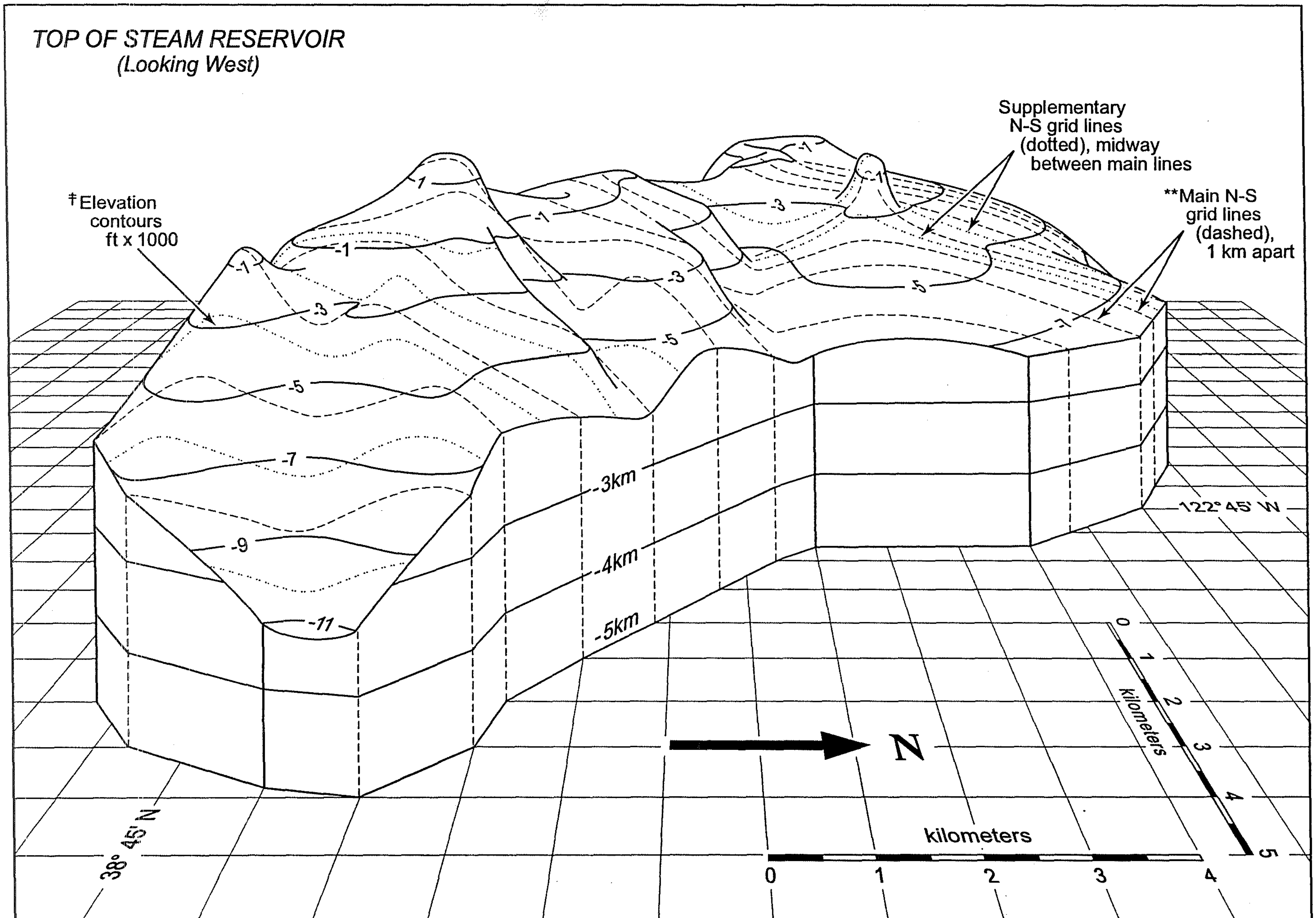
Material Transfer Processes → Those involving the movement ~~of mass~~ of mass in the crust without changing its volume & the crust's

Near-field MTP ⇒ those operating within the structural aureole of a pluton and which provide a means of moving material away from the immediate path of the magma.

Far-field MTPs – those which provide space for an invading pluton but operate beyond the pluton's structural aureole.

Good Example: lowering Moho; raising Earth's surface

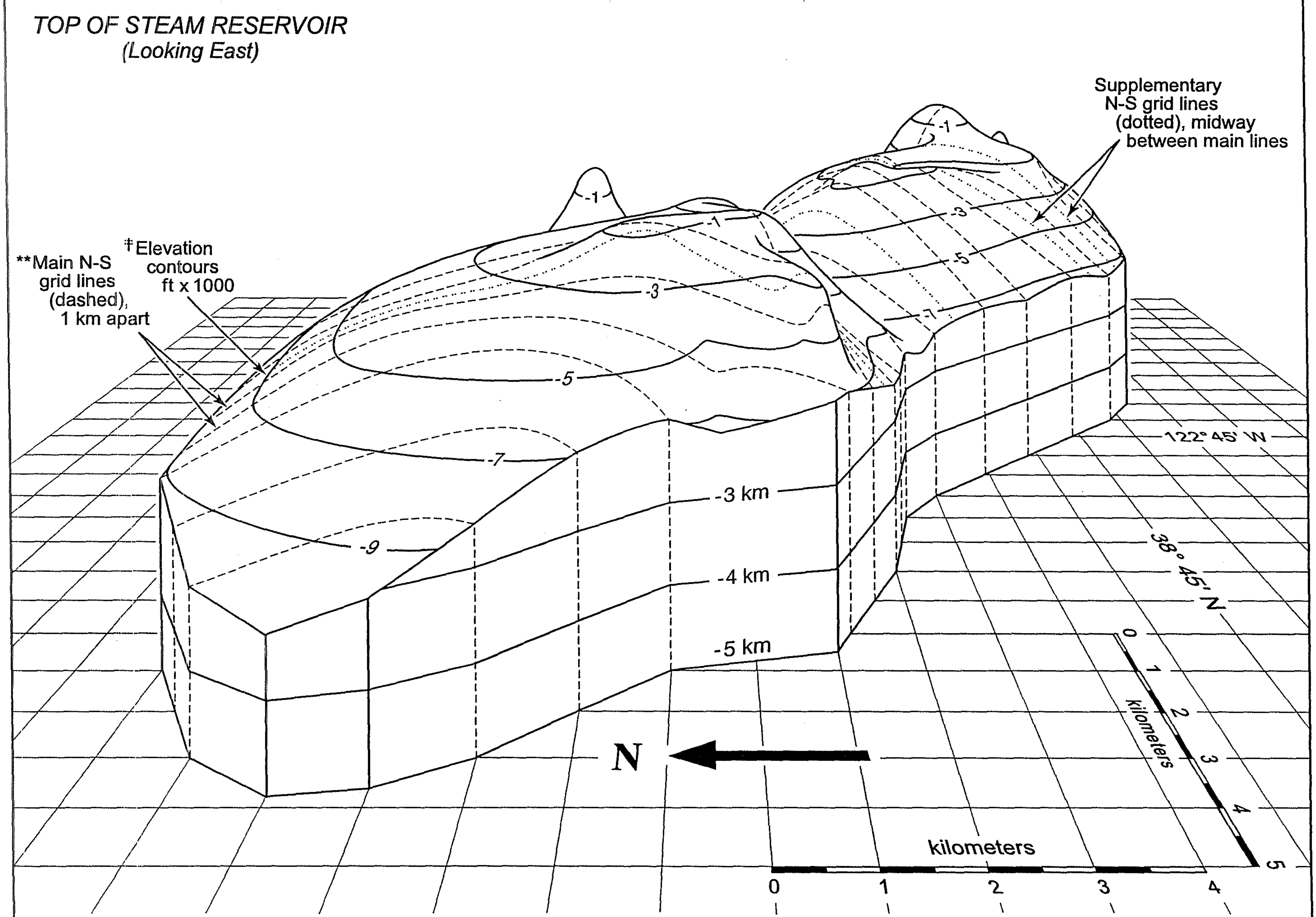
- felsite ~~area~~ areal extent
- 100 km^2 within steam reservoir
- if avg. elevation increased by 0.2 km (656') within this area by felsite doming — 20 km^3 extra space. (not much)
- need area of little sulphur ck. basin & volume of sedimentary fill = space avail. for pluton fill
- moving serpentine aside (cf Roman-Berdiel et al., 1997
- compaction in cont-met. aureole? (suspect insignificant)
- 



† Relative to mean sea level (msl):
1=305m. -1, -305m. -3, -914m. -5, -1524m. -7, -2134. -9, -2743m. -11, -3353m.

** Measured east and west from longitude 122° 45' W

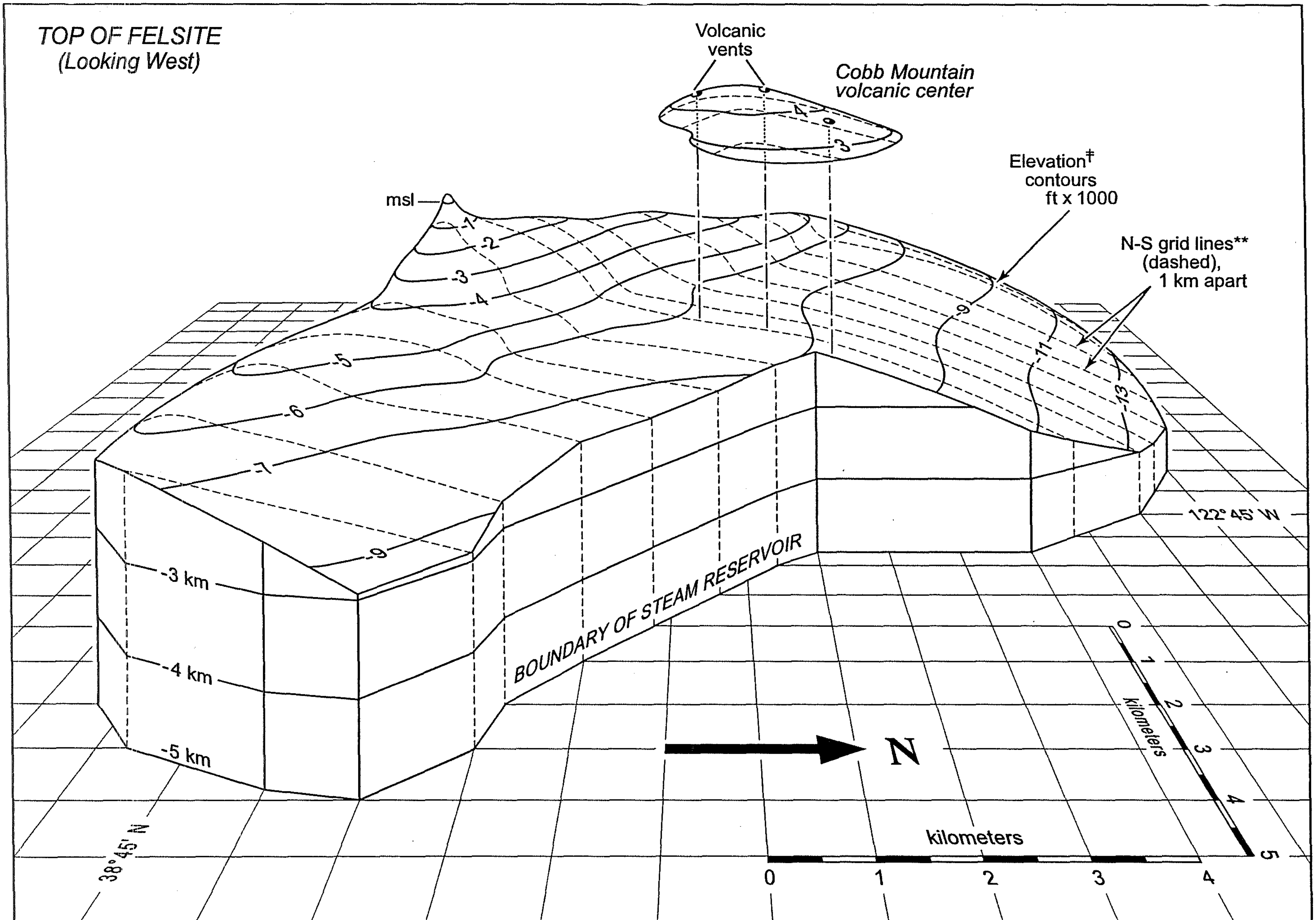
JBH00039



‡ Relative to mean sea level (msl): 1=305m. -1, -305m. -3, -914m. -5, -1524m. -7, -2134. -9, -2743m.

