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Abstract

At least seven major stratabound Pb-Zn deposits have been discovered in a small area on the southeast flank of the Anvil Batholith (Anvil Range Central Yukon). Twenty previous Pb isotope analyses of samples from 4 of the deposits are not anomalous to any great extent in the light of the Cambrian age of the deposits. Recent mapping has added greatly to the understanding of the detailed stratigraphy of the deposits and their position in the regional stratigraphy. Sulfide samples can now be selected with a much better understanding of their position in the deposit stratigraphy. An additional 32 new samples have been analyzed from the deposits in an attempt to see if in general terms an interpretation

of the Pb isotope data will or will not add support to the previously proposed metalogenic model. This model assumes that a deep source brine stripped Pb from sedimentary rather than volcanogenic material and transported it to the submarine surface, where sulfides were precipitated with a distinct stratigraphy from the brine pool.

Introduction

The regional geology of the Anvil area has been described in detail elsewhere, ¶a summary Lower Paleozoic and older sediments flank the southwest side of the Cretaceous Anvil Batholith (Figure 1). Subsequent to the Triassic, the layered rocks experienced intermediate pressure metamorphism of varying grade. ¶ ~~[illegible]~~ Near Blind Creek (Figure 1) metamorphism reached greenschist facies grade; 10 miles to the north, it attained amphibolite facies grade. The layered rocks reveal a complex structural geometry that can best be described in terms of at least 4 phases of deformation the ~~whose~~ ages of which are probably similar to that of the metamorphism.

At least 7 massive deposits have been found adjacent to or in the calcareous pelitic Lower Cambrian Vangorda formation. Most of the deposits are in the Vangorda formation near its gradational basal contact with the Mt Mye formation which is a non calcareous pelitic unit. These deposits (Faro Vangorda Grum Dy Swim Sea and SB figure 1) are strata-bound and most have an internal stratigraphic succession (the Anvil Cycle) that may be repeated a number of times within one deposit. The Anvil Cycle consists of at least three recognizable units; the oldest is a ribbon banded graphitic quartzite which is overlain by a pyritic quartzite, ~~which~~ this in turn is overlain by the youngest unit ~~con~~ which is composed of massive pyritic sulfides and baritic massive sulfides. The deposits (with the exception of the Dy deposit) are generally not associated with large volumes of volcanic material and the volcanic material that is present is ① higher in the stratigraphy ② consists of flows ③ is basaltic with intraplate trace ~~&~~ element characteristics.

A working hypothesis for the formation of the deposits is one of brine eruption. The brine originates in the ~~grit formation~~ Proterozoic Hadrynian Grit Unit which probably underlies the Mt Mye formation. The grit unit is an informal term for large volumes of impure clastic sediments of late Proterozoic age that underlie large parts of the Cordilleran geosyncline. This unit probably had the porosity and permeability necessary to provide large volumes of brine in Cambrian times. The brine could have been heated in the grit unit by intruding basic sills; this intrusive activity may also have helped the brine break through the overlying Mt Mye formation to reach the submarine surface. The Anvil Cycle may have resulted from the exhalative activity of the brine in a second order starved basin environment (possibly

A decrease in the amount of sediment mixing with the brine pool as it "aged" may be responsible for the different units in the Anvil Cycle; the cycle may also contain evidence of changing conditions at source as the brine pool develops at surface.

Lead isotope data: Anvil Area
General interpretation

Pb isotope analyses have been made on galenas from 5 of the 7 deposits from the Anvil area and on one galena from the NA deposit which occupies an equivalent stratigraphic position on the northeast of the ~~batho~~ Anvil Batholith. Results are also available from earlier work by P LeCouter ( ). The Faro and Swim deposits have been analyzed during the present study and by LeCouter. There is a small but consistent difference between the two data sets and for comparison purposes in this paper LeCouter's data has been multiplied by a "normalizing" factor. The present data is presented in Tables 1 2 and 3

Generally the deposits have very similar Pb isotope ratios which suggest negative single stage ages using the growth curve of Stacey and Kramers (1975). These ages range from -25 bys for the SB deposit to .301byr for the Vangorda and Faro deposits.

Another way of interpreting Pb isotope data has been developed by Doe and Zartman (1979). In part they have classified recent Pb leads empirically ~~based~~ and then ~~on~~ ~~where~~ they plotted them in xvy and xvz diagrams (lead notations in Table 4). In this way they recognize graph areas on xvy and xvz plots occupied by such broad categories of leads as magmatothermal and enclosed basin ~~and~~ ~~[illegible]~~ leads to name a couple (Figure) They have extended the usefulness of this classification back in time by developing a set of lead evolution growth curves (orogenic, upper crustal, lower crustal and mantle (Figures)). These curves are not single stage growth curves in the strict mathematical sense, but are developed using a dynamic mixing model which involves the processes of erosion and subduction and a/as the Pb isotope reservoirs after which the curves are named.

The Anvil data are plotted in figures 1 and 2 from which it can be seen that on the x v y plot (figure 2) the Anvil Pb is between orogenic and upper crustal in character, and from figure 1 (x v z plot) that the Pb, if allowed to develope to the present, would plot in the enclosed basin field. For comparison Bathurst (.46 byr) and Pine Point (.35 byr) are plotted. The single stage ages of the Anvil data using the Doe and Zartman growth curves are much closer to their probable geologic age of Lower Cambrian.

