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RESURGENT VOLCANIC CENTRES AND THEIR ROLE IN PORPHYRY COPPER LOCALIZATION

by Burton J. Devere

RESURGENT VOLCANIC CENTRES AND THEIR ROLE IN PORPHYRY COPPER LOCALIZATION

BURTON J. DEVERE

Due to their wide-spread occurrence and economic importance, porphyry copper deposits, are targets of extensive worldwide searches. What was once thought to be unique to Southwestern North America and the South American Highlands is now known to exist from the northern reaches of Canada to tropical islands of the Pacific.

Research and studies concerning alteration and metallization associated with porphyries ~~has~~ have moved rapidly ahead (1) and the concepts of ore genesis have undergone close scrutiny (2) but there have been few if any advancements in the concepts of porphyry copper localization beyond ideas held in the early 1950s.

J.D. Lowell and J.M. Guilbert touched on some well known but rarely understood features in their recent paper (1): "Several lines of evidence suggest relatively shallow depths of formation and significant variations in water content in the porphyry environment. Shallow emplacement is consistent with the appearance of breccia pipes associated with ring and radial diking and with vertically telescoped zoning".

Shallow emplacement, breccia pipes, ring and radial dikes are features which are developed during the life span of a particular type of volcanic structure, the resurgent volcanic centre or caldera.

CLASSIFICATION OF VOLCANIC CENTRES

The classification of volcanic centres, i.e. calderas and vents, is cumbersome for many reasons and a complete review can not be attempted here. Briefly (for ordered genetic discussion, not descriptive classification), calderas and vents may be divided into two main groups:

(1) Those associated primarily with mafic-shield volcanos and whose origin is independent of pyroclastic eruptions (Kilauea Group) (3)

(2) Those that are associated primarily with differentiated volcanos and whose formation

is preceded or accompanied by voluminous pyroclastic eruptions (Krakatau Group) (3).

The mafic-shield, Kilauea Group volcanic centre is not favourable for the localization of intrusives of the porphyry copper type and does not exhibit features similar to volcanic centres which are favourable. Furthermore, the extrusives emitted from vents within these centres are basaltic and rarely contain much pyroclastic material.

The Krakatau Group of volcanic centres are exemplified by eruptions of great volumes of pyroclastic material and andesitic flows. These centres are not in toto favourable for localization of porphyry copper type intrusives, but two types, Butte and Bougainville, are; both of which appear to be resurgent centres. The main difference between the two types is in the nature of their crustal collapse, extrusive materials, intrusives, and physical location.

MECHANICS OF RESURGENCE

Prior to discussing the two different types of resurgent centres, a brief description of the mechanics of resurgence might assist in understanding the sequence of geological events. From the study of resurgent cauldrons (4) a remarkably systematic pattern of predictable components emerge. These are generalised into seven stages which encompass volcanic, structural and sedimentary events. Although sedimentary events may be greatly overshadowed by the volcanic and structural events, yet they serve to define periods in the development of the resurgent volcanic centre.

STAGE 1 - REGIONAL TUMESCENCE (4)

Regional tumescence refers to the initial development of a volcanic centre. It is a process of swelling and doming caused by increasing pressure in the magma chamber. During this period radial and concentric fractures are formed along which pyroclastic eruptions eventually take place.

STAGE 2 - PYROCLASTIC ERUPTIONS (4)

At some optimum time, regional tumescence is terminated by eruptions of large volumes of ash flows from the domical fracture systems.

STAGE 3 - COLLAPSE (4)

Collapse of the crust is caused by the removal of large volumes of material from the magma during Stage 2. The crust may collapse either as a coherent block or as a fragmented mass, thus forming the initial caulderas.

STAGE 4 - PRERESURGENT VOLCANISM AND SEDIMENTATION (4)

The period following collapse is one of instability both in the magma chamber and within the newly-formed cauldera. Steep unstable walls undergo caving, avalanching and gravity sliding. With the restoration of magma pressure caused by the collapse, the detrital sedimentation may be accompanied by pyroclastic or flow eruptions. During this time the earliest of the intrusive rocks, dikes and plutons, are emplaced in and along the radial or ring fractures.

STAGE 5 - RESURGENT DOMING (4)

With the increasing pressure of the magma the caldera is uplifted, domed and fractured anew, at which time additional dikes and plutons are emplaced within the fractured and broken crust.

STAGE 6 - RING FRACTURE VOLCANISM AND BRECCIATION (4)

Volcanism and intrusive emplacement associated with ring fractures follows the resurgent doming. The newly opened fractures are filled and breccia bodies are developed. The breccia development (5) may be caused by subsidence removal of material along pre-existing zones of weakness by magma withdrawal caused by venting elsewhere within the caldera.

STAGE 7 - TERMINAL SOLFATARIC AND HOT SPRING ACTIVITY (4)

This final period or dying of the volcano is one of crustal adjustments, crystallization of major plutons, minor dike emplacements, terminal solfataric and hot spring activity. It is during this period that hydrothermal alteration and metallization would be most extensive.

The amount of time envisaged from the beginning of regional tumescence to the end of volcanic activity is in the range of 12 million years ± 2 million years (4). But it should be understood that volcanic activity may not end but stage 7 may be the very early part of stage 1 starting the cycle anew.

Mineralization within the resurgent centre is generally believed to be associated with the final stage of development the Terminal solfataric and hot spring stage, but mineralizing solutions could start moving within the vents as early as stage 4 (Pre-resurgent volcanism and sedimentation). Host rock preparations, open voids, fractures and breccias, are well developed by the beginning of stage 7 and it is reasonable to conclude that metallization fluids distilled from the crystallizing magma would be attracted to these broken low pressure zones in the volcanic complex.

Resurgent domes (4) by their very nature tend to obscure and destroy evidence of previous subsidence, particularly in older terrains. The extent to which a subsided cauldron block can recover its former elevation by resurgence is not known. It seems that most uplift is domical with a minimum of uplift at the periphery of the sunken block; hence, even after doming, the periphery of the block should still show some evidence of subsidence. It may be, in some resurgent structures there is complete recovery to the former elevation and perhaps even excessive recovery. If this is possible perhaps many high-level, fault bounded plutons are related to the resurgent stage of development.

The concept of resurgence must embrace all stages of uplift from simple structural domes and fracture domes to domes that are pierced by a central pluton. Some resurgent structures may be buried by post caldera volcanic flows, whereas others may show no post caldera volcanism. Pre-volcanic basement rocks that are exposed in resurgent domes should not be surprising, especially in areas of thin volcanic cover.

BUTTE TYPE OF RESURGENT CENTRE

The Butte type of resurgent volcanic centre is exemplified by voluminous pyroclastic eruptions, granitic plutons with radial and ring dike complexes. Crustal collapse was as a coherent block, thus forming maximum magma chamber pressure for the development of the resurgent system. Intrusive bodies are channelled into zones of least resistance which helps to form the stacking and telescoping of the plutons. Extrusive flows are of the more felsic type with only minor basic flows. These resurgent centres are generally located in cratonic environments and are common throughout the Basin and Range and Rocky Mountain provinces of North America, the highlands of South America and possibly exist, but have not yet been recognized elsewhere throughout the world.

BOUGAINVILLE TYPE OF RESURGENT CENTRE

The Bougainville type of resurgent centre is located in volcanically active eugeosynclines and island-arc systems and is exemplified by violent pyroclastic eruptions, andesitic flows, dioritic-granodiorite plutons with simple ring structures. The crustal collapse in this type of caldera is fragmental giving rise to numerous small volcanic vents and a general diffusion of material coming off the magma which is opposite to the Butte type where material coming off the magma is concentrated in particular channelways along zones of least resistance.

RESURGENT VOLCANIC CENTERS - PORPHYRY COPPER DEPOSITS

In comparing porphyry copper deposts to resurgent volcanic centres one very important aspect must be remembered, porphyry copper type intrusives are the root systems to resurgent calderas. Therefore direct comparisons between existing resurgent calderas and porphyry copper deposits are not possible. But the several features in common to both leads one to the conclusion that their similarities are more than just coincidence.

Porphyry copper deposits are not found directly related to mafic-shield volcanic centers and neither are resurgent caldrons. Resurgent calderas owe their existance to eruptions of great volumns of pyroclastic material. Extensive and numerous pyroclastic deposits cover large areas of southern Arizona and New Mexico (6). These deposits could possibly represent the pyroclastic eruption phase of numerous resurgent centres which could now be represented by the porphyry copper deposits found in that region. The Elkhorn mountain volcanics in Montana (7) could be the equivalent type of pyroclastic formation in the Butte area. In both cases the pyroclastic formations pre-date the intrusions associated with the porphyry copper deposits which also fits the model of resurgent development.

Concentric fracture-dike systems are one of the prerequisites in the development of the resurgent centre and are probably the single feature which most distinguishes them from other volcanic centres. Many porphyry copper type deposits exhibit concentric features which take on many forms. They may be found as breccias or breccias and dikes as at Toquepala (8), as numerous stocks in concentric alignments similar to Butte (9) or simply as dikes like Ajo (10) and Santa Rita (11).

Radial fracture-dike systems are also common but are not as diagnostic as the concentric systems; for several barren volcanic centers are known to exhibit extensive radial dike developments, i.e. The Spanish Peaks in Colorado. But radial and concentric fracture - dike systems occurring together in the same complex would imply development of a resurgent center and is the case at Climax (12) and Poison Ridge (13). Fracture and fault patterns are of help in comparing similarities of resurgent centres and porphyry copper deposits. In addition to the fracture patterns age relationships may be indicated which can be correlated with periods of activity within the volcanic caldera. One area which has been studied in detail, the Santa Rita Quadrangle, (11) demonstrates an intricate sequence of fracturing and intrusive emplacement which outlines the succession of resurgent developments within that complex. The sequence includes four periods of fracturing and dike emplacement plus the deposition of coarse detrital sediments prior to the advent of Miocene (?) volcanism. Dikes and plugs of quartz latite and rhyodacite intrude coarse, poorly sorted, detrital sedimentary deposits. These sediments, located in the Hanover area, are interpreted to be remnants of detrital sedimentary beds deposited within the confines of a now eroded caldera.

The time span for the development of a resurgent centre or caldera was earlier estimated at 12 million ± 2 million years (4). Recent age dating of intrusive masses and volcanics in the Boulder batholith of Montana (7) indicate 16 million years ± 2 million years for the development of that intrusive complex. The pyroclastic eruptions lasted for six to eight million years, while the bulk of the batholith was emplaced beneath and within the volcanic pile during a time span of six million years. Some leucocratic masses were intruded during the next few million years, so that the entire batholith was emplaced within about 10 million years. Unfortunately other areas have not yet been dated in such detail so similar correlations cannot yet be made.

ALTERATION AND MINERALIZATION

When the resurgent dome has regained or exceeded its original elevation there is a good possibility that intrusives are exposed and can be examined to determine if they are altered and mineralized. If the intrusives have not been exposed by resurgence or erosion then the

determination of mineralization at depth becomes more difficult. But since the final stage in the development of resurgent centres is believed to be associated with alteration and metallization some surface manifestations of those processes can be expected. This is assuming that the resurgent complexes are not covered by post-resurgent rocks. The alteration and mineralization would encompass all types of hydrothermal development from hot spring and fumarolic activity through well developed alteration zoning.

The study of alteration related to resurgent volcanic centres has not been pursued beyond the stage of speculation consequently there is little published information from which to draw conclusions. The suggested alteration study guidelines are derived from field observations correlated with the limited number of references which are believed applicable

Mineralization in the form of sulfur deposits with or without furmarolic and hot spring activity is usually related to pyroxene rich andesites, quartz andesites and dacites (14). They are generally regarded to be associated with sulfur rich hydrothermal systems which normally are lacking in base metal concentrations (15). Pyrite is common as are zones of propylitic and argillic alteration.