** Measured east and west from longitude 122° 45' W

JBH00038



‡ Relative to mean sea level (msl): 4=1219m. 3, 914m. -1,-315m. -2, -610m. -3, -914m -4, -1219m. -5, -1524m. -6, -1829m. -7, -2134. -9, 2743m. -11, -3353m. -13, -3960m

**Measured east and west from longitude 122° 45' W

JBH00036

Subject: manuscript more stuff
Date: Fri, 7 Apr 2000 09:45:56 -0600
From: "denis l norton" <denis@ruralnetwork.net>
To: "Jeff Hulen" <jhulen@egi.utah.edu>

Jeff:

1)On the Tvstime plot that shows temperature for 2 locations in the lithocap, lets smooth the tit on the high temperature one, when i replay that curve there may be some instability in the numerics contributing to part of the tit. Rather than explain at lenght what is going on numerically here lets smoooooth it.

2)Tom also encouraged me to add some prose on "salt water", as per your and his request please include the following disclaimer:

In this study, the natural fluid has been represented by the EOS for the H20-system. Samples of the fluids in many hydrothermal system trapped by fluid inclusions imply that fluid compositions ranged from several to zero molal NaCl equivalents during the quartz deposition. Departure of fluid compositions from the single component H2O-system would alter the nature of convective fluid transport in several ways. With increased concentrations of other components in the fluid, the critical point will shift to higher temperatures and pressures then at large concentrations will evolve to a critical line. The influence of the nonlinear transport properties associated with the critical region will however still exert a strong control on the hydrothermal processes. These effects need to be explored but await the generation of a robust EOS for multicomponent fluids, and better geologic definition of how these fluids are initially distributed in the system.

Variations in fluid densities caused by variable concentrations of aqueous components would alter buoyancy forces, heat capacities, shift state conditions at which critical phenomena are encountered, and introduce local heats of mixing among fluids of differing composition. Generally the uncertainties in depths below the ancient ground surface, emplacement times of the magma, permeabilities, how fluid percolates through a hierarchy of fractures, and the relationship between observed fluid inclusion data and flowing fluid compositions appear to be partially self-compensating errors intrinsic in the application of the theory of magma-hydrothermal systems to reality. Over all errors in the timing of events caused by all of these items are probably on the order of plus or minus 50to70 K years. There remains considerable opportunity for refinement of estimates made about the felsites history as well as for discovery of new concepts.

d

Mercuryville Fault Zone
strikes of major high-angle faults and fault trends

N5 – N5W		N5 - N5E	
N5-10W	0.6, 0.7, 1.1 (2.4)	N5-10E	
N10-15W		N10-15E	
N15-20W		N15-20E	
N20-25W	0.4	N20-25E	
N25-30W	1.6, 1.3, (2.9)	N25-30E	
N30-35W	1.3, 0.9 (2.2)	N30-35E	1.4 ~~(ACFZ)~~
N35-40W	2.0, 1.5, 1.4, 1.2, 0.5 (6.6)	N35-40E	
N40-45W	0.8, 3.5, 1.3, 0.7, 0.5 (6.8)	N40-45E	
N45-50W	0.6, 2.6, 1.2, 1.6, 1.3, 0.8, 0.7 (8.8)	N45-50E	
N50-55W	0.9, 0.8 (2.7)	N50-55E	
N55-60W	1.2, 0.9, 0.5, (2.6)	N55-60E	
N60-65W	2.4, 0.7, 1.0 (4.1)	N60-65E	
N65-70W	0.8	N65-70E	
N70-75W	1.0	N70-75E	
N75-80W	0.5	N75-80E	
N80-85W	1.0,	N80-85E	1.7 (ACFZ)
N85-90W		N85-90E	

PDZ Trend 11.3 km @ N42°W
5 km @ ~~N57~~ N44°W
5.3 km @ N52°W

Maacama fault zone

strikes of major high-angle faults & fault segments

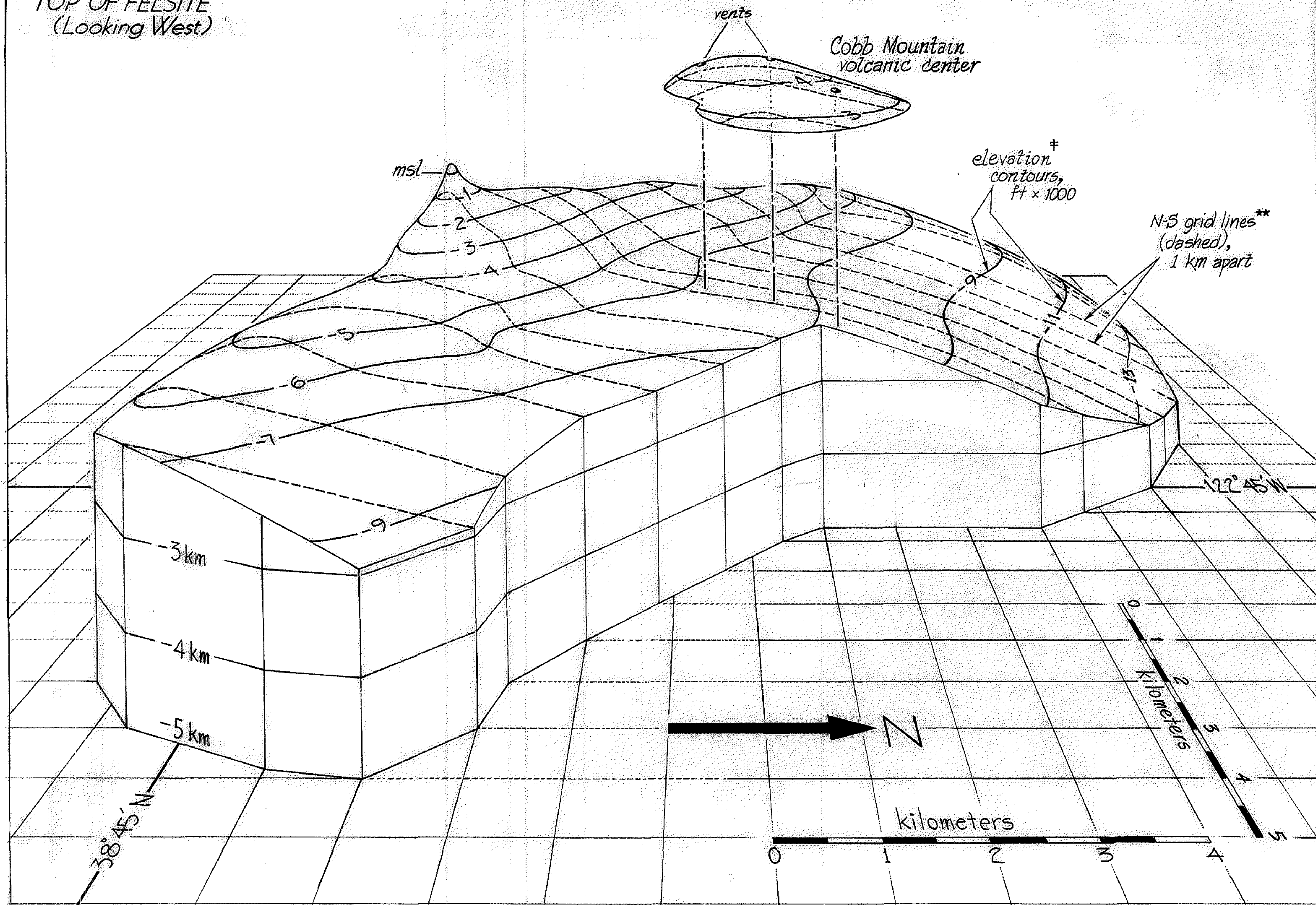
N5 – N5W		N5 – N5E	
N5-10W		N5-10E	
N10-15W	1.0, 1.2	N10-15E	
N15-20W	1.7	N15-20E	
N20-25W	0.7, 0.8,	N20-25E	
N25-30W	1.5, 1.7	N25-30E	
N30-35W		N30-35E	
N35-40W	2.7, 7.3, 1.5, 3.5, 3.5	N35-40E	
N40-45W	6.2, 1.6, 0.9, 1.3, 3.2	N40-45E	
N45-50W	1.9, 4.1, 1.4, 2.9	N45-50E	
N50-55W	1.2, 1.5, 1.3, 0.8, 0.4, 1.0, 3.8	N50-55E	
N55-60W	0.8	N55-60E	1.4
N60-65W	0.8, 1.3,	N60-65E	
N65-70W		N65-70E	
N70-75W	1.4	N70-75E	
N75-80W	0.4	N75-80E	
N80-85W	1.0, 1.2, 1.2	N80-85E	
N85-90W	1.1, 1.7	N85-90E	0.9,

N42W-45W gen Trend

20.1 km @ N42°W

7.4 km @ N48°W

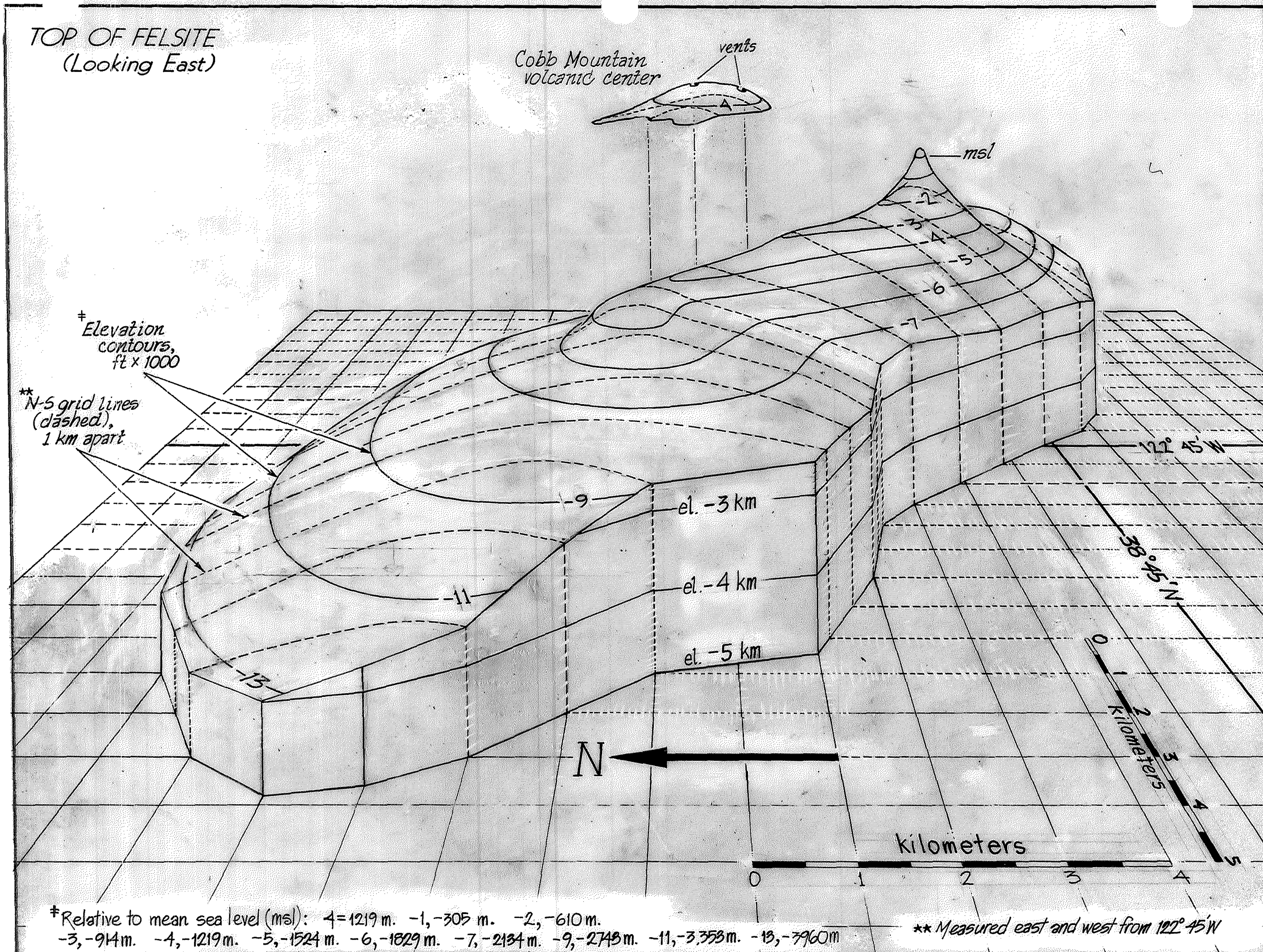
TOP OF FELSITE (Looking West)