The stratigraphy of the Dy deposit is relatively well understood and drill core mapping has identified a fine structure of lithostratigraphic units that can be grouped into at least 5 Anvil cycles. Twenty two samples were analyzed from 2 drill holes ~~[illegible]~~ Samples represent about 2 ft of core and were collected from 10 different lithostratigraphic units representing the complete stratigraphy of the Anvil Cycle. For convenience samples are grouped into two groups, the first contains samples from the bottom of the cycle and the second samples from the middle and top (Table). The average x and z values for the two groups are different at the 1σ level. There does not seem to be any significant variation of Pb isotope ratios ~~of~~ from a single lithostratigraphic unit along strike from one drill hole to the next.

If the across unit variation in x and z values is significant then many explanations can be found for it; two are proposed here, ①: The lower x and z values in the upper part of the Anvil cycle are caused by introduction of a small component of volcanogenic Pb derived from depth. This Pb is mixed with a large component of crustal Pb with higher x and z (more radiogenic) values. Both Pb leads originate at depth and are brought to the surface by the brine. ②: the lower x and z values are caused by a decrease in the amount of near surface radiogenic Pb (high x and z values) contaminating the less radiogenic Pb brought to the surface by the brine. This contamination would take the form of an increased sediment component at the base of the Anvil Cycle. These two proposals are developed in a later section.

Faro deposit

Nine samples from the Faro deposit were analysed by Lelonter( ); it is now known that the Faro deposit consists of one large Anvil Cycle and three additional samples were analysed from the bottom, middle and top of the cycle (Table). Each sample was analysed twice to improve accuracy. It appears that the sample from the base of the cycle has higher x and z values than samples from higher in the cycle; the results are significant at 10. This result is the same as that for the Cy deposit which is composed of a number of cycles.

SB deposit

Four samples were analysed from the SB deposit (Table) and the results are similar to those for the other deposits though the spread in x values is larger.

Swim deposit

Two new analyses from the Swim deposit helped in the comparison of LeCouteur's data set with the present data set. The results are in Table __ and plotted in figures

NA deposit

A single sample was analysed from the NA deposit. The Pb isotope data is significantly different from that of the Anvil deposits and in fact is similar to the Anvil Batholith vein analyses of LeCouteur (.). It is unlikely that the Pb in the NA deposit has any relationship ~~with~~ to the Pb in the Anvil deposits

Detailed interpretation of Pb isotope data

The general characteristics of the Pb data have been discussed, but in detail ([illegible]) it can be seen that data from the deposits plot on a short line (Figure). The slope of the line through the 7 Anvil deposits is .21; this is similar to the slope obtained by Le Couteur ( ) and corresponds to a T_1 age of 2.7 by for T_2 = .6 by or a T_1 age of 2.72 byr for a T_2 of .55 byr. The slope of the line ~~as~~ is proportional to a T_1, T_2 age pair only under fairly ~~limiting~~ limiting conditions. In this case where it is suspected that the line is formed by the mixing of two components, two major conditions must be met (1) that at about 2.7 by the two components were isotopically similar and (2) from 2.7 by to ≈ .55 by. the two component Pbs have developed under approximately closed system conditions. Le Couteur assumed that

~~the~~ both Pb components were crustal and that the more radiogenic one originated from the metamorphosed host rocks; This proposal is no longer tenable because the Gran and Dy deposits have high average x values but are located in low grade metamorphic rocks.

The less radiogenic component could be derived from volcanogenic rocks at depth, in which case the the line probably has no age significance. Possible cooperation of the volcanogenic Pb contaminant hypothesis is found in the correlation of average x values for each deposit v ~~the~~ total spread in x values for each deposit (Table Figure) The correlation suggests mixing of a uniform non radiogenic Pb ~~within a basin~~ (volcanogenic component) with a less uniform more radiogenic component (Pb from the grit unit). The proposal that the radiogenic component could be near surface Pb seems unlikely because Pb leached from older sediments (the grit unit in this case) is usually more radiogenic than Pb leached from recent sediments (material adjacent to brine pool in this case).

If the two component ~~of~~ leads responsible for the line (Figure 3) are grit-unit-leach Pb and deep source volcanogenic Pb then obviously the SB deposit has the ~~least~~ smallest volcanogenic component and the E sea deposit the greatest; also the line should ~~project back~~ intersect to a reasonable y value for Eo Lower Cambrian volcanogenic Pb which infact it does (Figure 3; mantle growth curve).

The Anvil leads do project forward in time to plot in the enclosed basin field of Figure) of Doe and Zartman (1979). It is possible to subdivide the enclosed basin field on the x v z diagram into probable ~~???~~ source rocks. areas. This is feasible because sediments may have comparable U concentrations but different Th/U ratios. In fact the average Th/U ratio for sandstones is 3.8 that of shales 3.3 and carbonates < 1 (Turekian and Wedepohl 1961). Black shales which are enriched in U will have very low Th/U ratios. Leads which ~~have~~ had a sandstone source will tend to plot higher in the enclosed basin field on a x v z plot than ~~x~~ Pb leads from a shale source. The Anvil data does tend to plot high in the x v z plot certainly in comparison to its position in the x v y plot so that the suggestion of ~~a moderately high Th/U~~ a source sediment with moderately ~~???~~ high Th/U ratio is not unreasonable.