Solfataric alteration indicates the movement of hydrothermal solutions but does not in itself imply base metal deposition. The solutions which have been active are usually sulfureous and aqueous vapours which attack the volcanic wall rock leaving an end product of chlorite, montmorillonite, kaolinite and silica (often opaline). Pyrite is ubiquitous and is usually the sole sulfide developed during the alteration - metallization process. Silver and gold deposits in veins and breccia bodies are known to occur within zones of this type (Rosita Hills, Colorado and Gilt Edge, South Dakota) and it is possible that they represent the far fringe of base metal deposition at some distance, either vertically or horizontally within the resurgent complex.

Propylitic and argillic alteration zones, usually with abundant pyrite, kaolinite and secondary silica should be separated from the previously described zones of solfataric alteration. These zones often contain veins and veinlets of base metal mineralization which in the final sense are the positive indications of base metal deposition. These veins and veinlets are often

enclosed in envelopes of either secondary biotite, sericite or potassic feldspar or a combination of those products. The veins, similar to veins in sulfataric zones, are frequently gold and or silver bearing as is the case at the Kerwin and Stinkingwater deposits in Wyoming. Alteration in the premineral volcanics overlying and surrounding mineralized intrusives at Bougainville (16) is characterized by processes including biotization, chloritization, silicification, kaolinization and pyritization. Biotization appears to be directly related to the copper-gold mineralization but the other types of alteration appear to be developed at a later stage. Thus it would appear that base metal mineralization within the resurgent complex is reflected by secondary biotite-potassic alteration in the overlying and surrounding premineral rocks. These alteration features are often overlooked or unrecognized due to their possible minor development and or the dominate effects of the argillic alteration. The problem is usually even more complex due to the masking of the entire hydrothermal alteration suite by supergene alteration derived from the oxidation of abundant pyrite within the argillic zone.

SUMMARY AND CONCLUSIONS