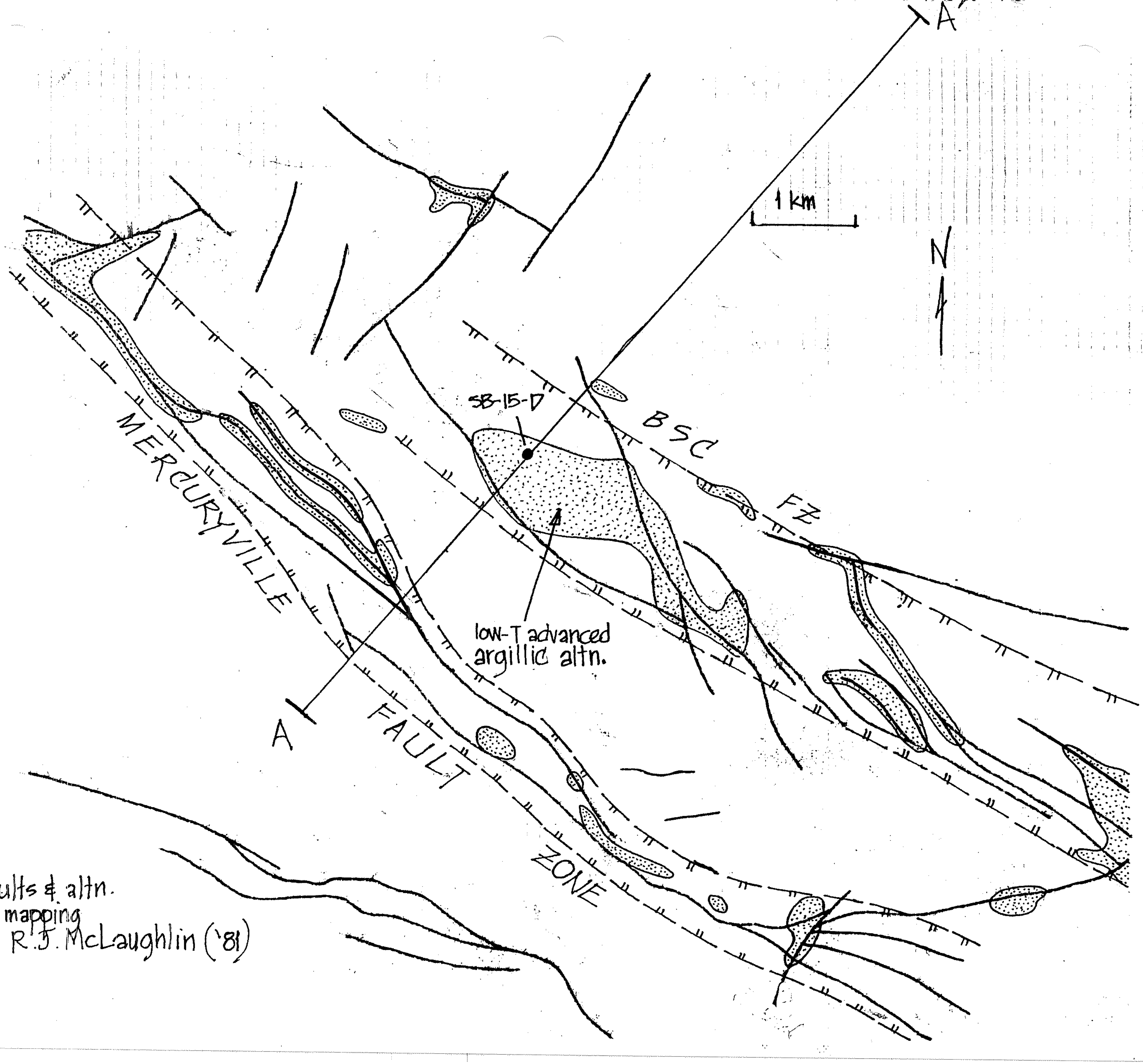
‡Relative to mean sea level (msl): 4=1219 m. 3, 914 m. -1, -305 m. -2, -610 m. -3, -914 m -4, -1219 m. -5, -1524 m. -6, -1829 m. -7, -2134 m. -9, -2743 m. -11, -3353 m. -13, -3960 m

**Measured east and west from longitude 122°45'W

DRAFT!



TOP OF FELSITE
(Looking East)
Cobb Mountain volcanic center
vents
A
msl
-2
-3
-4
-5
-6
-7
-9
-11
-13
‡Elevation contours, ft × 1000
**N-S grid lines (dashed), 1 km apart
el. -3 km
el. -4 km
el. -5 km
122° 45' W
38° 45' N
N
kilometers
0 1 2 3 4 5
kilometers
0 1 2 3 4
‡Relative to mean sea level (msl): 4=1219 m. -1, -305 m. -2, -610 m.
-3, -914 m. -4, -1219 m. -5, -1524 m. -6, -1829 m. -7, -2134 m. -9, -2743 m. -11, -3,353 m. -13, -3960 m
** Measured east and west from 122° 45' W



faults & altn.
fr. mapping
by R.J. McLaughlin ('81)

Feet/Meter = 3.280839895/1
Meters/foot = 0.304614307
9687.52 ft^2/pixel

Albers Equal Area Projection:

1st Standard Parallel = 38.83 N
2nd Standard Parallel = 38.77 N
Central Meridian = 122.77 W
Central Parallel = 38.80 N

Volumes: ToF and paleosurface = 14,522,480,928,000 ft^3
ToSR and paleosurface = 7,399,159,776,000 ft^3
ToF to - 5km = 10,755,263,289,600 ft^3

VOLUMETRIC ANALYSIS

To facilitate the analysis the data we first projected to an Albers equal area projection. A standard footprint of the maps was then generated using a combination (merge) of both the top of the felsite and top of the steam reservoir maps.

Top of the Steam Reservoir to + 1 km

A three dimensional Riemann sum was used to estimate the volume of the rock between the top of the steam reservoir and the paleosurface. The paleosurface was assumed to be 3280.80 ft. (1 km) above sea level.

To facilitate this process a combination both vector and raster GIS domains were used to prepare the data. Top-of-the-steam reservoir contours (reference), relative to sea level in feet, were digitized into a vector GIS database and attributed with depth values ranging from -7500.00 to +1500.00 feet (Fig. If needed?). This data set was then rasterized into a grid format with each pixel, or grid cell, representing 3600 ft^2 ft (60.00 ft^2 x 60.00 ft^2) (Fig. If needed?). A formula was then set up to determine the difference between the elevation values of the top-of-the-steam reservoir and the paleosurface. The calculation was simplified by adding 7500.00 to all elevations, thus clearing negative values. This gave a new range of +0.00 to +9000.00 feet. The complete formula is shown below:

$$T_v = \left[P_a * \left(\sum\left((S + A) - (P_{v1...n} + A)\right)\right)\right]$$

where T_v is the total volume, P_a is the area of one pixel, S is the paleosurface elevation in feet, A is the constant used to eliminate negative numbers, P_v is pixel elevation values, and n is the total number grid cells.

In practice the above operation had to be done in two steps. The first was to generate a new raster image containing the difference values produced from:

$$P_{d1...n} = ((S + A) - (P_{v1...n} + A))$$

where $P_{d1...n}$ is the difference value for each pixel in the output grid.

The next step was to export the difference values as an ASCII data set which, in essence, represented a single column, with an area P_a, containing all of the difference values. The ASCII data were further processed with a script to give the sum of the difference data and to multiply the sum by P_a to give the total estimated volume of rock. The results:

T_v=7,399,159,776,000 ft^3

\

Top of Felsite to + 1 km

A similar procedure as described above was used with the exception that the maximum depth was 8500 ft. below sea level and the minimum depth as 500 ft. above sea level.

T_v=14,522,480,928,000 ft^3

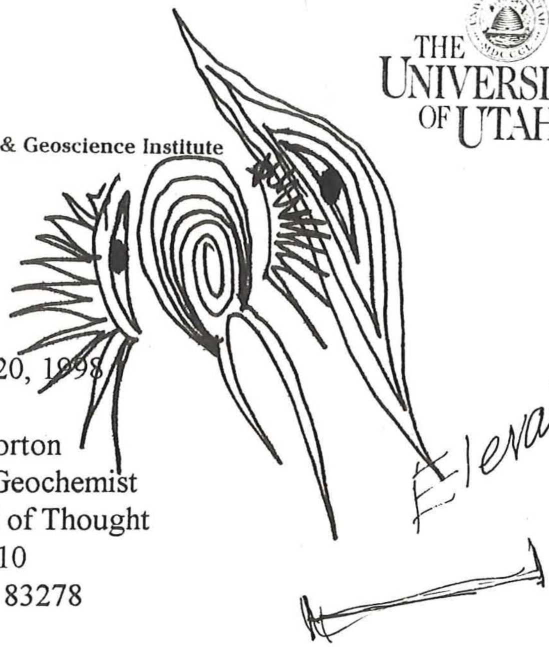
Felsite Volume to 5 km depth (- 16,414.2 feet)

Volume below the known mapped felsite :

16404 (5 km) was added to each of the felsite depth values. The highest point is 500 ft. above, and the lowest point 8500 ft. below sea level. The maximum difference is 16904 ft. and the minimum difference is 7914 ft.

T_v= = 10,755,263,289,600 ft^3

THE UNIVERSITY OF UTAH
Energy & Geoscience Institute



Elevate item 5 to beginning

Paragenetic scheme

Fels. 5-hour depth, etc → system magmatic

December 20, 1998

Denis L. Norton
Geologist-Geochemist
The School of Thought
P.O. Box 310
Stanley, ID 83278

Dear Denis:

Below is the outline we discussed for the Geysers thermal-history paper when last I was in Stanley, or rather, at the Rico River Rancho. It was good to see you guys, for sure, and I half expected you might stop down this way. You're always welcome, of course. I mean it.

A good name for those two fine Great Pyrenees – the whitebarks.

Did you get the pendant and mineral specimen? tourmaline

Anyway, here goes:

Acid scen? 500°C–2–300°C magmatic

IGNEOUS AND HYDROTHERMAL HISTORY OF THE GEYSERS STEAM FIELD, CALIFORNIA

1. **Abstract** (JH and DN)

2. **Introduction** (JH and DN)

   A. Purpose and scope (attorneys at law)

   B. Mathematical modeling constrained by multiple geothermometers (fluid-inclusion; vitrinite and pyrobitumen-reflectance; thermally sensitive secondary minerals, etc.)

   C. Another constraint – system still vigorously active

   D. Apply unique insights gained during similar modeling of (tens?, hundreds?) of magmatically-hydrothermal systems around the world, including porphyry copper systems.

EGI
University of Utah Research Park
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Tel: (801) 581-5126 • Fax: (801) 585-3540
www.egi.utah.edu

through that section Big Sulphur Creek.

E. Is it feasible that The 1.1-1.1 Ma Geysers felsite, >100 km^3 in known volume, could still be the heat source for the modern vapor-dominated geothermal system? If not, what is the likely nature and timing of post-felsite magmatism. Did emplacement of these younger igneous bodies have anything to do with the changeover from liquid- to vapor-dominated conditions?

F. Is the only analysis of the absolute timing of this transition (Hulen et al., 1997) a reasonable one; and if not what are its flaws? What alternative timing scenario?) would be mor appropriate?

G. Can we explain the prominent northwest-southeast elongation of the felsite and The Geysers. Do we want to for this paper? Or would another be appropriate.

Denis – I've enclosed Dalrymple's rough draft FYI. I wrote a very cursory geologic setting for the felsite for this paper as 88th author, but have held back all the maps, geologic cross sections, alteration/mineralization sections for our paper. Told those guys I wanted to place all that material in a separate forum since I'd been working on it for years (and didn't want to just hand the stuff over to 'em, much as they'd have appreciated it)

H. How does the "high-temperature" reservoir fit into the model?

You may want to reserve your analysis of this for your paper(s) with Brickowski and Blackwell, and that'd be fine with me, but I would like us to be able to include one or two models which incorporate the effects of convection on heat transfer out of the felsite. OK?