~~The~~ Pine Point has been reanalysed (4 ~~early~~ samples) during this study (Table Figure 1 & 2) and the new single stage model age is .316 byr which is not much younger than the deposits Devonian age. The Anvil deposits have single stage ages ~~with~~ which are considerably younger than their geologic age. This suggests that in comparison to ~~the~~ Pine Point the Anvil Pb spent some time in a [illegible]'y high μ environment immediately prior to mineralization. There are at least two ways of obtaining a high μ environment in sediments. The first is by preferentially leaching Pb from the U rich fraction of a rock. This in fact means removing Pb from easily reached locations such as grain surfaces and microfractures where soluble U has previously existed. The second is to remove Pb from organic rich black shales which have previously concentrated heavy metals especially U. The existance of radiogenic Pb leaches from sandstones has been documented by Doe Hedge & White (1966) and it seems reasonable to assume that the brine would remove from the grit unit a Pb which ~~would have~~ had resided in a fairly high μ environment for a short time; ~~The environment would~~ that is grain boundary Pb whose age ~~does~~ would not exceed the sedimentary age of the grit unit. The different age offsets of the Anvil and Pine point data may result from the fact that the Anvil deposits extracted their Pb from sandstones whereas the Pine Point deposit aquired its Pb from the more pelitic McKensie shale basin (Beales and Jackson).

Summary

Lead isotope data will not provide unique ages nor will it give exclusive support to a single metallogenic model. It will provide evidence as to the ultimate source of lead in the deposit though this may not ~~say anything about~~ help in understanding the specific process of formation of the deposit.

In the Anvil area the Pb isotope data tends to support the hypotheses that

(1) the majority of the Pb in the deposits was derived from or upper crustal – orogenic ~~rocks~~ source,

~~(2) This source may have been~~

(2) that may have had a sandstone ~~character~~ rather than shale or carbonate character.

(3) This Pb was progressively mixed with a less radiogenic component probably volcanogenic

Pb derived from basic sills in the gort unit.

The confidence placed in these conclusions is severely limited by the small spread in data values, but the arguments used serve at least to illustrate the sort of potential usefulness of Pb isotope work in ore genesis.

Table 1 Dy deposit data

Drill Hole ①

	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}
B	18.431 (.1)+ 18.419 *	15.628 (.08) 15.610 *	38.343 (.11) 38.321 *
B	18.443 (.04) 18.431 *	15.662 (.05) 15.644 *	38.406 (.03) 38.384 *
B	18.443 (.1) 18.431 *	15.694 (.09) 15.676 *	38.399 (.18) 38.377 *
M/T	18.395 (.03) 18.383 *	15.678 (.2) 15.660 *	38.359 (.01) 38.337 *
?	18.423 (.06) 18.411 *	15.703 (.06) 15.685 *	38.406 (.1) 38.384 *
?	18.408 (.1) 18.396 *	15.676 (.06) 15.658 *	38.537 (.07) 38.515 *
?	18.423 (.07) 18.411 *	15.668 (.07) 15.650 *	38.353 (.07) 38.331 *
M/T	18.391 (.1) 18.379 *	15.609 (.11) 15.591 *	38.216 (.07) 38.195 *

Drill Hole ②

	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}
B	18.485 (.08)+ 18.473 *	15.680 (.05) 15.662 *	38.505 (.17) 38.483 *
? M/T	18.436 (.07) 18.424 *	15.673 (.06) 15.655 *	38.348 (.1) 38.326 *
B	18.401 (.06) 18.389 *	15.651 (.05) 15.633 *	38.326 (.05) 38.304 *
M/T	18.429 (.11) 18.417 *	15.666 (.11) 15.648 *	38.359 (.19) 38.337 *
M/T B	18.401 (.09) 18.389 *	15.668 (.08) 15.650 *	38.426 (.08) 38.404 *
B	18.415 (.09) 18.403 *	15.666 (.09) 15.648 *	38.437 (.07) 38.415 *
B	18.416 (.11) 18.404 *	15.617 (.1) 15.599 *	38.289 (.03) 38.268 *
B	18.419 (.1) 18.407 *	15.679 (.04) 15.661 *	38.214 (.1) 38.193 *
B	18.423 (.09) 18.411 *	15.690 (.07) 15.672 *	38.486 (.13) 38.464 *
B	18.402 (.02) 18.390 *	15.646 (.06) 15.628 *	38.328 (.08) 38.306 *
B	18.463 (.07) 18.451 *	15.673 (.10) 15.655 *	38.561 (.1) 38.539 *
B	18.477 (.05) 18.465 *	15.697 (.1) 15.679 *	38.460 (.1) 38.438 *
M/T	18.388 (.25) 18.376 *	15.661 (.18) 15.643 *	38.357 (.02) 38.335 *
M/T	18.398 (.1) 18.386 *	15.683 (.09) 15.665 *	38.262 (.08) 38.241 *

B bottom Anvil cycle M middle T top.

Table 2 Anvil deposits

Pb isotope data

	$^{206}Pb/^{204}Pb$	1σ	$^{207}Pb/^{204}Pb$	1σ	$^{208}Pb/^{204}Pb$	1σ
Furo Deposit						
T	18.342	(.09)	15.625	(.1)	38.290	(.1)
M	18.316	(.09)	15.645	(.08)	38.205	(.1)
B	18.414	(.06)	15.674	(.1)	38.364	(.08)
Swim deposit						
	18.337	(.08)	15.649	(.04)	38.299	(.05)
	18.327	(.08)	15.624	(.08)	38.136	(.11)
SB deposit						
	18.530	(.09)	15.655	(.01)	38.397	(.15)
	18.370	(.03)	15.678	(.05)	38.394	(.06)
	18.586	(.05)	15:670	(.02)	38.783	(.05)
	18.436	(.07)	15.673	(.08)	38.426	(.09)
NA deposit						
	18.188	(.08)	15.696	(.08)	39.245	(.08)

T top Anvil cycle, M middle, B bottom

Table 3

By Deposit

Average results for ① units at bottom of Anvil cycle and ② units in middle or at top of Anvil Cycle.