Resurgent volcanic centres are a particular type of volcanic caldera or vent. They are developed through a series of events which include: doming with concentric and radial fracturing, voluminous pyroclastic eruptions, crustal collapse, intrusion of central plutons and dikes, resurgent doming and renewed fracturing, intrusive emplacement-brecciation, and hydrothermal alteration. These events and their end products, plutons, dikes, breccias, and fracture systems are all compatible with and are exemplified by many porphyry copper type deposits and their surrounding environments.

The search for resurgent volcanic centres, with the ultimate goal of porphyry copper discoveries, can be initiated along the following lines:

1. Rule out mafic-shield volcanic areas.

2. Select areas with evidence of extensive pyroclastic volcanism.

3. Examine pyroclastic areas for ring dike complexes and areas with complex histories of intrusions.

4. Watch for evidences of doming and subsidence.

Upon the selection of particular targets, examinations should be made which pay attention to alteration and mineralization in which the following may apply:

1. If sulfur deposits occur within the volcanic complex the chance for base metal deposition is believed to be poor.

2. Solfataric alteration is generally regarded as unfavourable for near surface base metal concentrations.

3. Areas of argillic alteration which contain veins or patches of secondary biotite, potassic feldspar and sericite with or without evidence of base metals are the positive indications of near surface (± 2,500 feet) base metal deposition.

Comparisons are no better stated then by V.D. Perry in ~~this~~ his paper "The Significance of Mineralized Breccia Pipes" in which he says: "Billingsley and Locke have referred to the repeated occurrences of Tertiary volcanic formations in proximity to important Tertiary mineral districts in the western U.S. The parallelism of the South American porphyry copper belt and the Andean Volcanic chain from Peru to central Chile suggests a genetic connection between the great deposits and nearby volcanic features. The regional relations suggest volcanic eruption and magma loss as a reason for collapse, subsidence and consequent concentration of mineralizing fluids".

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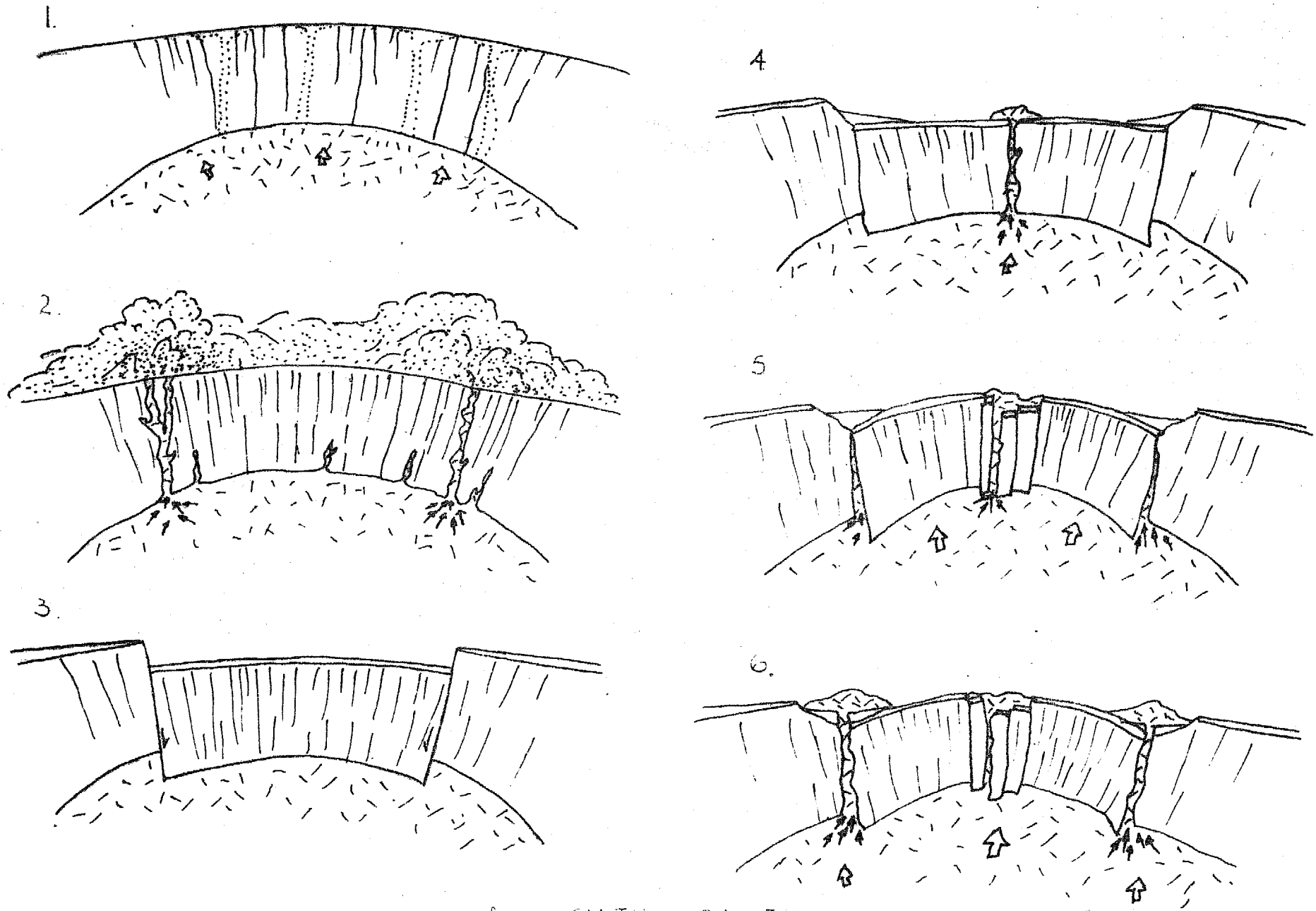
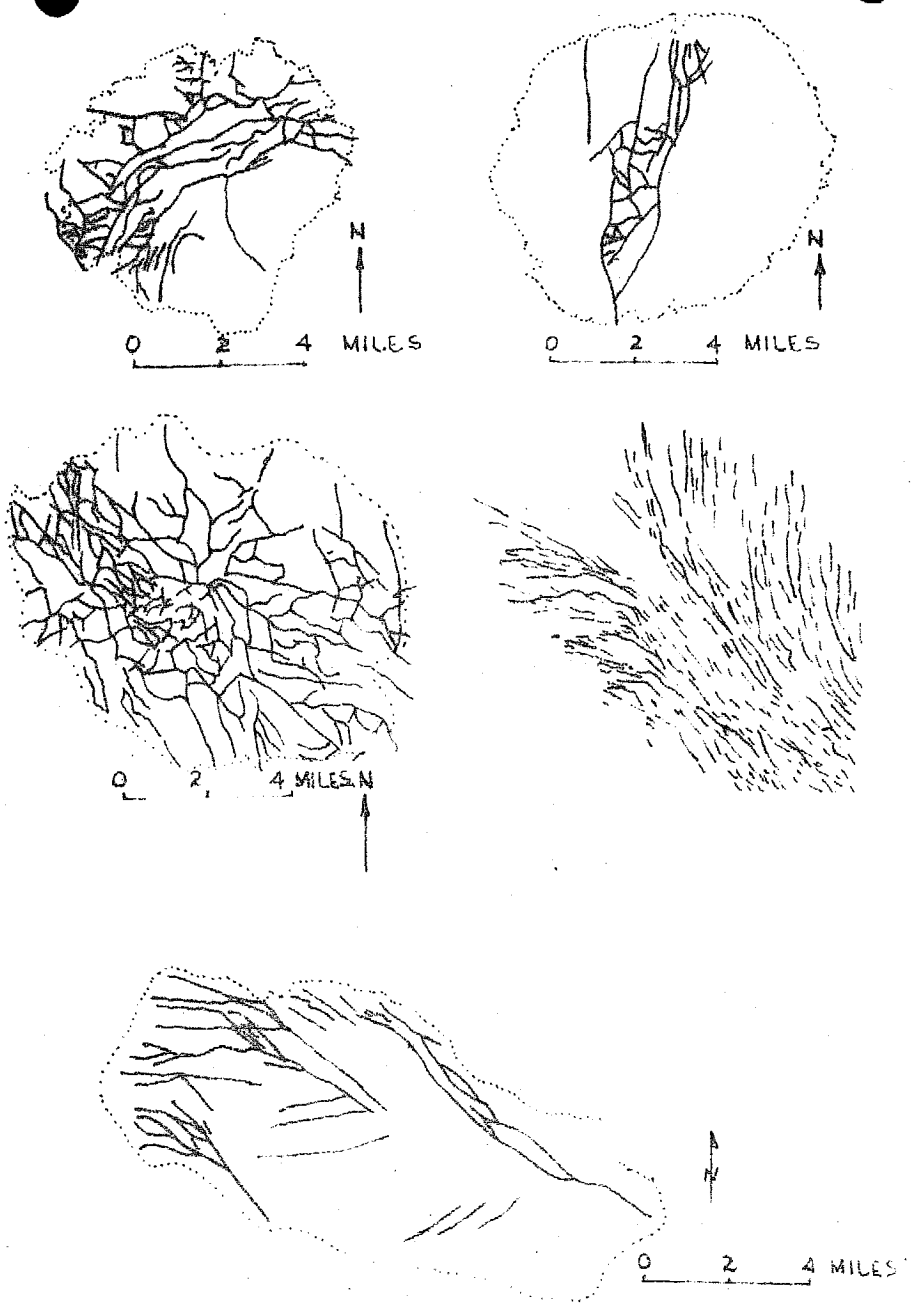
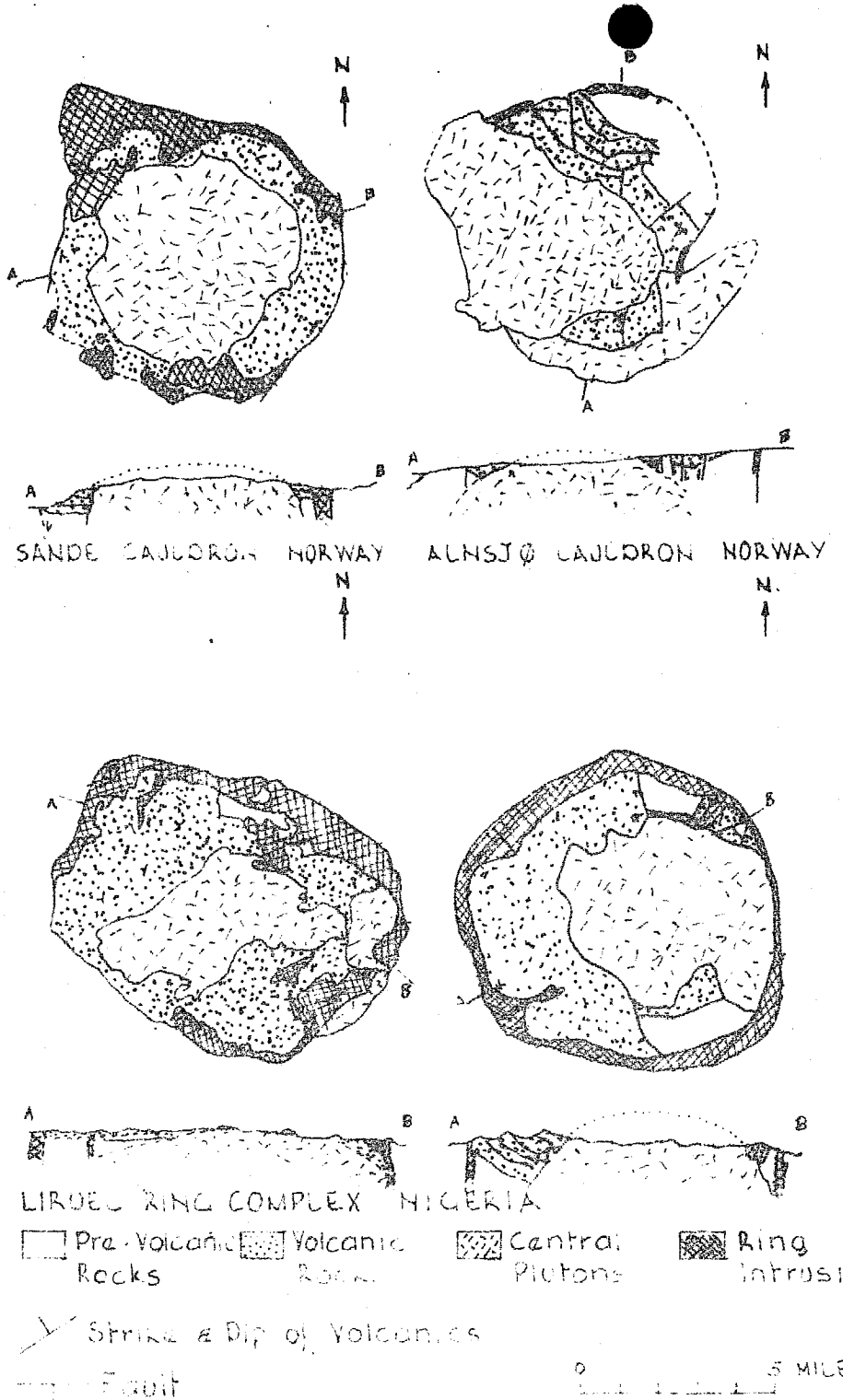
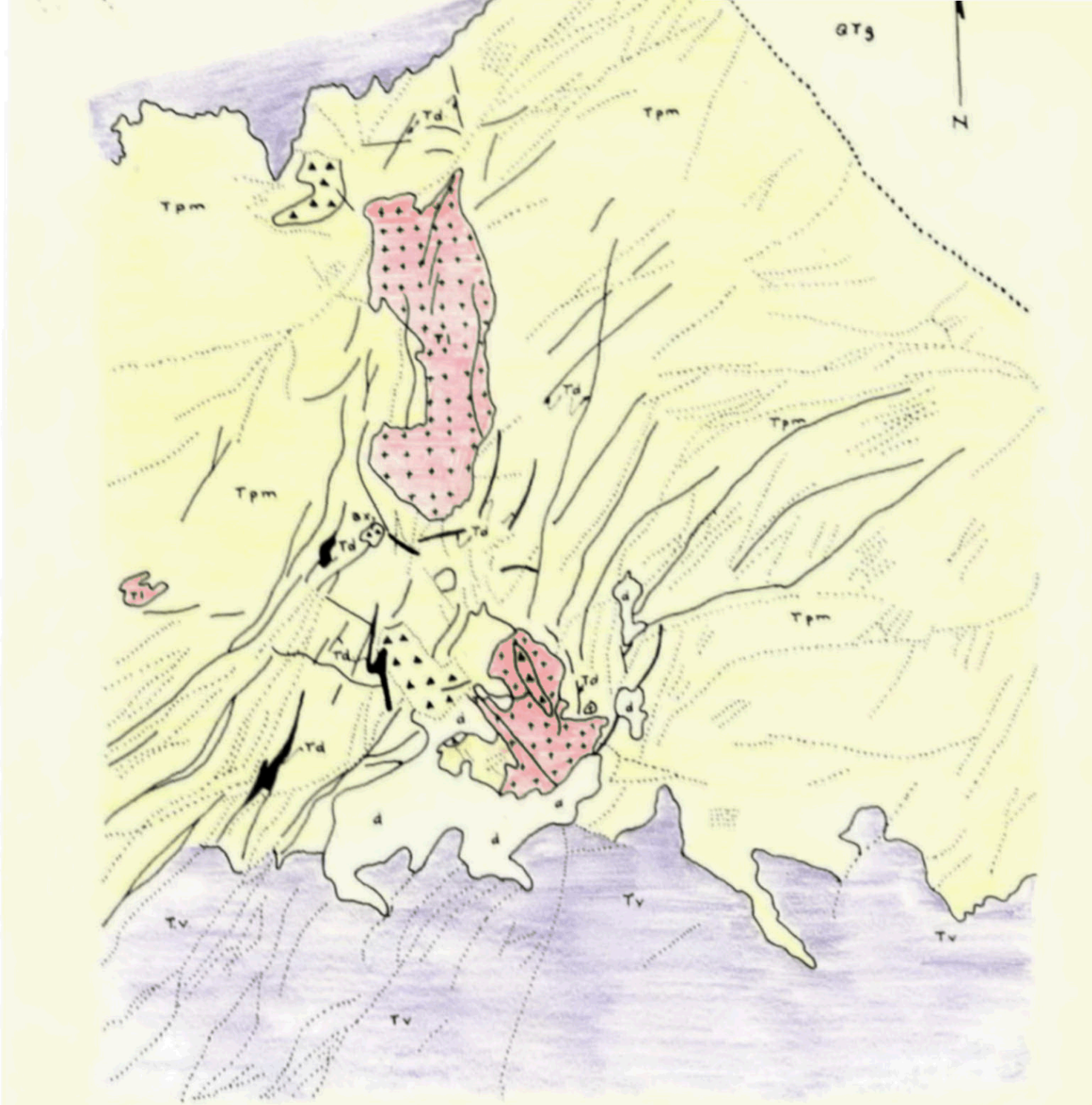