3. *Geologic Setting* (JH and DN)

A. Relationship to the Clear Lake volcanic field (lithospheric slab windows, asthenospheric upwelling, crustal melting, etc. We can be very brief on this since several authors have covered it pretty well.

B. Structural preparation for emplacement of the felsite (San Andreas system, pull-aparts, strike-slip faulting, "sigmoidal bends" (DN)). How was such a huge body accomodated; how was the necessary space created?

C. Correlation of felsite with Cobb Mountain volcanic center. Why did a magma chamber large as the felsite only erupt a few km^3 of volcanic material? Is this paucity of volcanics tied in with creation of vapor-dominated conditions?

D. Summary of age, petrogenesis, mineralogy, texture, likely emplacement temperatures of the felsite's three main igneous rock types. Mention abundant vesicles in the high-level microgranite porphyry, which looks pretty much identical

combine 5 & 3
+ shape, form / current thermal state
equiv.
3-D

to some of the late felsic dikes in the Sawtooth batholith (see accompanying photographs.

E. Summary of The Geysers hydrothermal system as it's presently known. Very brief, again, since Joe Moore has covered a lot of it, and we don't want to be redundant. I can, however, add a lot of secondary-mineral maps which haven't appeared previously, and which might help constrain the system's evolution somewhat).

4. *Geothermometric Constraints for the Models* (JH)

A. Fluid inclusion summary from Moore and Gunderson, 1995

B. Secondary-mineral geothermometry from same and other publications, augmented by felsite secondary-mineral level maps and cross sections (?)

C. Organic-matter geothermometers – Here's where a lot of new material can be added. Should perhaps prepare a schematic cross section showing paleo-isotherms relative to the felsite as indicated by these and the other two types of geothermometers.

5. *Physical and Thermal Properties of The Geysers Felsite* (DN, JH)

A. Shape, known volume, extrapolated or geophysically constrained volume, density, etc.

B. C_p, H, "rho", etc.

Denis, I believe we talked about putting this into a table for convenience of reference.

6. ***Tabulated and discussed variables and constraints utilized for numerical approximation of hydrothermal history.***

7. *Models* (DN)

8. *Discussion and Conclusions* (DN, JH)

A. Need or lack thereof for additional magmatic input after initial emplacement of the felsite at 1.2

B. Type and timing of additional magmatic input required (deep beneath initial felsic pluton or into the body of the pluton once it was partially crystallized, etc.). Any physical evidence which might bear upon this (dikes with certain compositions and ages, etc. – pretty slim pickin's for this latter).

C. Conductive heat transfer sufficient to explain paleoisotherms? No, I know, but we should explain from your model why it couldn't be so.

D. Porosity and permeability required in convective system(s) to explain secondary-mineral distribution and paleo-isotherms.

E. Nature and timing of transition from liquid- to vapor-dominated conditions.

F. Correlations with porphyry copper or other magmatic-hydrothermal systems you've analyzed?

G. Implications for exploration and development?

H. Recommendations for additional research.

8. ***Acknowledgements***

9. ***References***

FIGURES

Location map

Regional geologic map

Geologic level maps and cross sections of The Geysers felsite – maybe 3-D (yes)

Know ages of igneous intrusion and secondary mineralization – paragenetic diagram

Multiple models of hydrothermal circulation and heat transfer around the felsite

Some sort of summary diagram ?)

TABLES

Chemical, thermal, and other physical properties of the felsite

Ditto for the Franciscan metagraywacke/metavolcanic host rocks

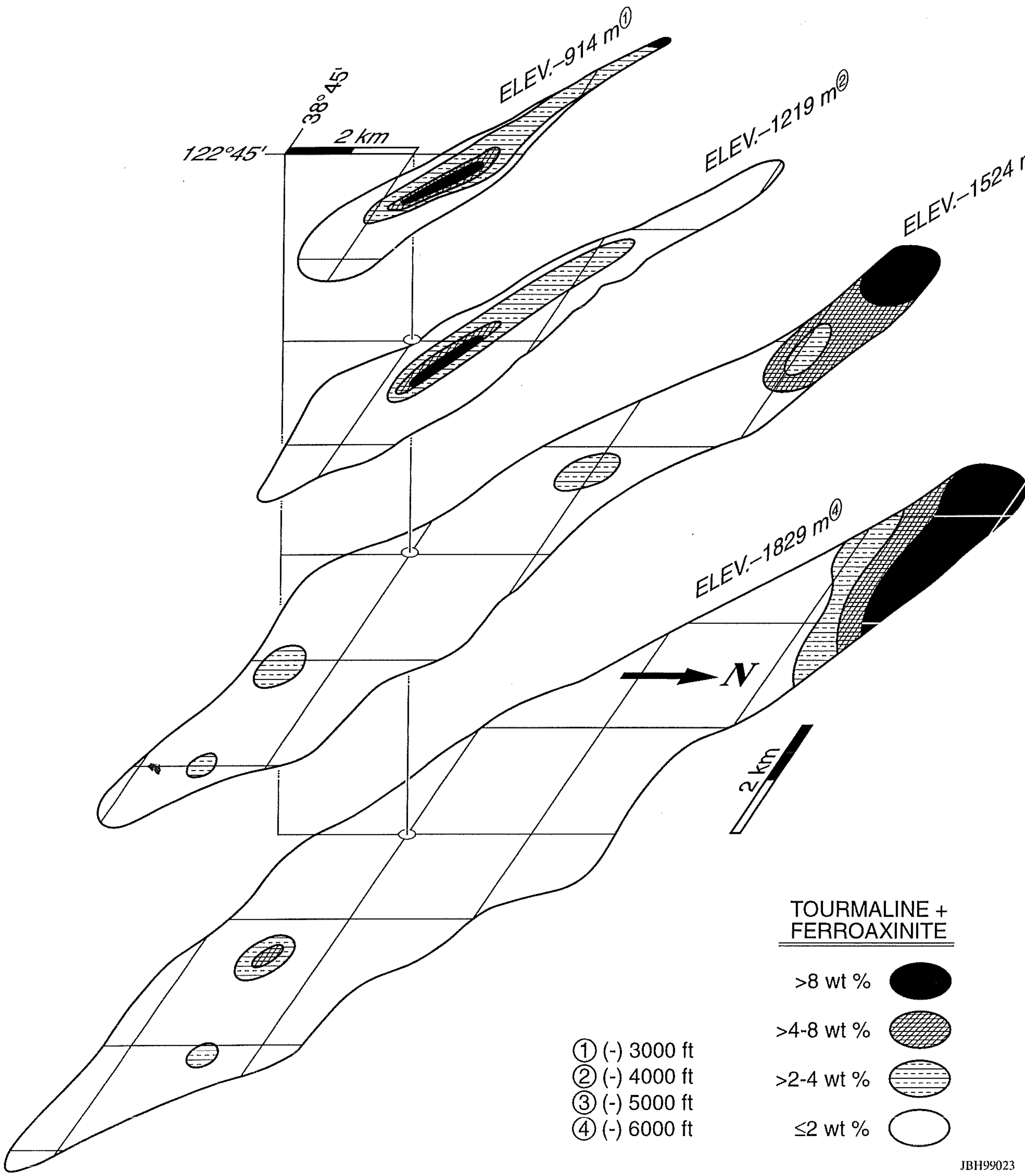
Ditto for the fluids involved ("connate", meteoric, magmatic, etc.)

Denis –

Also enclosed FYI are three photomicrographs of the felsic dike we sampled near Redfish Lake. It's a microgranite porphyry, vesicular, much like the one forming the cupola of The Geysers felsite. Also contains a microcrystalline, early-crystallized, acicular opaque mineral resembling sea-urchin spines, which I've seen nowhere else but The Geysers. Have sent Geysers and Sawtooth samples off for polished-section preparation, and when they get back will get some "probe" data to satisfy my curiosity.

One photo is at 50X (field of view 5.6 X 3.7 mm) crossed nicols; another is a 100X version of a portion of the first. Letter abbreviations are as follows (see accompanying photomicrographs): G – granophyric groundmass; m – myrmekitic texture; Q – quartz, late-stage, probably micropegmatitic; K – potassium feldspar, probably also late-stage; A- albite, definitely late-stage, crystal projecting into vesicle (V); FI – fluid inclusions in quartz. M – coarse mica, either muscovite, or, more likely, bleached biotite.

The other photo is at 200X and shows a few trains of secondary fluid inclusions in the late-stage quartz. From their liquid to vapor ratios, I'd say they'll have a T_h of about 180°C.


ELEV.–914 m ①
ELEV.–1219 m ②
ELEV.–1524 m ③
ELEV.–1829 m ④
38°45'
122°45'
2 km
N
2 km
TOURMALINE + FERROAXINITE
>8 wt %
>4-8 wt %
>2-4 wt %
≤2 wt %
① (-) 3000 ft
② (-) 4000 ft
③ (-) 5000 ft
④ (-) 6000 ft
JBH99023