	$^{206}Pb/^{204}Pb$ 1σ	$^{207}Pb/^{204}Pb$ 1σ	$^{208}Pb/^{204}Pb$ 1σ
① 13 analyses	18.420 ±.008	15.648 ±.007	38.377 ±.027
② 5 analyses	18.388 ±.007	15.641 ±.013	38.289 ±.03

Table 4 Anvil data

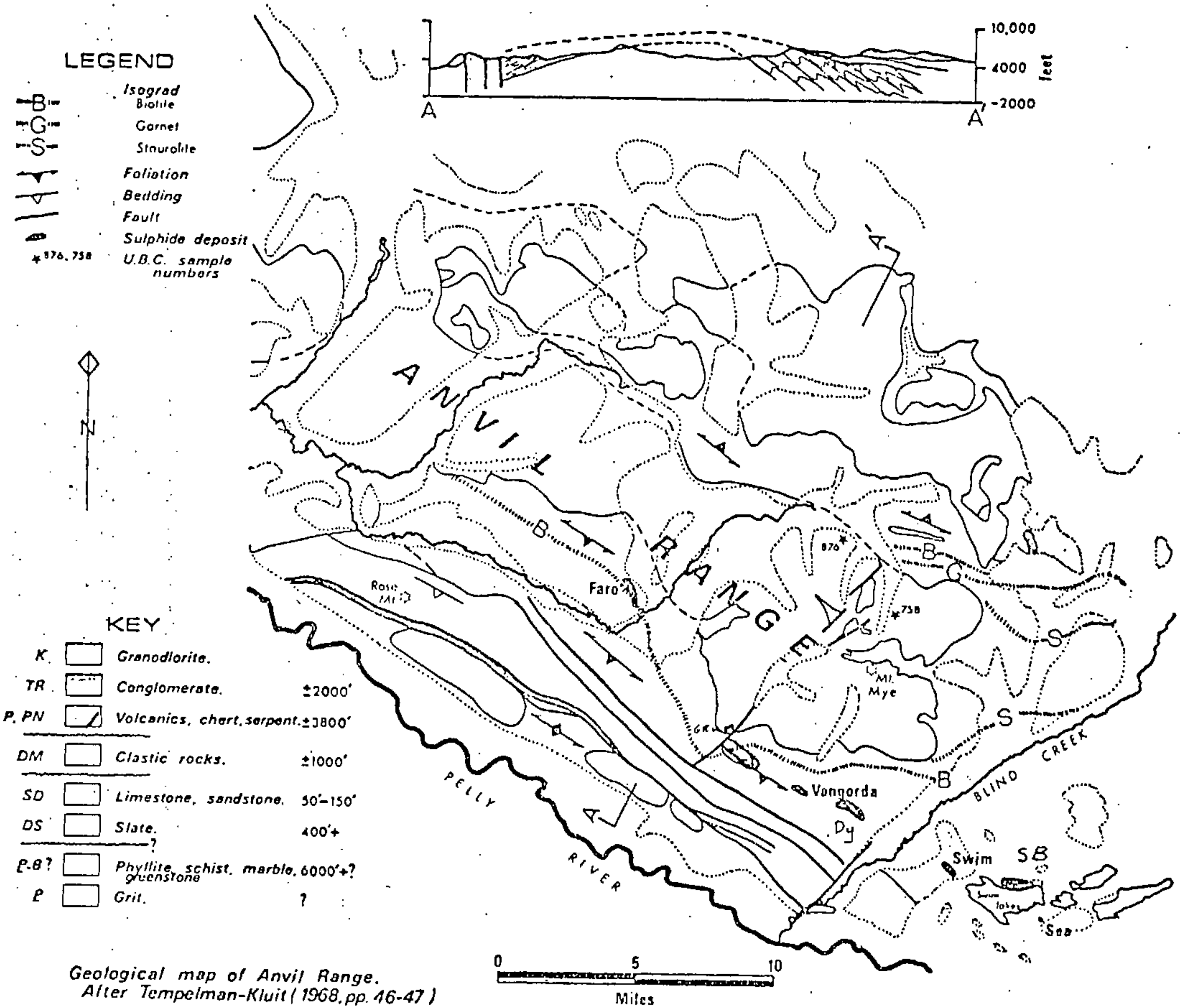
Summary of average values

	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$\Delta\, ^{206}Pb/^{204}Pb$	Age+	μ°
NA	19.188	15.696	39.238		- -.219	9.94
Veins	19.215	15.700	39.238			
SB	18.481	15.669	38.500	.22	.251	9.96
Dy	18.411	15.649	38.359	.097	.262	9.89
Grum	18.404	15.654	38.338	.104	.278	9.92
Faro	18.357	15.648	38.286	.097	.301	9.90
Vangorda	18.345	15.644	38.232	.019	.301	9.89
Swim	18.332	15.637	38.218	.01	.297	9.86
Sea	18.396	15.629	38.231		.270	9.82
Other						
Pine Point	18.170	15.587	38.157		.316	9.68

+ single stage model age using Stacey and Kramers (1975) second stage starting coordinates

° μ effective second stage μ after Stacey and Kramers (1975)