from SMITH & BAILEY
Resurgent Cauldrons
G.S.A. Memoir 116 1968



FAULT PATTERNS OF RESURGENT DOMES
SMITH & BAILEY RESURGENT CAULDRONS
GSA Memoir [illegible] 1968





QTg — Upper miocene of younger gravel deposits

Tv — Miocene (?) volcanic & detrital rocks

Td — Tertiary dike rocks

Tl — Lower tertiary plutons of intermediate composition

Tpm — Pre-miocene rocks

Bx — Areas of Brecciated rocks

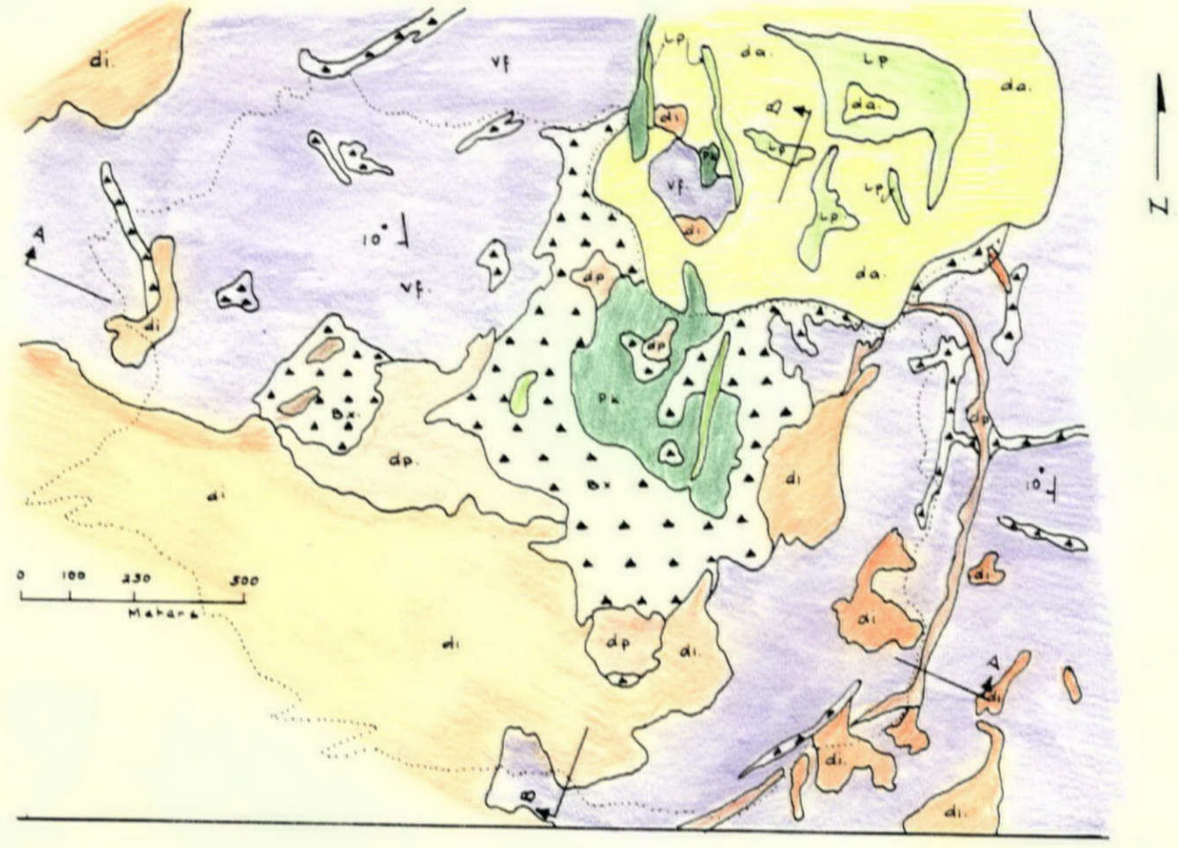
d — Dumps

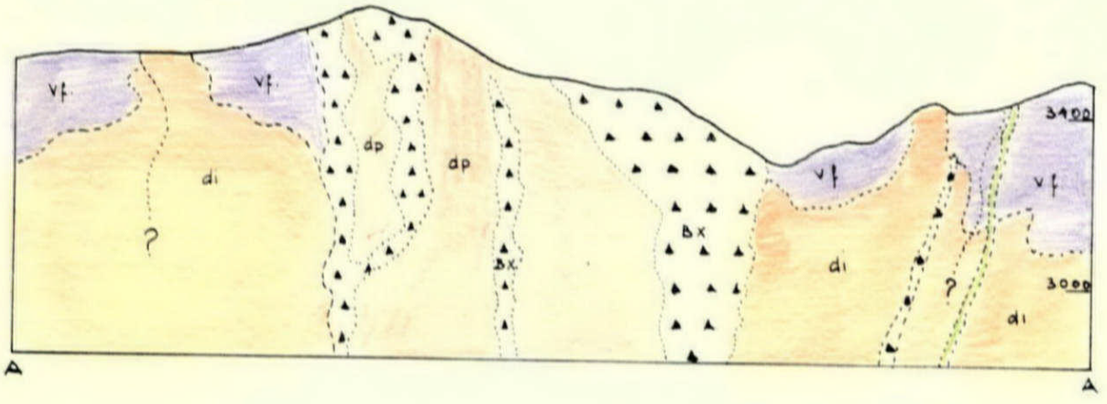
..... Faults

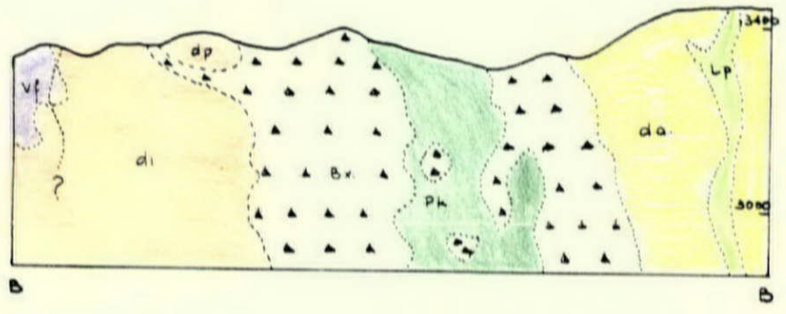
Generalized Geologic Map Santa Rita Area New Mexico

0 1 2 3 Miles

from Jones & Heron U.S.G.S. pp 555





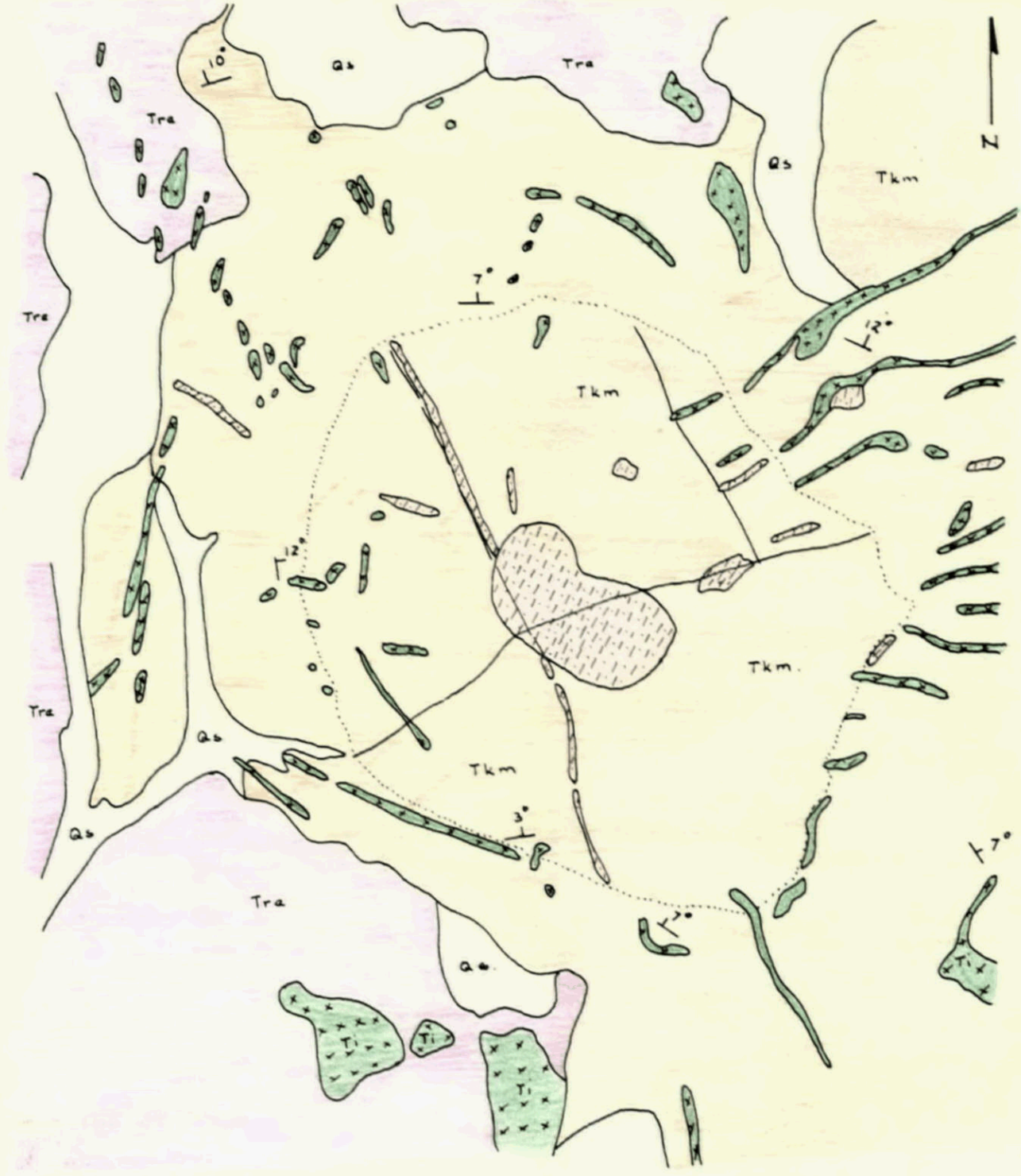


Lp	Latite porphyry
Pk	Pebble breccia
Da	Dacite agglomerate
Bx	Ore breccia
Dp	Dacite porphyry
Di	Diorite
Vf	Volcanic Flows
.....	Outline of Hydrothermal alteration zone

0 1 2 3 Miles

TOQUEPALA GEOLOGIC MAP AND SECTIONS

from Richard & Courtright. AIME Trans. Feb. 1958



Qs	Tre	Ti	Tpp	Tkm		
Surficial deposits	Rabbit ears volcanics	Latite porphyry	Poison porphyry	Middle formation	Fault	Outline of hydrothermal alteration zone

Poison Ridge Volcanic Centre

0 1000 3000 5000 feet

from Kinney & other U.S.G.S circular 594. 1968
modified by Devere 1969

GEOLOGIC MAP OF BOULDER BATHOLITH

from Tilling & others, in press

Czr

Post Batholith Rock Cenozoic Age

Kbg Kba Khc Kmc Kc Kd

Kbg Biotite granite
Kba Biotite adamellite
Khc Hell canyon pluton
Kmc Moose creek pluton
Kc Climax gulch pluton
Kd Donald pluton

Kpr Kh Kd Kgbm

Butt Quartz Monzonite & Related Rocks
Ka Alaskite, aplite & pegmatite
Kh Leucocratic variant homestake grades into alaskite
Kpr Leucocratic variant pulpit rock
grades into but locally cuts qtz monzonite
Kbgm Butte quartz monzonite

Kug Krc Kic

Kug Unionville granodiorite
Krc Radar creek pluton
Kic Pluton north of fish creek

Kmr Mafic rock

Ke

Ke Elkhorn Mt. volcanics

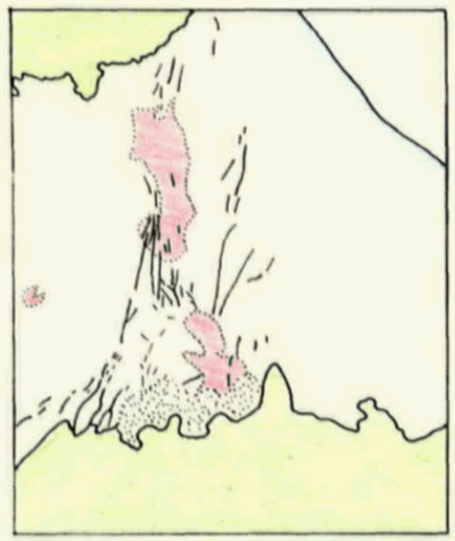
Mpr

Mpr Pre volcanic rocks

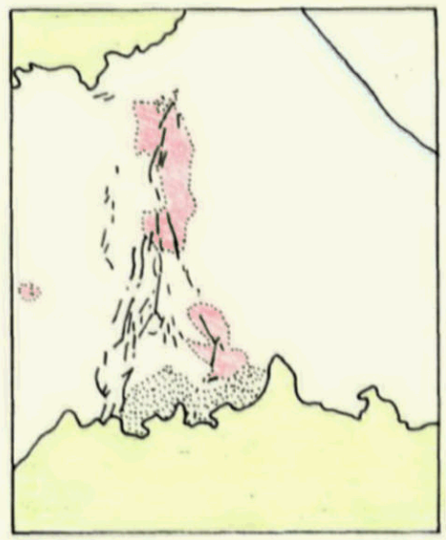
Ks

Ks Satellite plutons

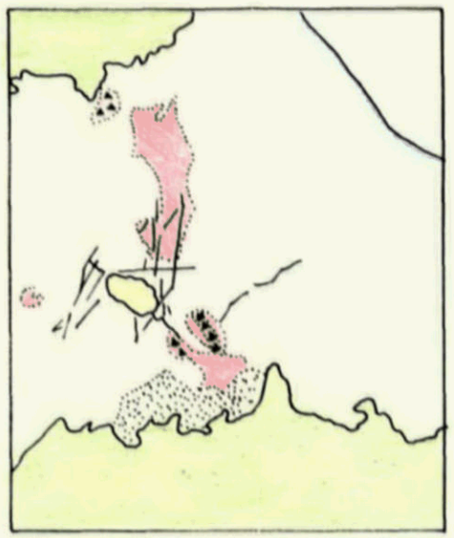
Steep fault Thrust fault



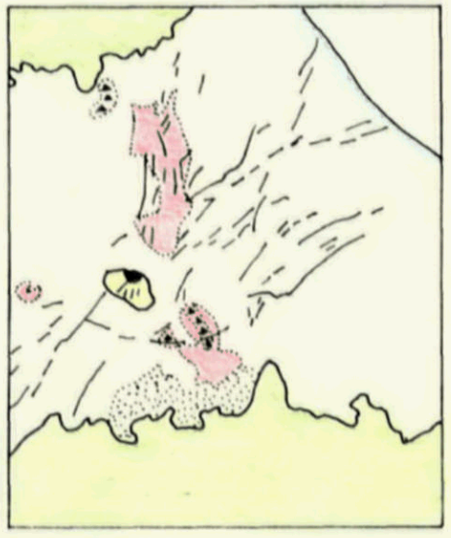
Granodiorite porphyry dikes



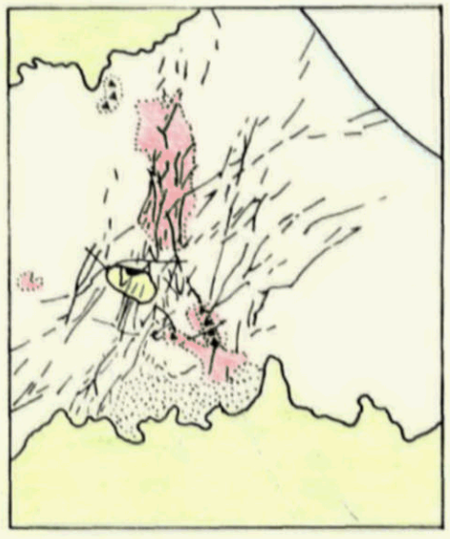
Quartz Monzonite porphyry dikes



Quartz latite porphyry dikes



Rhyodacite porphyry dikes



Composite

EXPLANATION

Chino Mine Dump

Edge of Miocene (?) Volcanic Rocks & Quarternary Valley Fill.