DRAFT JBH 03/09/99 modified 03/14/99

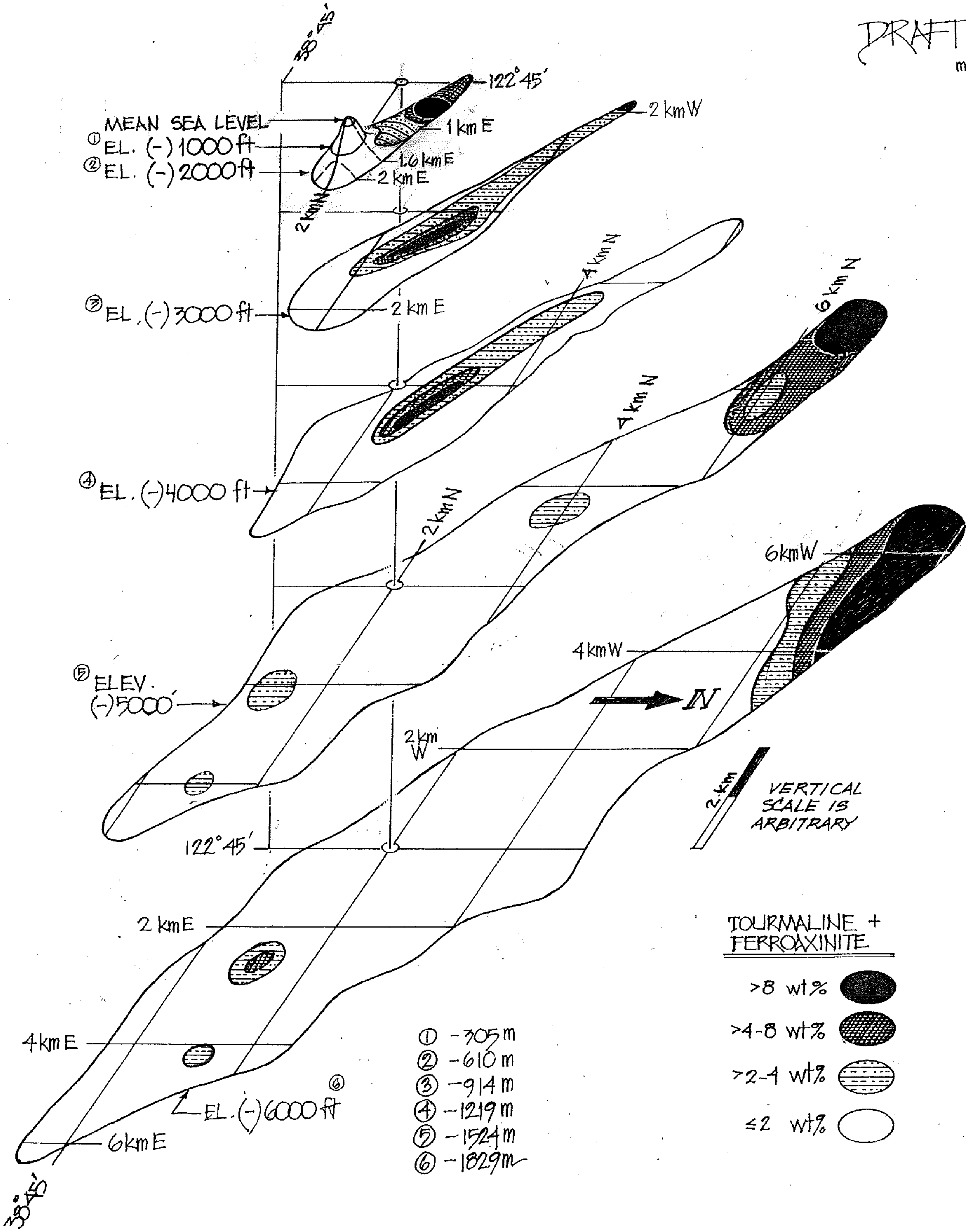
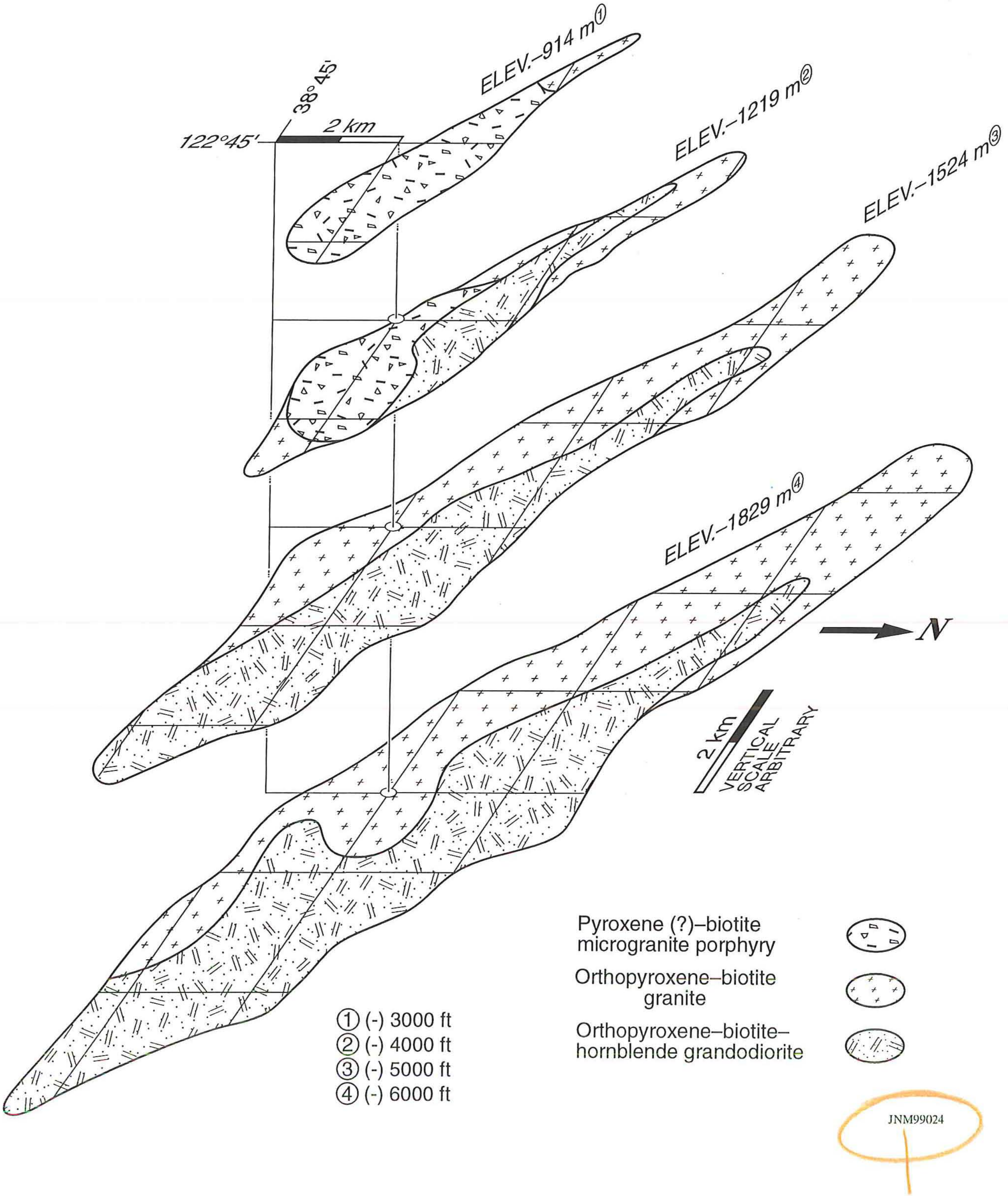
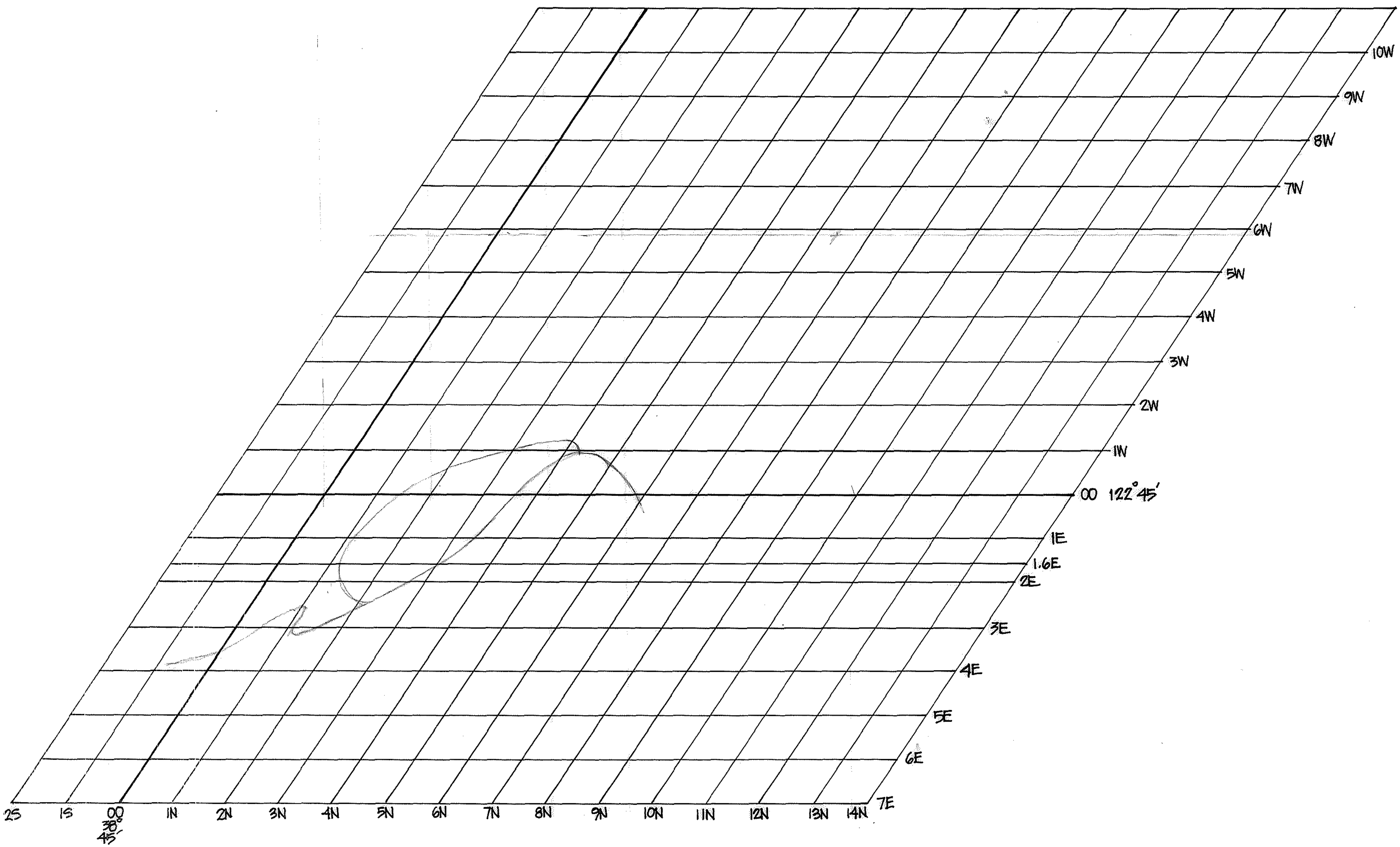


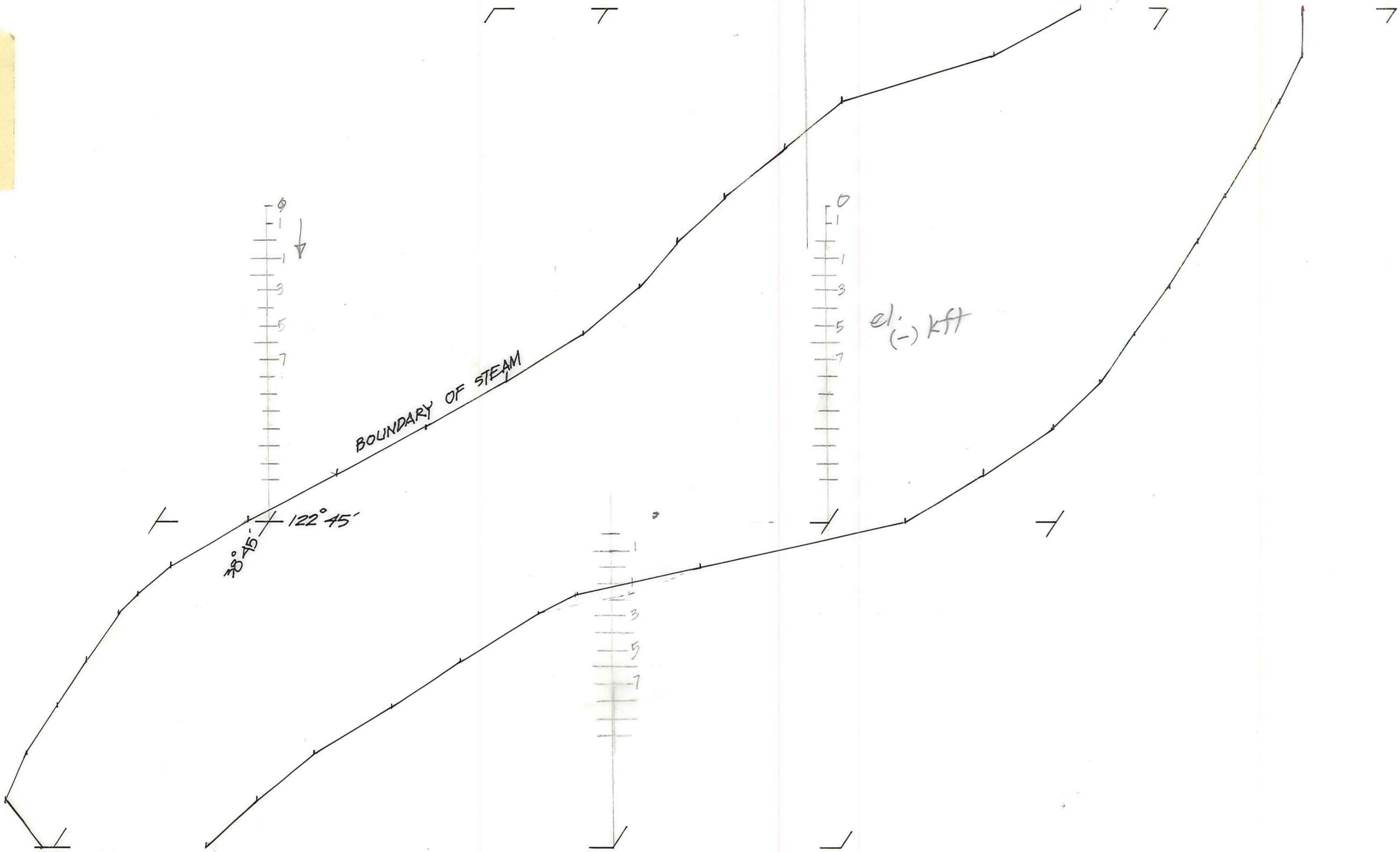
FIGURE. LEVEL MAPS OF THE GEYSERS PLUTONIC COMPLEX, SHOWING DISTRIBUTION OF BOROSILICATE MINERALIZATION.