Figure 1



Geological map of Anvil Range. After Tempelman-Kluit (1968, pp. 46-47)

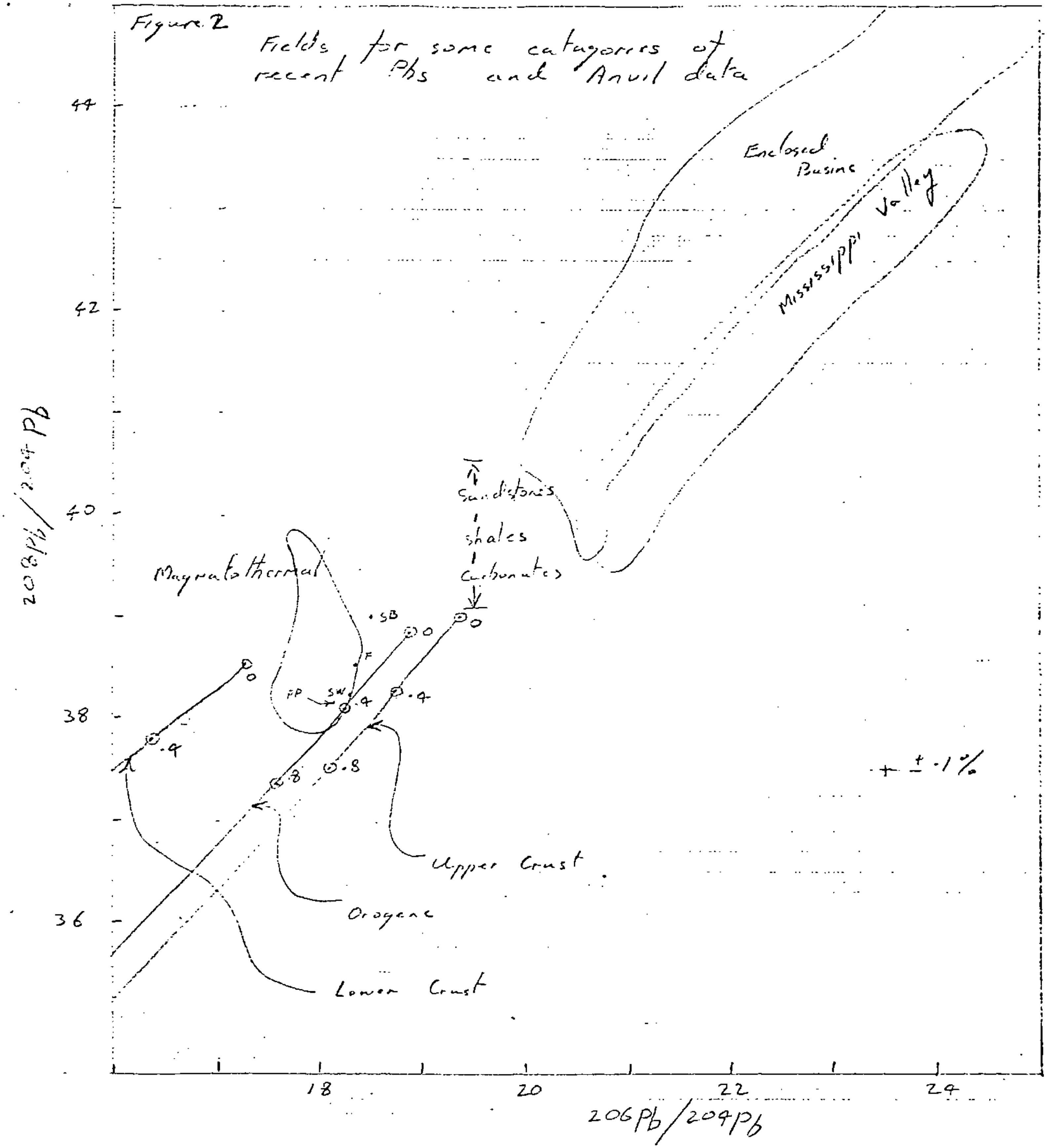


Figure 2
Fields for some categories of recent Pbs and Anvil data
Enclosed Basins
Mississippi Valley
Sandstones
shales
carbonates
Magmatothermal
SB
F
FP
SW
Upper Crust
Orogene
Lower Crust
± .1%
44
42
40
38
36
18
20
22
24
208Pb/204Pb
206Pb/204Pb

Figure 3.