Hanover Hole

Tertiary Breccias

Early Tertiary Stocks

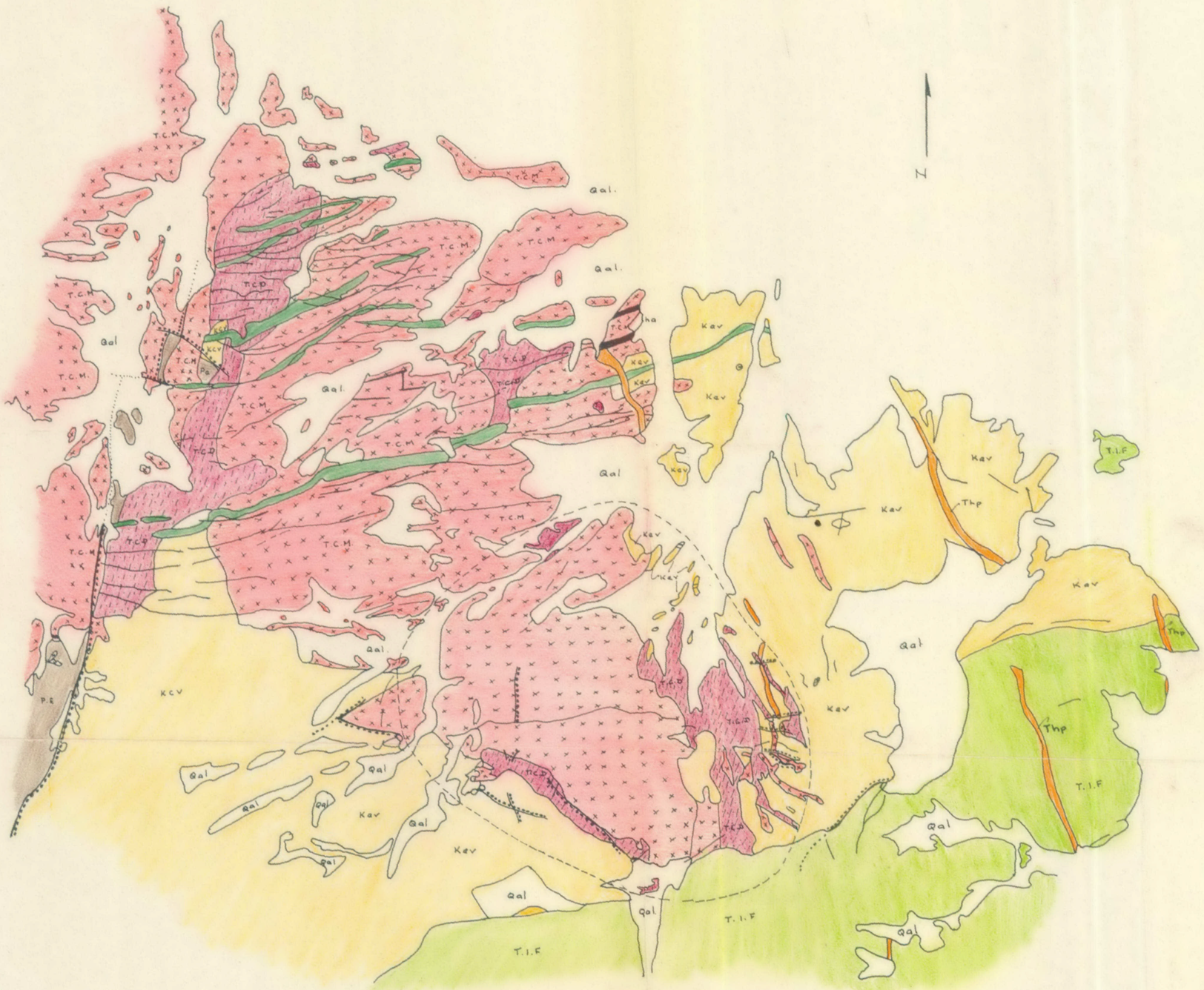
Mimbres Fault

0 1 2 3 4 5 6 miles

SANTA RITA DISTRICT

Poststock, Pre-miocene (?) fracture patterns shown by four successive dike swarms

from Jones & Hernon U.S.G.S pp. 555



Qal
Alluvium

Hospital Porphyry

T.I.F
Ajo volcanics

Hornblende andesite dikes

Feldspathic andesite porphyry

Tcm
Cornelia quartz monzonite main facies

Tcd
Cornelia quartz monzonite dioritic border facies

Kav
Concentrator volcanics

Pe
Precambrian Rocks undifferentiated

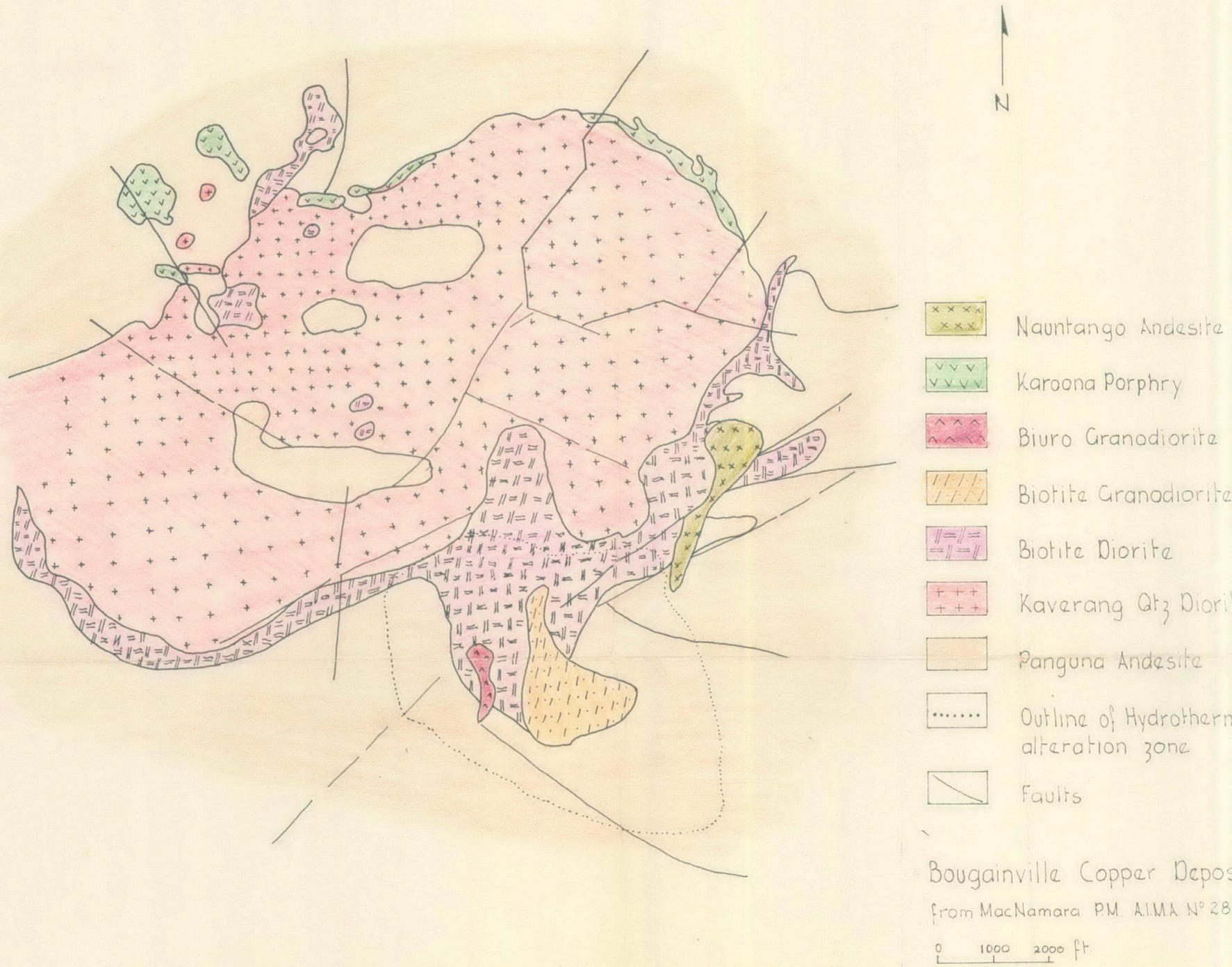
Faults

Outline New Cornelia Pit

Geologic Map Ajo Area
Arizona.

0 500 1000 2000 feet

from Gilluly. U.S.G.S. pp. 1946



Bougainville Copper Deposite

from MacNamara P.M. A.I.M.A. N° 288 Dec. 68

J. H. Courtright

THE APPLICATION OF NAPPE-TECTONICS TO THE ARIZONA-SONORA COPPER PROVINCE

A. Giesecke

November 1971

December 7, 1971

Dear Harold:

Enclosed you will find two copies of my talk on Nappes. One is intended for Tucson, the other for New York.

Any additional copies will be prepared at your discretion by Miss Molly and distributed accordingly.

Al Fischer

ASARCO Annual Exploration Meeting - Palm Springs, California

November 30, 1971

THE APPLICATION OF NAPPE-TECTONICS TO THE ARIZONA-SONORA COPPER PROVINCE

SUMMARY

Many interpretations about the structure within the Arizona-Sonora Copper Province have consciously, or unconsciously, been based on the concept of the autochthonous nature of the ore deposits. Under this concept, however, no universally valid theory about the regional structure and the distributional pattern of the ore deposits seems to emerge, even after many decades of intense efforts. To the author, this indicates that one of the underlying principles may not be correct.

Tentatively, another approach is offered here: allochthonous geology. Under this concept, nothing remained at its original place, but has travelled from far away. Such large and long-range transport is well known from many places of the world. The movements take place in the form of sheet-like Nappes which are tectonic rather than stratigraphic units. Often, such Nappes occur together in overlapping positions. Generally, they originate from the same source area, and their movements are uni-directional. The result of Nappism is a highly complicated structural situation which cannot be explained by "Lineaments","Trends", or fault patterns.

The application of Nappism to the Arizona-Sonora Copper Province holds the promise to permit hitherto impossible insights into the regional structure which might prove of great value to locate additional ore deposits.

With respect to the source area of the nappes, considerations about the Laramide orogeny, its volcanism, and the age and genesis of the Copper deposits of Arizona-Sonora, point to a specific belt: the batholiths of Baja California and California. Possibly, the Nappes represent the original roof of these batholiths. Then, the "Unroofing"would have been the work of Nappe tectonics, i.e. the removal of large sheets of roof via lateral sliding. In such a way, the Laramide metal concetrations which had

collected in the roof of the batholiths, was carried away more or less intact, and did not fall victim to the normal process of erosion which would have destroyed these metal concentrations. In other words: Nappism might have been the salvation of the Laramide ore deposits, removing them to a distant safe place of rest. The price, though, was high: the ore deposits might have been sliced many times, and spread throughout the area of nappe movement.

The distance of lateral movement would be about 200 miles, and the direction of movement from SW to NE.

In order to arrive at an undisturbed picture of the nappes, any "Post-Nappe" tectonics must be refitted, e.g. the San Andreas fault and its southerly extensions.

Recommendations:

1. Try a fresh approach. It might get us unstuck.

2. Apply Nappism. Try to identify each nappe (tectonic unit). Carry out mapping of nappe borders. Try to establish mineralization patterns for each nappe ("Puncture Pattern"). Correlate patterns from one nappe to the next, either upwards or downwards.

3. Carry out exploration in the source areas: the batholiths. Try to stack the nappes back again. Try to project features of nappes down into the batholith,-and vice versa.