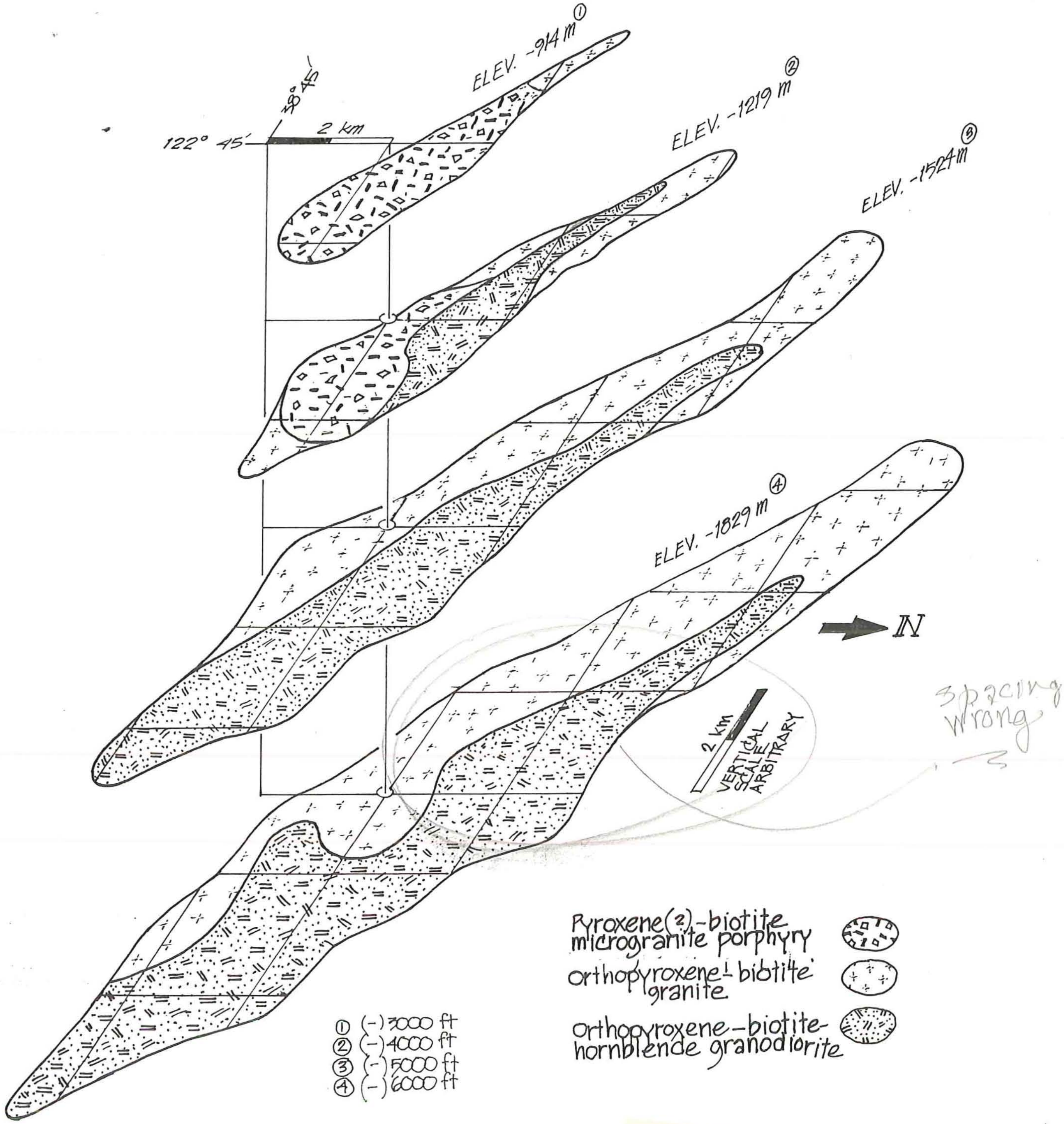


JNM99024

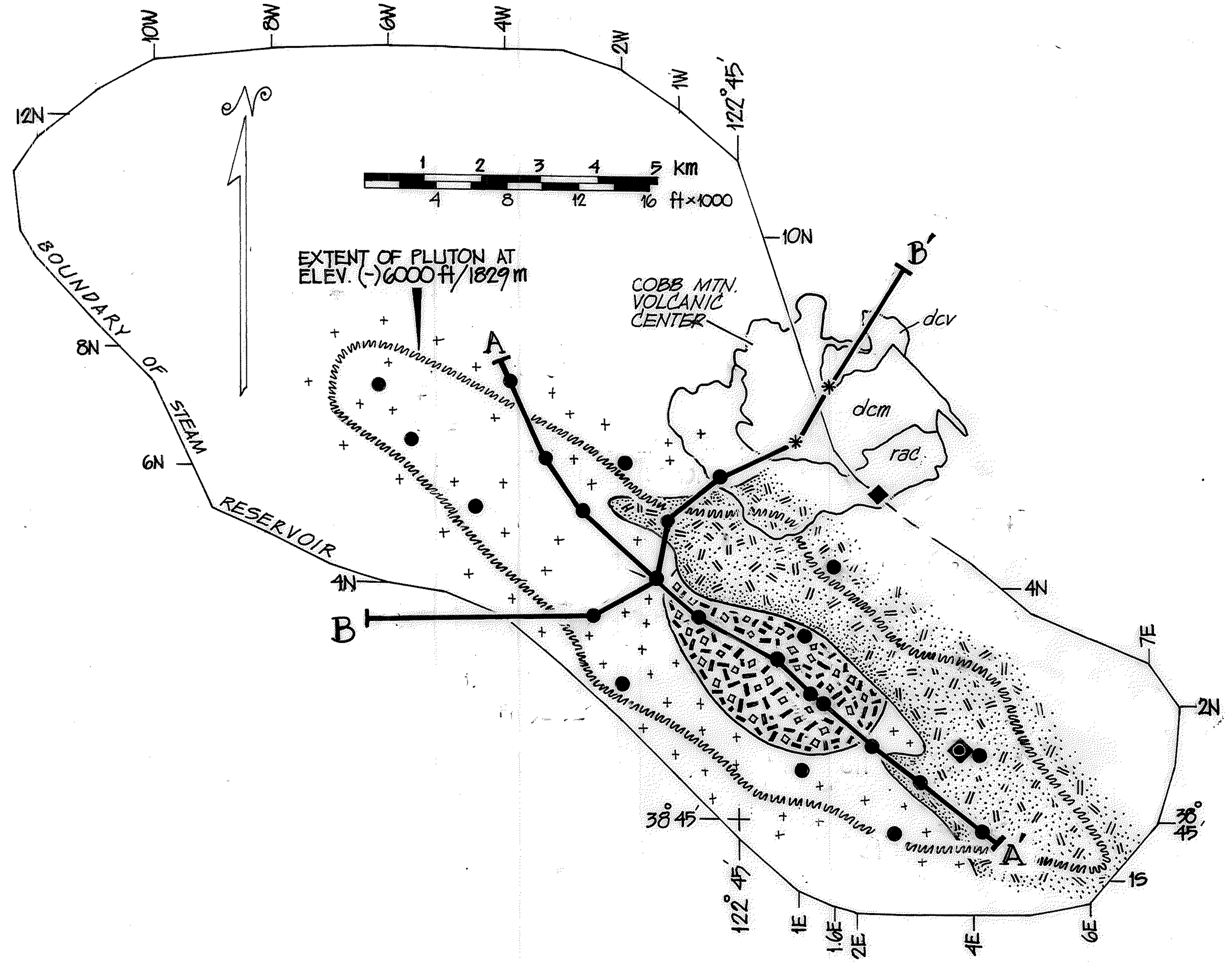
JBH


10W
9W
8W
7W
6W
5W
4W
3W
2W
1W
00 122°45'
1E
1.6E
2E
3E
4E
5E
6E
7E
2S
1S
00 38° 45'
1N
2N
3N
4N
5N
6N
7N
8N
9N
10N
11N
12N
13N
14N


BOUNDARY OF STEAM
38°45'
122°45'
el. (-) kft


38° 45'
122° 45'
2 km
ELEV. -914 m ①
ELEV. -1219 m ②
ELEV. -1524 m ③
ELEV. -1829 m ④
N
2 km
VERTICAL SCALE ARBITRARY
spacing wrong
Pyroxene(?)-biotite microgranite porphyry
orthopyroxene-biotite granite
orthopyroxene-biotite-hornblende granodiorite
① (-)3000 ft
② (-)4000 ft
③ (-)5000 ft
④ (-)6000 ft

JBH 99024


10W
8W
6W
4W
2W
1W
122°45'
12N
8N
6N
4N
10N
BOUNDARY OF STEAM RESERVOIR
1 2 3 4 5 km
4 8 12 16 ft×1000
EXTENT OF PLUTON AT
ELEV. (-)6000 ft/1829 m
COBB MTN.
VOLCANIC
CENTER
dcv
dcm
rac
A
A'
B
B'
4N
7E
2N
38°45'
1S
6E
4E
2E
1.6E
1E
122°45'
38°45'