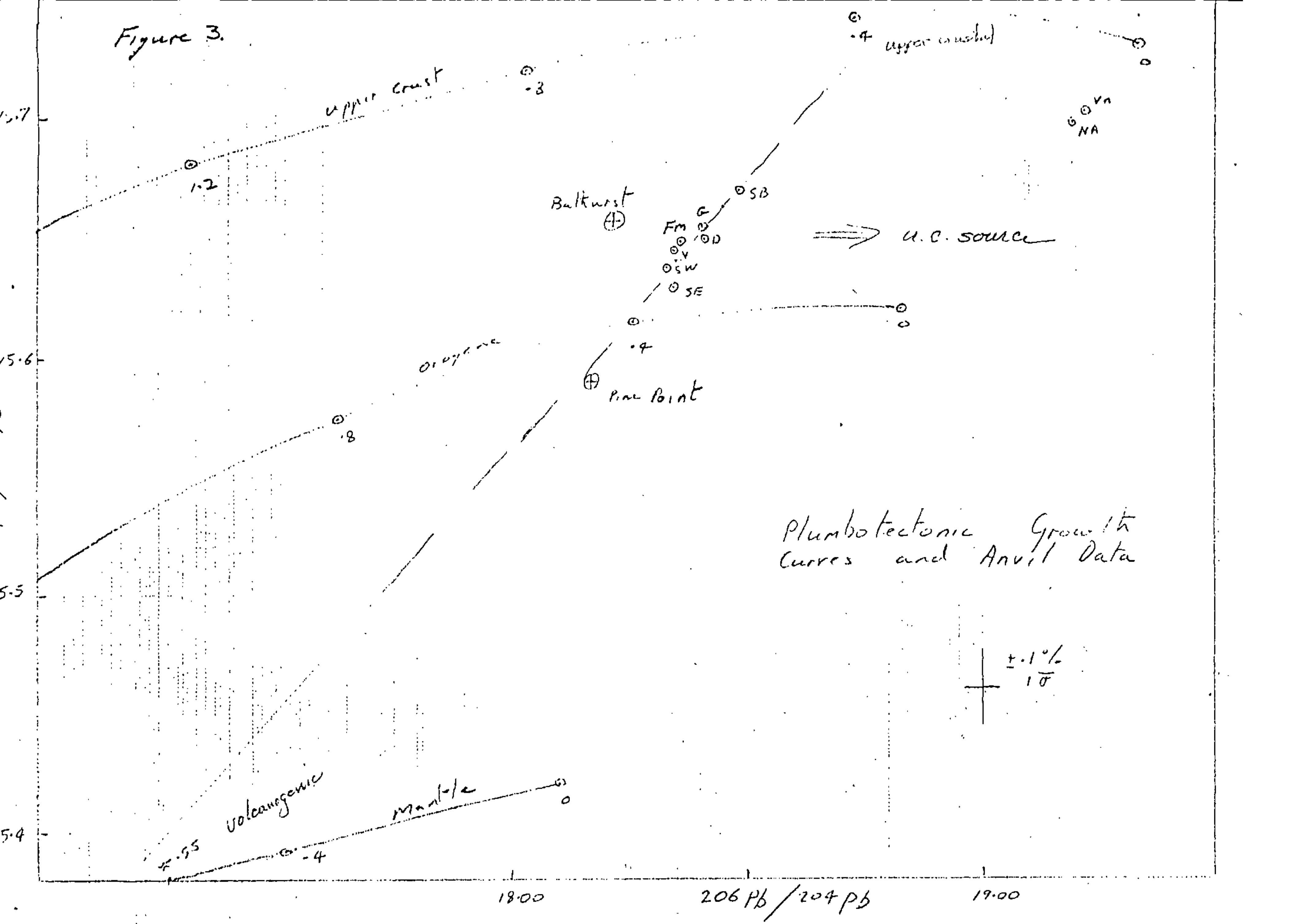
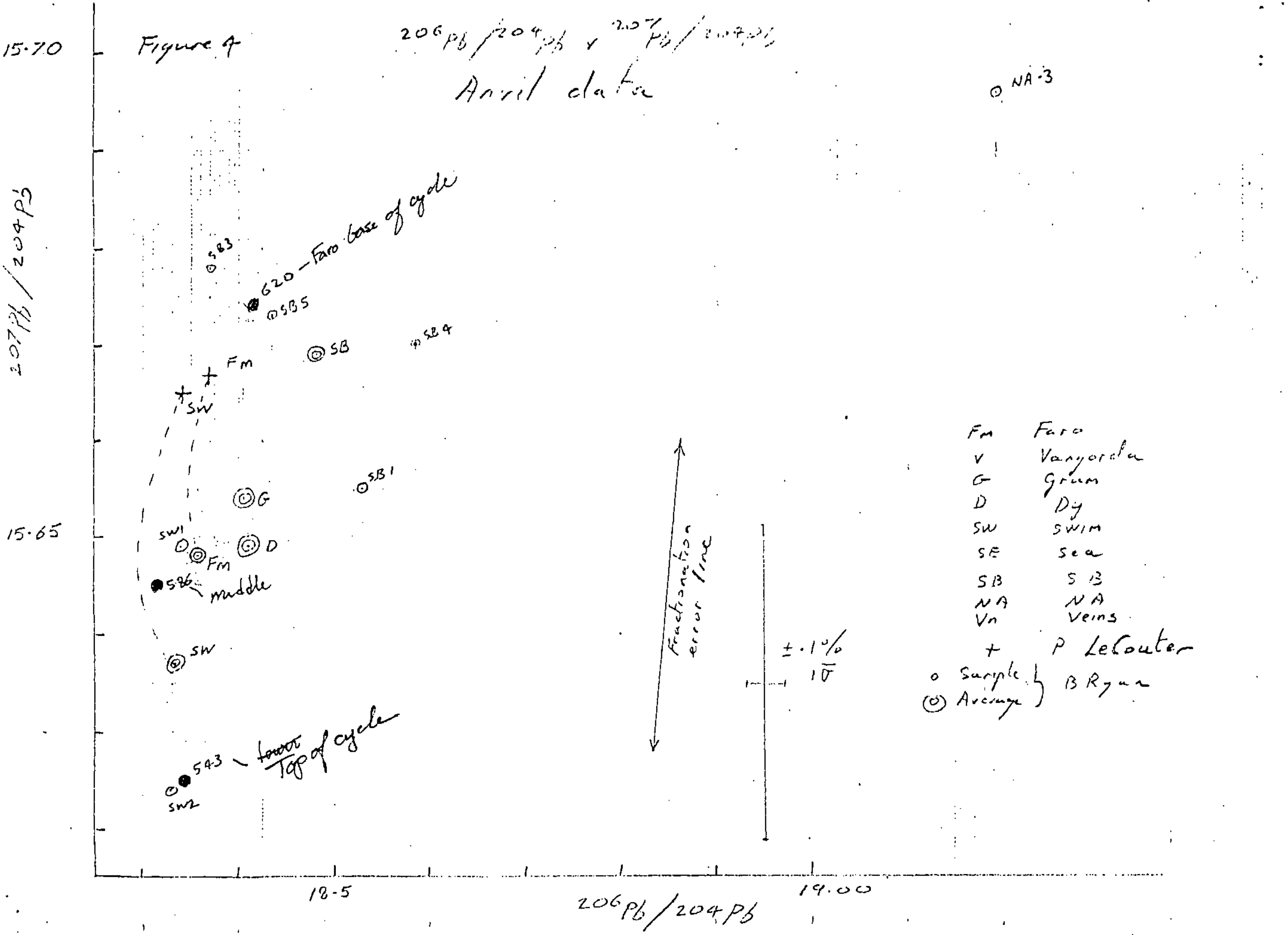