1. INTRODUCTION

When I received the letter from the Company that everyone has to make an exploration proposal, I realized that what we need now is a new "Working-Hypothesis". When I started to collect information about the hypothesis I am going to present to you, I found some information about ancient times which will interest you and which will throw light onto our present problems.

It is only 300 years ago that a very strange working-hypothesis was the underlying principle of the overseas exploration of the Spanish Empire. You will be astonished to learn that at that time it was accepted that sunshine steadily changes lead into gold. As a logical consequence of this working-hypothesis, the Spaniards directed their activities towards the equatorial countries of the world, assuming that there the intense heat of the sun would have changed more lead into gold than could ever have happened in colder climates like Canada or South Africa. This Spanish exploration campaign was quite successful, which indicates that a working-hypothesis does not necessarily have to be correct, as long as the area to be explored is large enough.

A second theory I came upon is about 200 years old. At that time the grandfather of geology, Werner, was convinced that volcanoes were the result of coal seams which had ignited and melted the rocks at depth. Logically, one would turn towards the belts of active volcanism when searching for coal deposits. Luckily, this concept did not find long-lasting consideration.

Today I will present a working-hypothesis just about 100 years old. It is "Nappism". It will be your duty to weigh the evidence and evaluate the theory and its application to our exploration problems.

2. NAPPISM

Nappism is a working-hypothesis that should be considered in Arizona and Sonora as an alternative, though not an exclusive one, to those in existence. I have chosen to talk about nappism because I think that this concept has a direct relation to exploration and mining in Arizona and Sonora and could fill a gap in our understanding of the over-all geology.

I chose Arizona for another reason too: today, as many mining companies go through a difficult economic cycle, we have to strengthen our "Home Front" first. Only if

there is no pessimism or despair at home can we continue to carry out our work beyond the seas.

Nappism in Arizona has not been sufficiently recognized, partly due to the lack of continuous outcrops, and partly due to the highly complicated local geological picture. That we are really dealing with nappism in Arizona can be deduced in various ways. Figure 1 shows a very general approach to the problem: the progress in recognizing the geology of a certain area is, to a large degree, a function of the local structural complications. In areas of autochthonous or "in-situ" geology, the progress will be fast and uninterrupted as knowledge increases through various stages: lithology, stratigraphy, magmatism, tectonics and facies. On the other hand, in an area of allochthonous or Nappe geology, progress is slow and levels off at an early stage. In such an area, the complicated tectonic picture interferes with further progress. Speed picks up again only after nappism has been introduced.

Arizona appears to be such terrain where the progress in Geology has leveled off. No over-all picture has emerged even after many decades of most intense efforts by most qualified geologists. The excess of stratigraphic names and the rapid jumps in facies and thicknesses have interfered with an Arizona-wide geological correlation. The time may now have arrived for this great variety of information to fall into place.

3. NAPPISM IN ARIZONA AND SONORA

Before we continue, I want to introduce nappes as a simple process of erosion rather than the result of highly complicated tectonics (Figure 2). Erosion is a continuous process which will remove, grain by grain, the volume of rocks which originate from the upheaval of a land mass. This normal process of "cut-and-fill" is a destructive one with respect to pre-existing ore deposits in the source area.

If erosion lags behind, steepening of the slope will lead to unstable conditions, and landslides will occur. Such landslides can already be considered as minor nappes.

If both erosion and landslides are unable to compensate for the rising of the hinterland, then a third high-intensity process will cut in and remove large slabs of rock by gravity gliding. This process of nappism is a non-destructive "en-bloc" transport with respect to pre-existing mineral deposits in the source area.

A simplified picture of a nappe is given in Figure 3. In this case, the nappe originates from an area of geosynclinal facies and has overridden rocks of identical age but different facies. The movement took place along a layer of minimum cohesive strength which could be gypsum, salt, tuff, serpentine, or the interface between basement and the sedimentary sequence. The source area of the nappe will show up as a permanent gap and create considerable isopach problems due to the fact that great thicknesses immediately border zero-thickness.

On the other hand, the area where the nappe finally came to rest is characterized by stratigraphic repetitions, abrupt facies changes, and unsurmountable isopach problems. Application of "in-situ" geology concepts will lead to a cul-de-sac where even intense and detailed work is in vain.

As nappes are giant landslides, they move downhill towards trough areas. The movement is uni-directional, and coincides with each nappe. Nappes are subject to the unevenness of the terrain which they override and will, to a certain extent, acquire a corresponding tectonic configuration. This is one of the reasons why nappes may be recognized by unique structural features.

As shown in Figure 4, nappes may produce opposing pictures of relative displacement. Re-matching nappe units is a delicate problem which requires fundamental understanding of nappes. For example, any vertical geological feature sliced by nappism may be found in inverted stacking. In Figure 4, the original highest portion of an intrusion may underlie its original footwall portion. Reassembly of the displaced portions is not an easy undertaking.

Figure 5 is a picture of the actual situation in California, Nevada and Arizona. Since Nevadan time, the rising batholith has been eroded and sedimentation took place on either side. To the West, the Great Valley sequence and the Franciscan sequence were laid down. To the East, a sequence of Triassic, Jurassic and Cretaceous sediments were deposited which, in Arizona, show a unique feature: they contain enormous exotic limestone slabs of Permian age which represent large, intraformational landslides. These landslides can already be considered as the beginning of the nappe era.

During Laramide time the upheaval of the batholith apparently increased considerably, and large-scale nappism and overthrusting took place. In the West, the Great Valley sequence moved for a distance of up to 50 miles over the Franciscan sequence. In the East, nappism took place in many areas. In the Clark Mountains, Southwest of Las

Vegas, the situation has been very well described in a recent publication, "Clark Mountain Thrust Complex in the Cordillera of Southeastern California: Geologic Summary and Field Trip Guide", by B.C. Burchfiel and G.A. Davis, March 1971[1]. The amount of displacement is estimated to be about 50 miles.

In post-Laramide time the upheaval of the batholith slowed down, and new tectonic movements occurred: in the West, the Coast Range thrust was intensely folded and its true character almost obliterated. In addition, the San Andreas fault started to slice the crust (present displacement: 310 miles). In the East, the block faulting of the Basin and Ranges took place and obscured the picture of the extensive nappes which had been formed before.

A general tabulation of these geological events is shown in Figure 6. It can be seen that both the magmatic pulses and the sliding of exotic slabs started in Triassic time, and reached their climax in late Cretaceous and early Tertiary time. The magmatic history of Baja California, California and Arizona shows certain differences which must be considered when trying to reassemble nappes at the source area. In other words, the magmatic history of a nappe must correspond to the magmatic history of its source area. With respect to Arizona, any nappe carrying copper porphyries dated at 60-70 m.y. age must find its source area with a magmatism of identical age.

4. THE PALEOZOIC IN ARIZONA

A simplified isopach picture and certain complications resulting from nappism are shown in Figure 7. Nappes will carry their original isopachs along, leave a large gap behind, and override areas of different thicknesses. In other words, a nappe will superimpose its own isopachs on an area of different isopach data. Any attempt to contour such a situation must necessarily face enormous problems.

It appears that such a situation occurs in Arizona, as demonstrated in Figure 8. Two features stand out here when viewing the isopachs of the Paleozoic. There is a gap with zero-isopachs to the West of the Lower Colorado River where actually thick geosynclinal sediments should be expected. Secondly, there is an unmotivated bulge of thicker sediments in Southeastern Arizona. Both facts can easily be explained by nappism through sliding of a large volume

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[1] Published in Geological Excursions in Southern California, UCR Campus Museum for Geological Society of America, Cordilleran Section Meeting, Riverside (California), 1971

of rocks from Southern California towards Southeastern Arizona.

5. THE CRETACEOUS VOLCANISM

Let me present you with another completely independent case of evidence in favor of nappism. This is the Eastern limit of the Cretaceous volcanics in Arizona. If we start at Lake Mead, this limit runs in a southerly direction for about 200 miles in a smooth, unbroken line until it reaches the area of Vicksburg (Figure 9). Here the line jumps East towards Lake Pleasant and then turns back sharply and runs in a southwesterly direction towards Yuma. Southeasterly of the line "Lake Pleasant-Yuma", the geological picture is suddenly very different. There are only isolated patches of Cretaceous volcanics in a large area, indicative of a "Gap". To the Northeast and East of the gap the Cretaceous volcanics reappear for a distance of up to 150 miles. Such a geological picture closely resembles situations caused by Nappism, and invites to move the outlying Cretaceous volcanics into the Gap area. However, instead of trying such approximate assembly, I want to present a more precise method first.

6. THE DIRECT REFIT OF THE SANTA CATALINA-RINCON NAPPE

Under the assumption that the Santa Catalina-Rincon Mountains represent a small, independent nappe which shows a rather characteristic rock composition, a direct refit onto the basement rocks of the corresponding gap area has been tried. The best result could be achieved by locking this nappe onto similar rocks to the Southwest of Ajo, using as criteria the extensive contact between gneiss and granite in the Santa Catalina Mountains (Figure 10). In addition, three granite stocks of the Rincon Mountains were matched with the basement at Ajo. As a result of this match, the gneisses of the Santa Catalina-Rincon Mountains are now correlated with the gneisses to the Southwest of Ajo. The displacement resulting from the above match is 140 miles. The direction of movement is N 85 E.

On the basis of the direct refit of one minor nappe, it has then been tried to bring the larger nappes back again into the gap area too. The result is represented in Figure 11. As can be seen, all nappes appear to originate from Southwestern Arizona and Northern Sonora. This attempt, however, is a rather provisional one and suffers from several shortcomings, one of them being the lack of geological maps from Sonora.

The rematch shows that the eastern limit of the Cretaceous volcanics now forms a continuous, smooth line which curves towards the Southeast. The reduction of the complicated and unmotivated present-day picture and the change to a simple outline is a strong point in favor of nappism.

7. NAPPISM AND PORPHYRY COPPER EXPLORATION

The application of nappism to the exploration for copper porphyries is based on simple principles which will be explained in various block diagrams. Figure 12 shows the situation of two nappes, both containing a sliced portion of an intrusive stock. Nappe No. 1 carries the originally lower portion. An idealized section below shows this situation and must be considered if trying to rematch the intrusive stock.

Each portion of the intrusive would show a trail of mineralization along its path of movement, i.e. along the surface on which the nappe rode. There is no trail of mineralization at the upper limit of a nappe.

Figure 13 shows a similar picture with a different dip of the nappes. Again, a simple rematch is not possible because the intrusive stock of Nappe 1 is actually a portion above the stock of Nappe 2.

Figure 14 shows the situation of one exposed and one blind portion of an intrusive stock. The only guide to the blind ore body is the trail of drag-ore along the base of Nappe No. 1.

In Figure 15, two cases are demonstrated: Case X shows a situation where the drag-ore guides to a target at depth. On the other hand, Case Y represents a situation where the drag-ore does not guide to a target because it has already fallen victim to erosion.

In Figure 16, the value of sampling the gouge of glide faults is demonstrated. Anomalies can be used as directional ore finders. Hence, gouge sampling is needed for the entire length of a glide fault. Possibly some of the drag-ore in glide faults has already been found during previous geochemical programs and showed up as exotic anomalies. Therefore, it appears recommendable to re-evaluate all existing exotic geochemical anomalies.

In Figure 17 a situation is shown where an intrusive stock has been sliced into four different portions, all of which are assumed to outcrop. The diagram indicates that under these conditions the sliced portions of the intrusive

stock will show a definite alignment which is nothing else but the direction of nappe movement. When talking about "Lineaments", "Trends" or "Lines", one should remember that nappism can easily produce a similar picture.