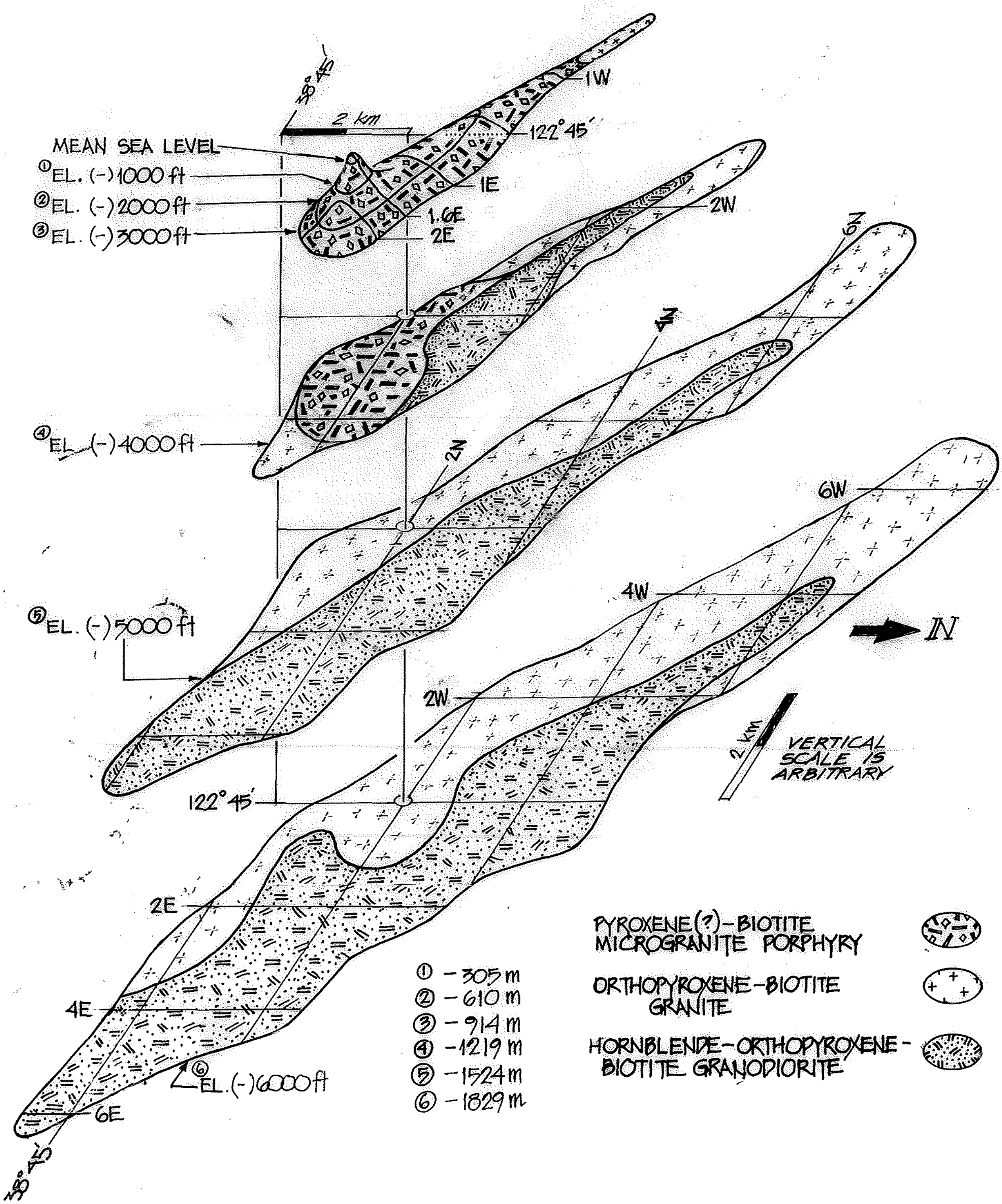
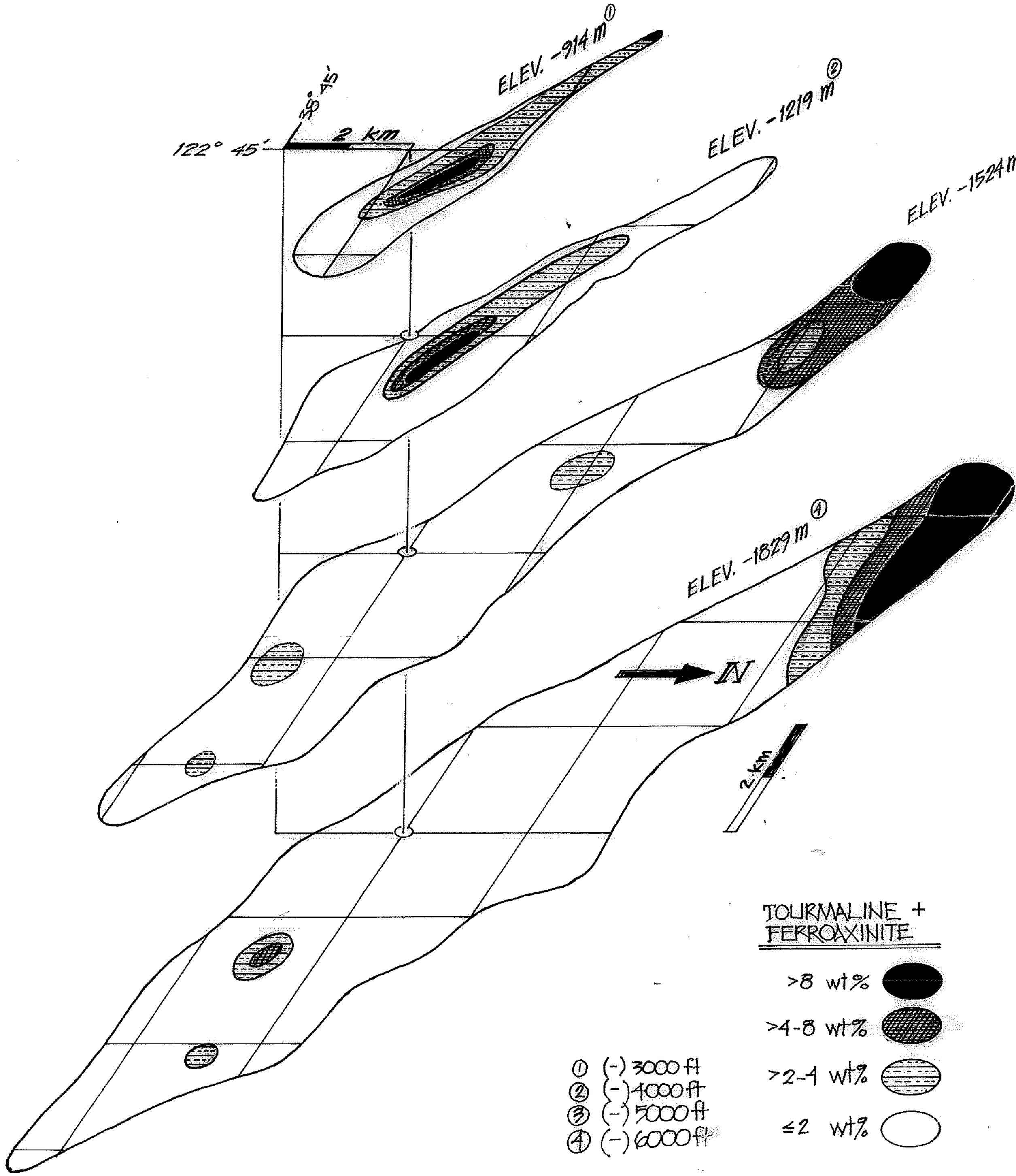
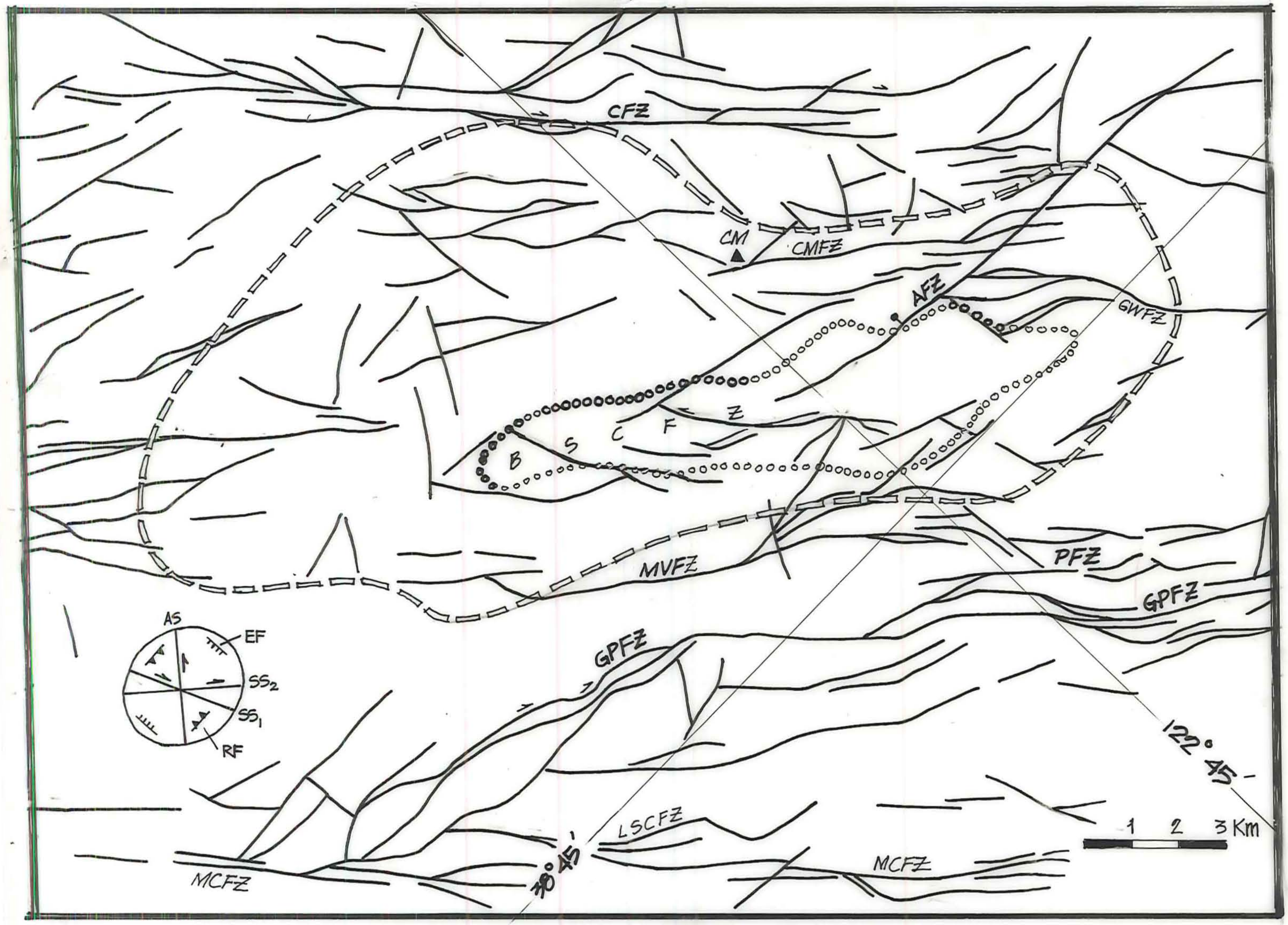
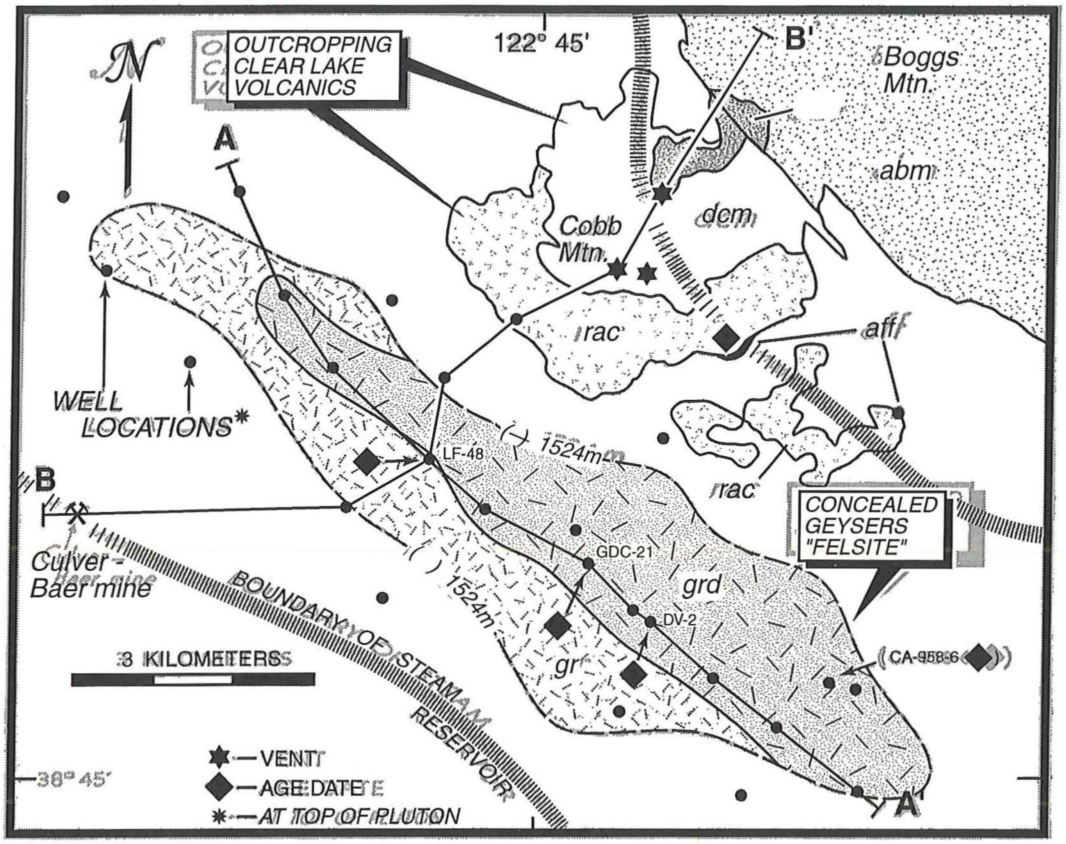


FIGURE . LITHOLOGIC LEVEL MAPS OF THE GEYSERS PLUTONIC COMPLEX ("THE FELSITE"). AREALLY RESTRICTED UPPER FOUR LEVELS COMBINED FOR CLARITY.