upper crust
orogene
volcanogenic
Mantle
Balkurst
Pine Point
SB
SE
SW
NA
U.C. source
Plumbotectonic Growth Curves and Anvil Data
±.1%
1σ
18.00
19.00
206 Pb / 204 Pb
15.7
15.6
15.5
15.4

Figure 4


206Pb/204Pb v 207Pb/204Pb
Anvil data
15.70
15.65
207Pb/204Pb
206Pb/204Pb
18.5
19.00
NA-3
SB3
620 - Faro base of cycle
SB5
SB
SB4
Fm
SW
SB1
G
SW1
Fm
D
586 middle
SW
543 Top of cycle
SW2
Fractionation error line
±.1%
1σ
Fm Faro
V Vangorda
G Grum
D Dy
SW SWIM
SE Sea
SB S B
NA NA
Vn Veins
+ P LeCouter
o Sample
⊙ Average
B Ryan

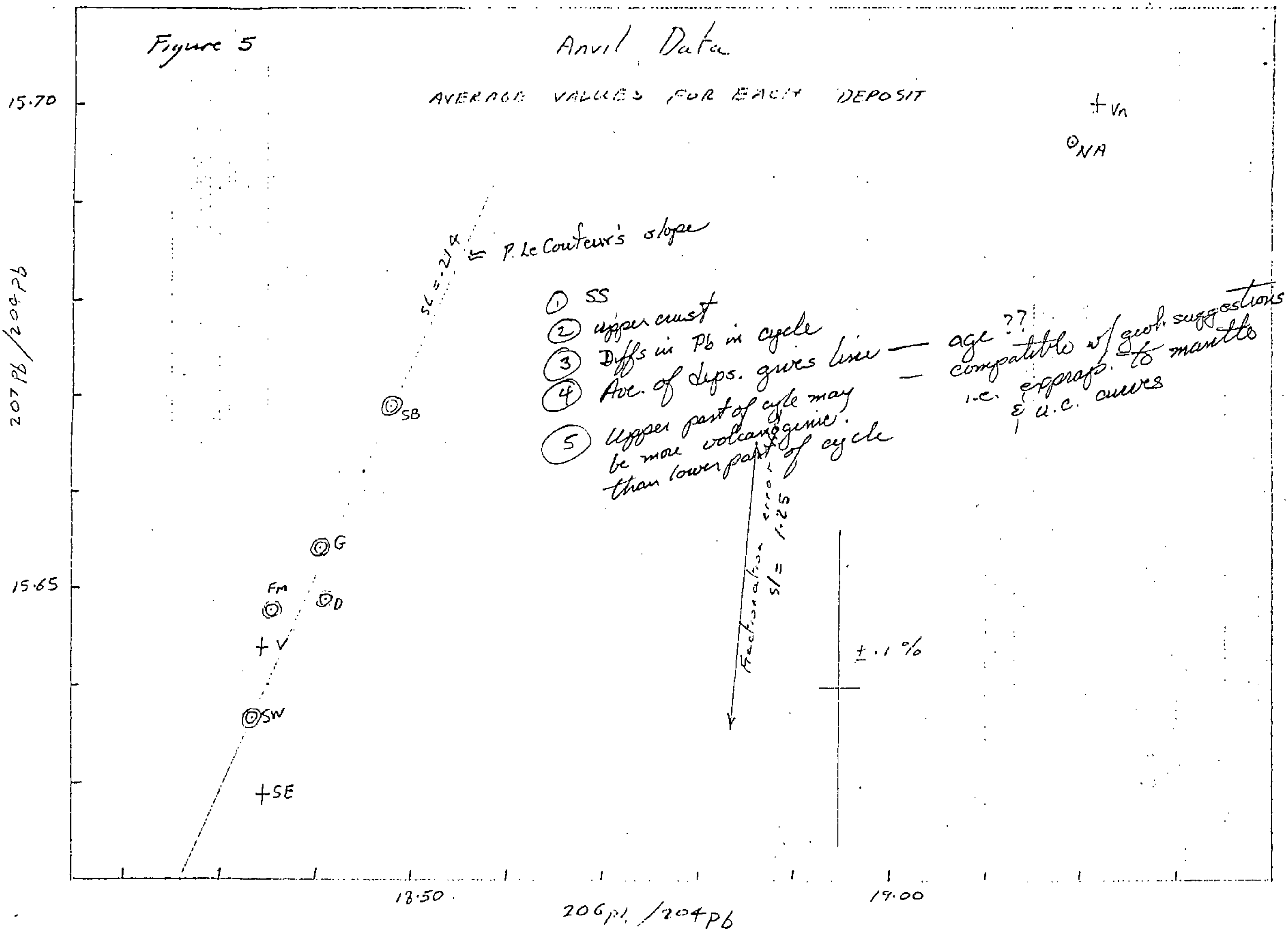
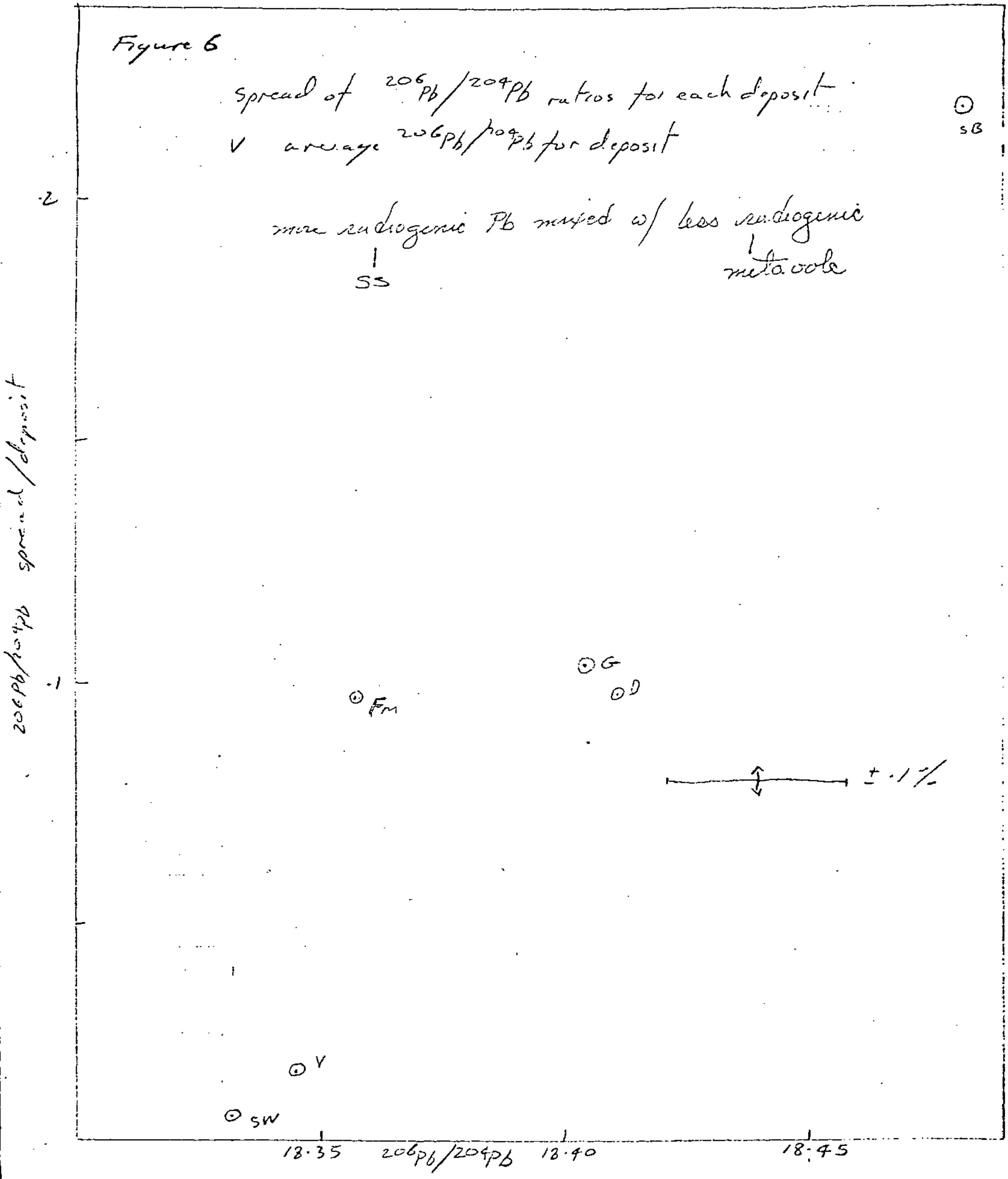


Figure 5
Anvil Data
AVERAGE VALUES FOR EACH DEPOSIT
15.70
15.65
207Pb/204Pb
Sl = .21 α ⇐ P. Le Couteur's slope
① SS
② upper crust
③ Diffs in Pb in cycle
④ Ave. of deps. gives line — age ?? — compatible w/ geol. suggestions i.e. extrap. to mantle & u.c. curves
⑤ Upper part of cycle may be more volcanogenic than lower part of cycle
Fractionation error sl = 1.25
±.1%
Vn
NA
SB
G
D
Fm
V
SW
SE
18.50
19.00
206Pb/204Pb

Figure 6


spread of $^{206}Pb/^{204}Pb$ ratios for each deposit
V average $^{206}Pb/^{204}Pb$ for deposit
more radiogenic Pb mixed w/ less radiogenic
SS
SB
G
D
Fm
V
SW
± .1%
.2
.1
18.35
18.40
18.45
$^{206}Pb/^{204}Pb$
$^{206}Pb/^{204}Pb$ spread/deposit