It is stressed here that the reassembly of an intrusive stock or pipe must not be limited to its mineralized portions, but should include also its barren portions. In our case, it was assumed that Nappes 1 and 2 carry actual mineralization, and that Nappes 3 and 4 are barren. As can be seen, the reassembly of the complete intrusive stock is no matter of matching neighboring outcrops.

8. NAPPES RESTACKED ON THEIR SOURCE AREA

In order to arrive at a complete understanding of nappism, it must be tried to restack the nappes on their original basement and interlock the pertinent geological features. In Figure 18 this is shown for a batholith which changes upwards into minor intrusive stocks. If such reassembly has been achieved, geological features can be projected from one nappe to the other and down into the basement,--and vice versa. Such projections may lead to unrecognized areas of potential value in one of the nappes, or in the basement. It goes without saying that the higher portions of an intrusive body carry a better chance for exploration than the deeper roots at the batholithic level.

9. FINAL WORD

At the present early stage of nappism in Arizona, it has not been possible to provide you with more than six reasons to become a "nappist". The first reason was the stagnancy in the progress of geological knowledge. The second reason dealt with exotic limestone slabs in the Mesozoic. The third was actual exposure of nappe faults. The fourth depended on the isopachs of the Paleozoic. The fifth reason was related to the facies of the Cretaceous volcanics. The sixth reason was the actual refit of a nappe onto its source area. Though none of these points by itself might convince you, I ask you to weigh all arguments together. Do open your mind to nappism before it has become commonplace. Nappism is on its march forward, has reached Las Vegas already and will very soon invade Arizona. To keep ahead of our competitors we cannot afford to wait for the arrival of Nappism but must try its application today already.

10. RECOMMENDATIONS

My recommendations can be put down into a few simple sentences which appear easy to apply. But let me warn you at this point that nappism is an easy approach only from the distance, and that the field work is an enormously complicated search for knowledge, hampered in Arizona by a lack of continuous outcrops across strike. Nevertheless, nappism must be tried at this stage of exploration in Arizona because it holds the promise of being an exploration tool which can bring fast and cheap results.

My recommendations are:

(1) Apply nappism in Arizona and Sonora (possibly also in New Mexico and California). Figure 19.

(2) Draw structure maps. Show all faults, emphasizing the glide faults. Such maps must show contour lines of the major faults.

(3) Draw isopach maps of whatever stratigraphic unit appears to have a sufficiently large regional extent and clear-cut definition.

(4) Carry out a sampling program of glide fault gouges. Locate the glide faults in the field, sample the gouge at intervals similar to target dimensions, and apply normal geochemical metal determinations. Any anomaly--be it a new one or an old, exotic one--must be entered into the structure map and final interpretation made under the concept of nappism.

(5) Restack the nappes onto their source area and interlock geological features between nappes and basement. Project geological features upwards or downwards and use such projections to outline potential areas of mineralization.

(6) Study the source area of the nappes for low-grade, large-volume mineralization (Figure 19).

11. OUTLOOK

Nappism is both a pleasant and a highly rewarding approach. Pushing mountains for over 100 miles back to the place where they came from is fascinating. But it is more than fascinating, because it also throws a sudden light on complicated geological situations which could not have been solved before. Suddenly everything falls into place, and out of stagnation we move forward onto a higher level

of understanding. Is there any better exploration tool than a full understanding of the local and regional geology?

A. Giesecke

December 7, 1971

AG:mt

LIST OF FIGURES

1	Speed of Progress
2	Erosion, Landslides, Nappes
3	Nappes
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6	Tabulation of Geological Events
7	Isopachs and Nappes
8	Paleozoic Isopachs
9	Cretaceous Volcanics
10	Refit of Nappe
11	Refit of Nappes
12-18	Block Diagrams
19	Geological Regional Map

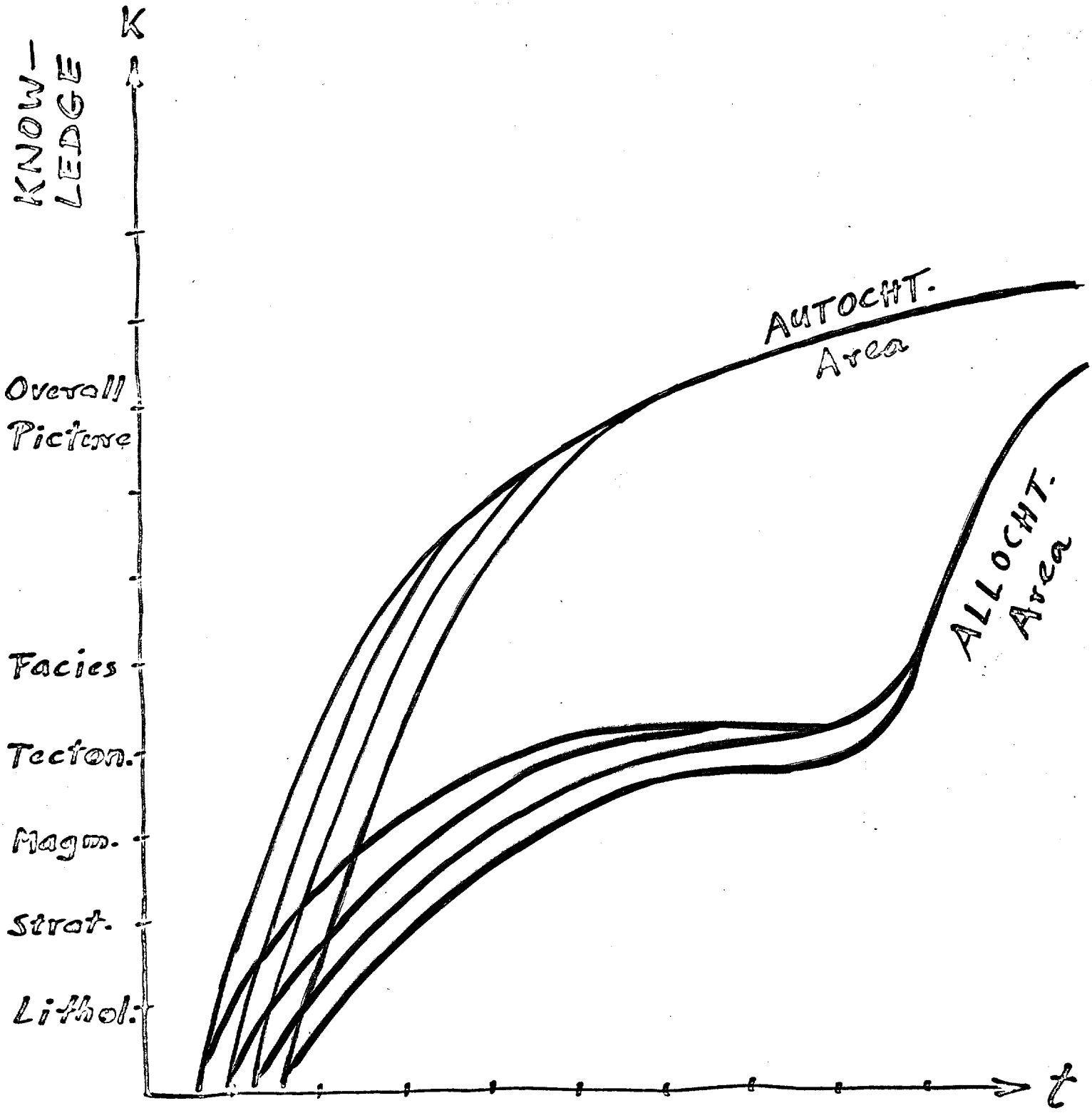
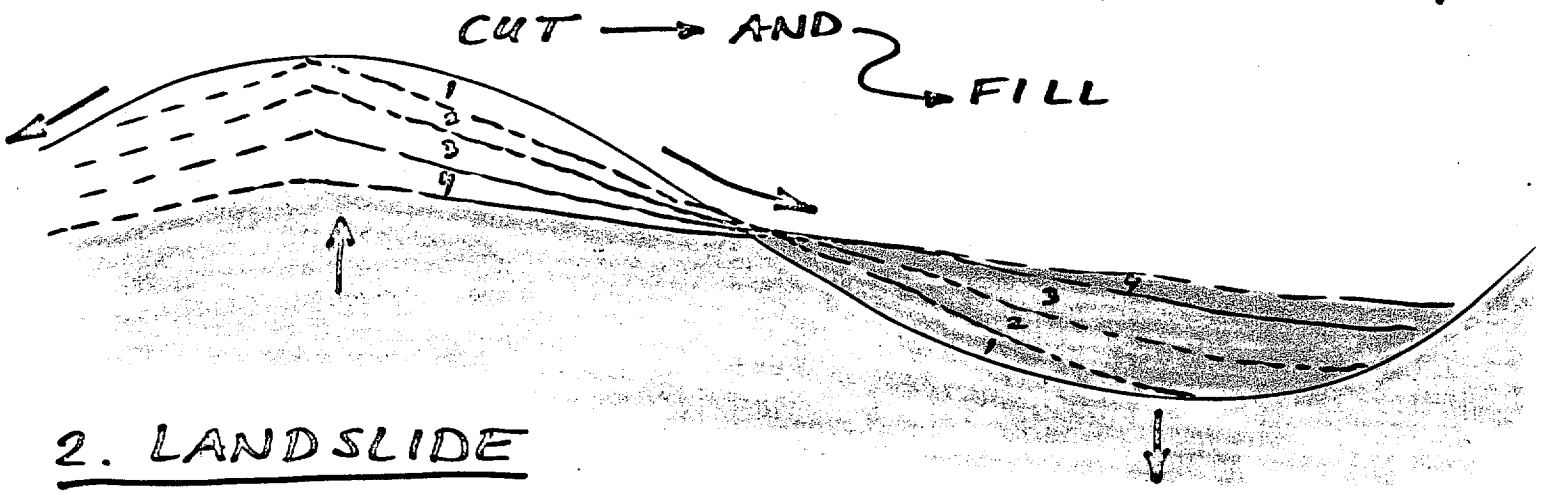


Fig. 1

Speed of Progress:
Geological Understanding versus Time.

1. EROSION

Continuous Process.
Destructive Grain by Grain Transport



2. LANDSLIDE

3. NAPPES

Occasional High-Intensity Process, cuts in when Erosion lags behind.
Non-destructive "en bloc" Transport.