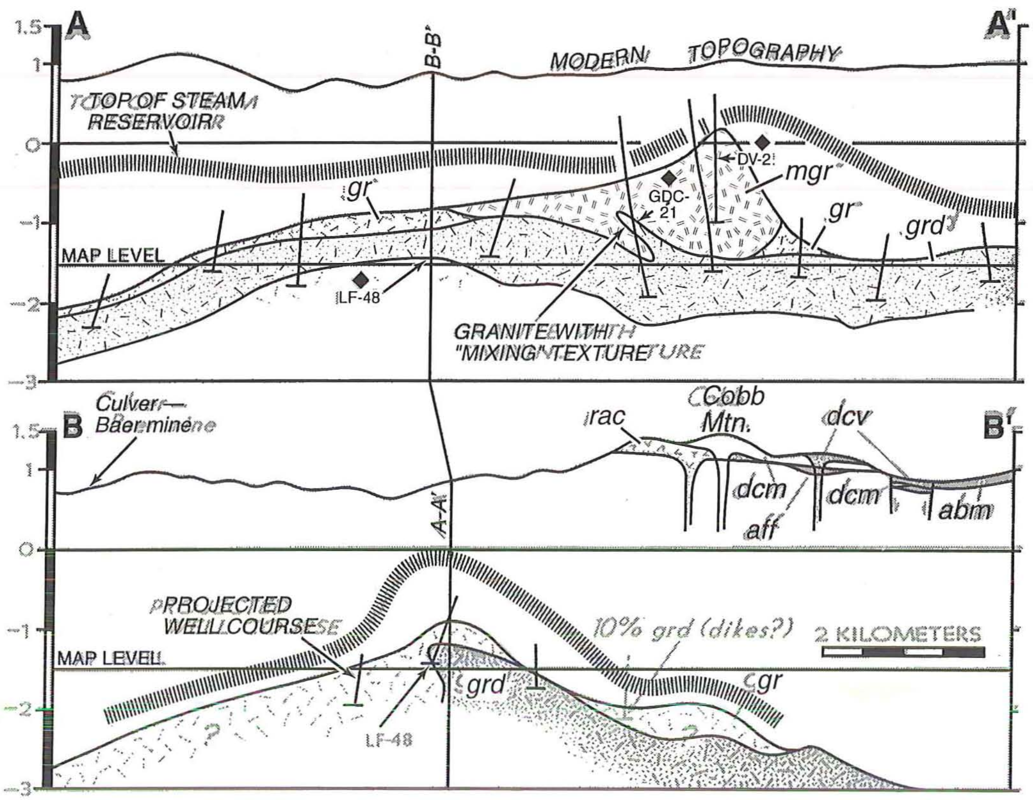
DRAFT JBH 03/09/99




CFZ
CM
CMFZ
AFZ
GWFZ
B
S
C
F
Z
MVFZ
PFZ
GPFZ
GPFZ
AS
EF
SS2
SS1
RF
122° 45'
38° 45'
LSCFZ
MCFZ
MCFZ
1 2 3 Km

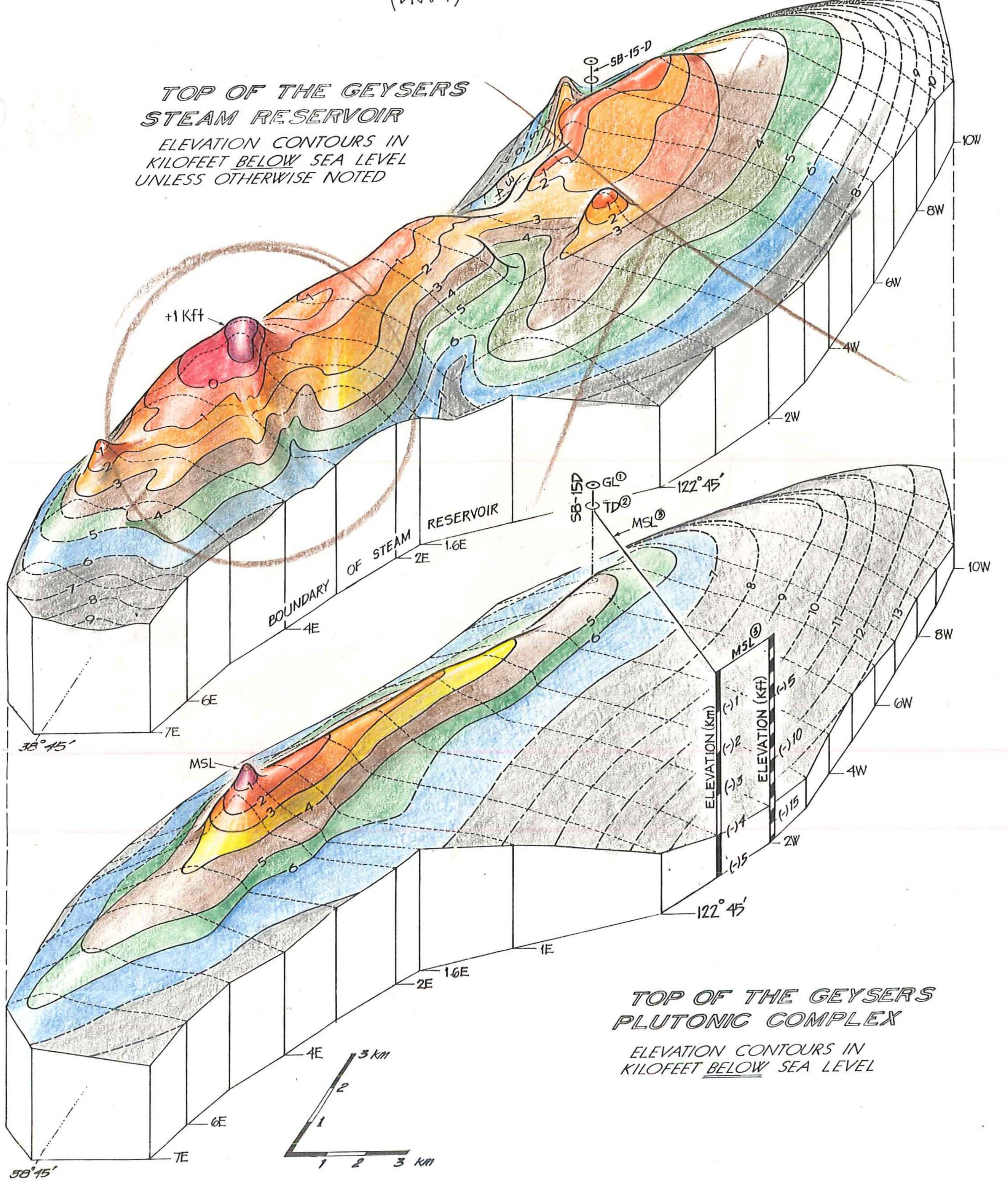


122° 45'
OUTCROPPING CLEAR LAKE VOLCANICS
B'
Boggs Mtn.
abm
A
dcm
Cobb Mtn.
rac
aff
WELL LOCATIONS*
LF-48
(–) 1524m
B
rac
CONCEALED GEYSERS "FELSITE"
GDC-21
Culver - Baer mine
grd
BOUNDARY OF STEAM RESERVOIR
DV-2
(–) 1524m
3 KILOMETERS
gr
CA-958-6
VENT
AGE DATE
AT TOP OF PLUTON
38° 45'
A'



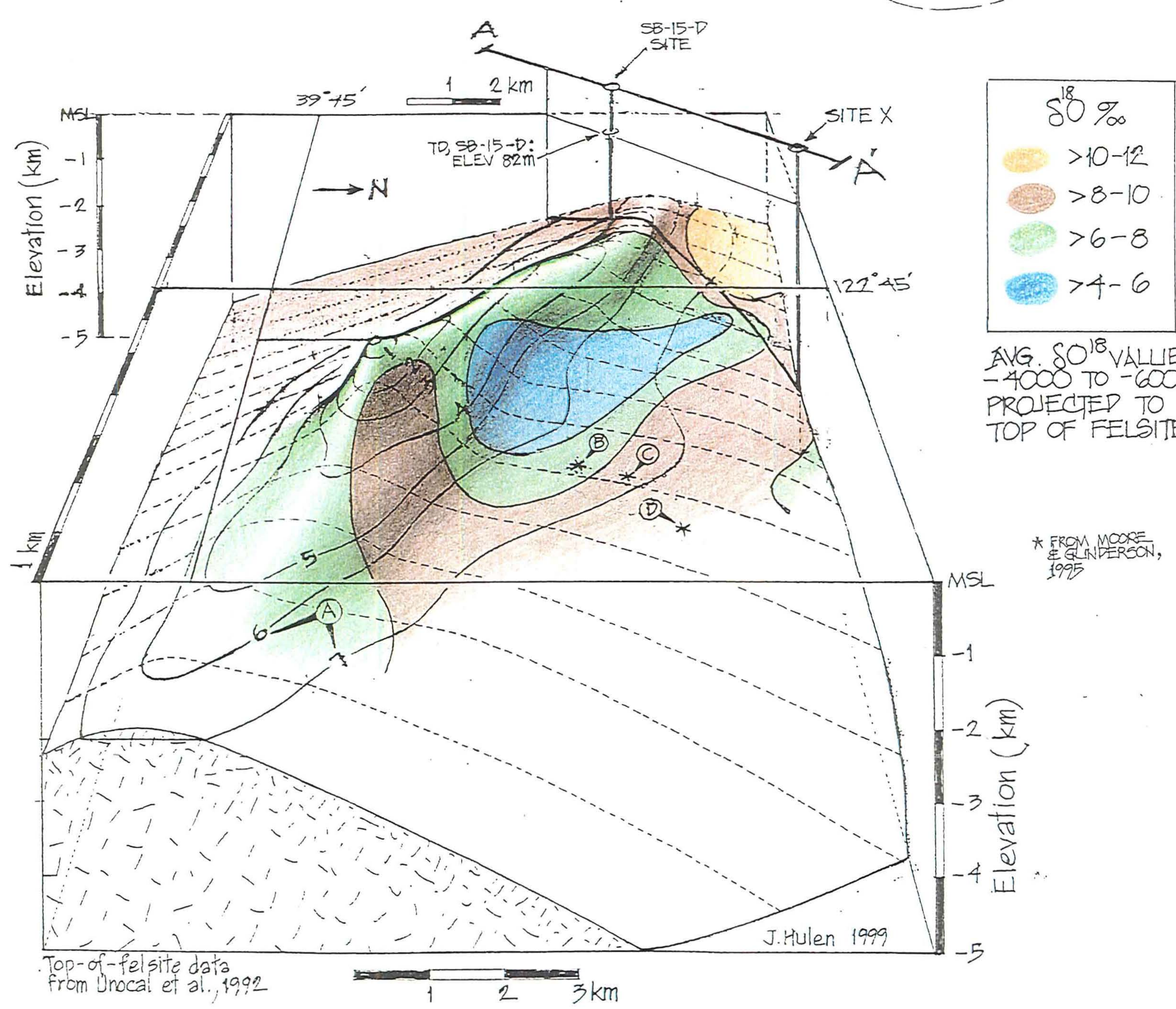
A
A'
B-B'
MODERN TOPOGRAPHY
TOP OF STEAM RESERVOIR
ELEV, KILOMETERS
1.5
1
0
-1
-2
-3
DV-2
mgr
gr
GDC-21
gr
grd
MAP LEVEL
LF-48
GRANITE WITH "MIXING" TEXTURE
Culver—Baer mine
B
Cobb Mtn.
rac
dcv
B'
dcm
dcm
aff
abm
A-A'
PROJECTED WELL COURSE
10% grd (dikes?)
2 KILOMETERS
MAP LEVEL
grd
gr
LF-48

(DRAFT)



TOP OF THE GEYSERS STEAM RESERVOIR
ELEVATION CONTOURS IN KILOFEET BELOW SEA LEVEL UNLESS OTHERWISE NOTED
SB-15-D
+1 Kft
BOUNDARY OF STEAM RESERVOIR
10W
8W
6W
4W
2W
122° 45'
1.6E
2E
4E
6E
7E
38° 45'
SB-15D
GL①
TD②
MSL③
MSL
ELEVATION (Km)
ELEVATION (Kft)
(-)1
(-)2
(-)3
(-)4
(-)5
(-)10
(-)15
1E
TOP OF THE GEYSERS PLUTONIC COMPLEX
ELEVATION CONTOURS IN KILOFEET BELOW SEA LEVEL
3 km
1
2
3 km
38° 45'

DRAFT



Ⓐ ELEVATION CONTOUR, FT X 10^3 BELOW MEAN SEA LEVEL (MSL)

* VENT LOCATIONS, COBB MTN. VOLCANIC CENTER, PROJECTED VERTICALLY DOWNWARD TO TOP OF FELSITE

Ⓑ Rhyolite of Alder Creek (1.2Ma), elev. 1390m

Ⓒ Dacite of Cobb Mtn. (1.1Ma), elev. 1430 m

Ⓓ Dacite of Cobb Valley (1.1 Ma), elev. 1100 m

FIGURE 1 PERSPECTIVE 3-D BLOCK DIAGRAM OF THE UPPER SURFACE OF THE GEYSERS FELSITE. SECTION A-A', WHICH PASSES THROUGH COREHOLE SB-15-D, WAS CHOSEN FOR NUMERICAL THERMAL HISTORY MODELING TO APPROXIMATE PEAK PALEOTEMPERATURES OBTAINED FROM FLUID-INCLUSIONS AND VITRINITE REFLECTANCE.