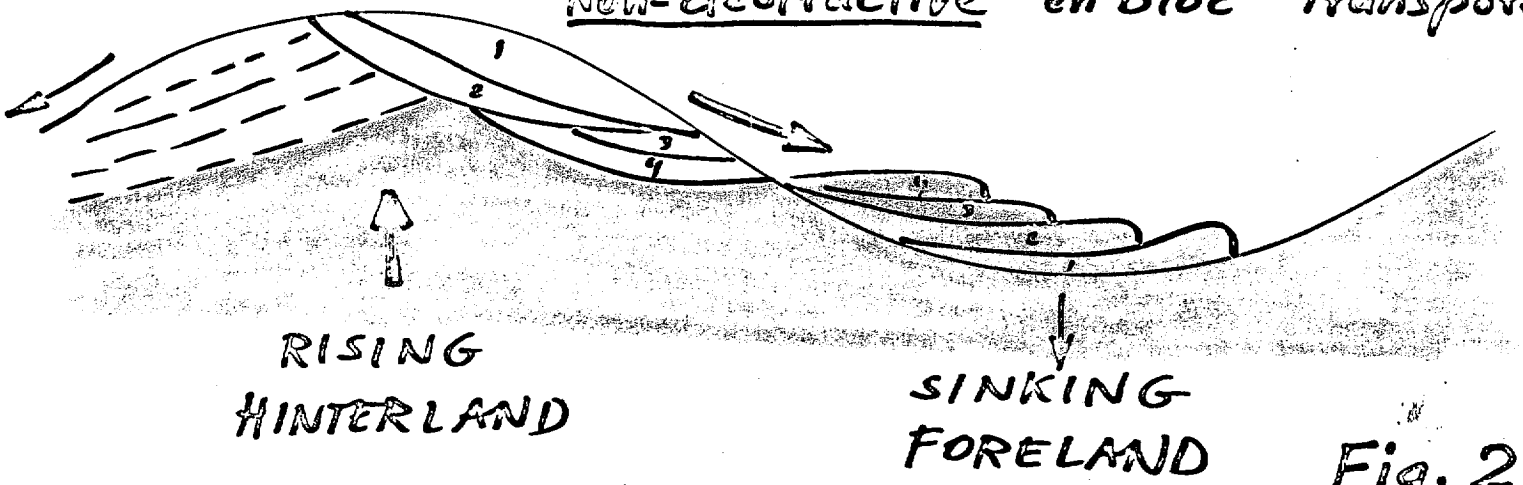
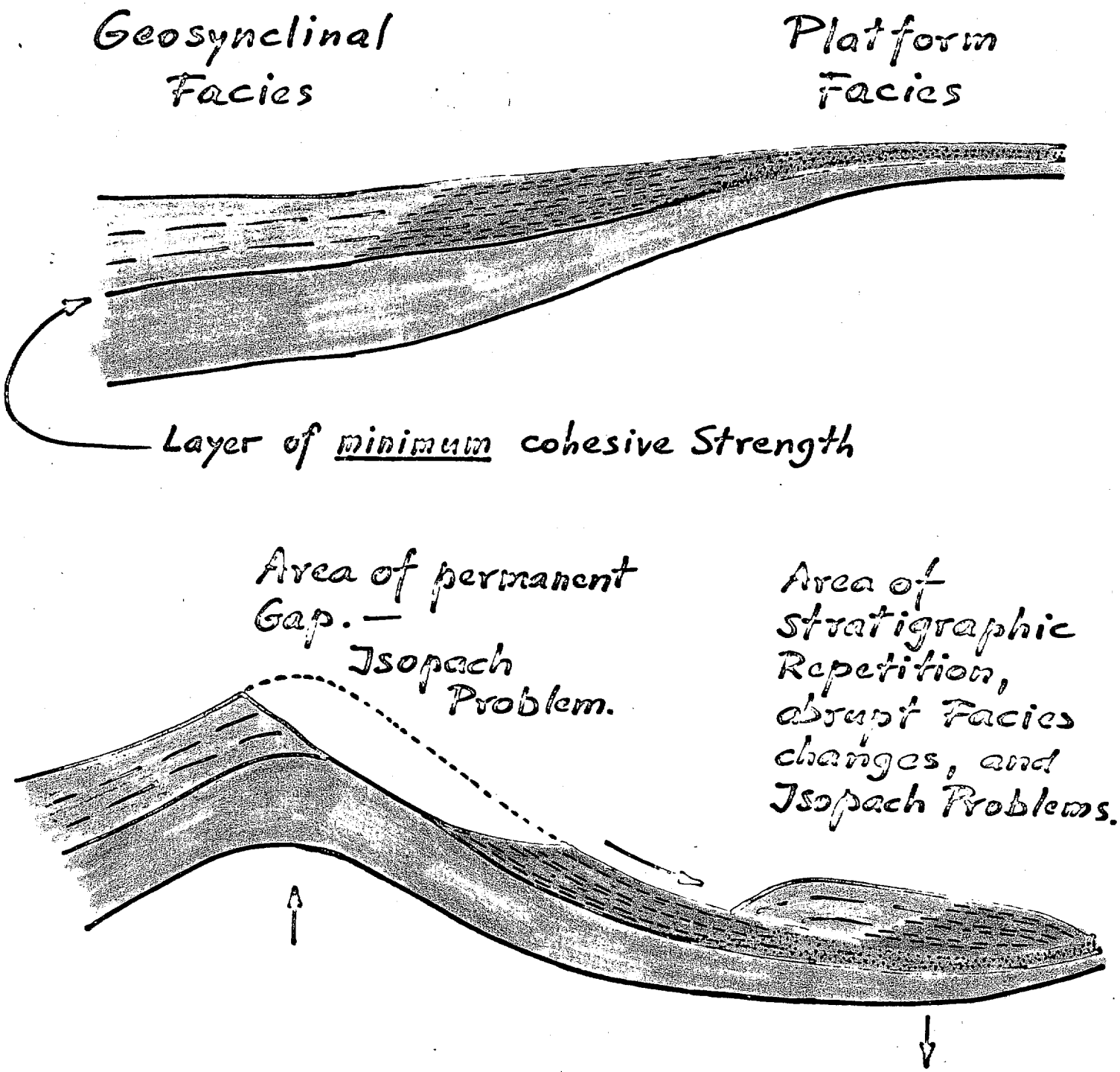


Fig. 2



Nappes create a geological Picture which can never be solved by autochthonous Geology.

Fig. 3

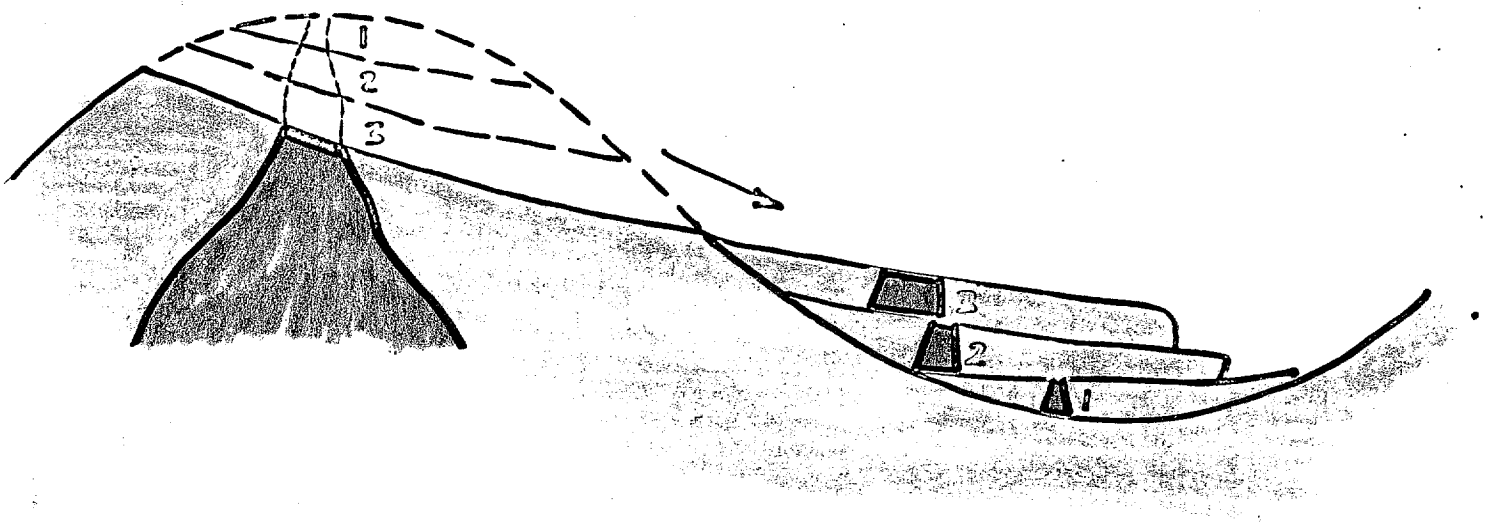


Fig. 4

NAPPISM may result in <u>inverted</u> stacking.

NAPPISM is <u>Uni-directional</u>. Between one NAPPE and the other, movement may appear opposed.

Nappes are tectonic units using <u>bedding</u> planes for movement. Any vertical geological feature will be sliced.

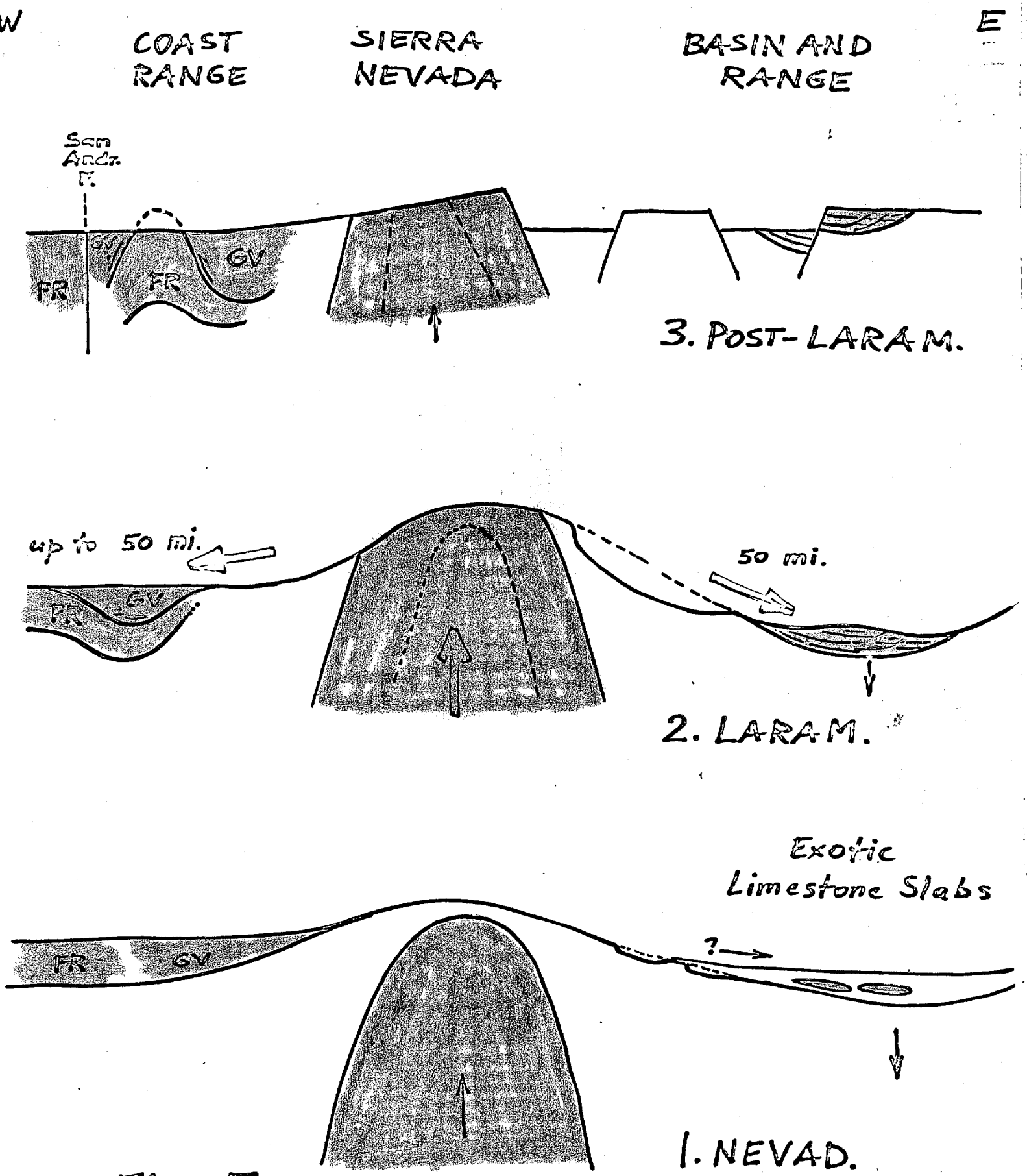

W
E
COAST RANGE
SIERRA NEVADA
BASIN AND RANGE
San Andr. F.
GV
FR
GV
FR
3. POST-LARAM.
up to 50 mi.
50 mi.
GV
FR
2. LARAM.
Exotic Limestone Slabs
?
FR
GV
1. NEVAD.

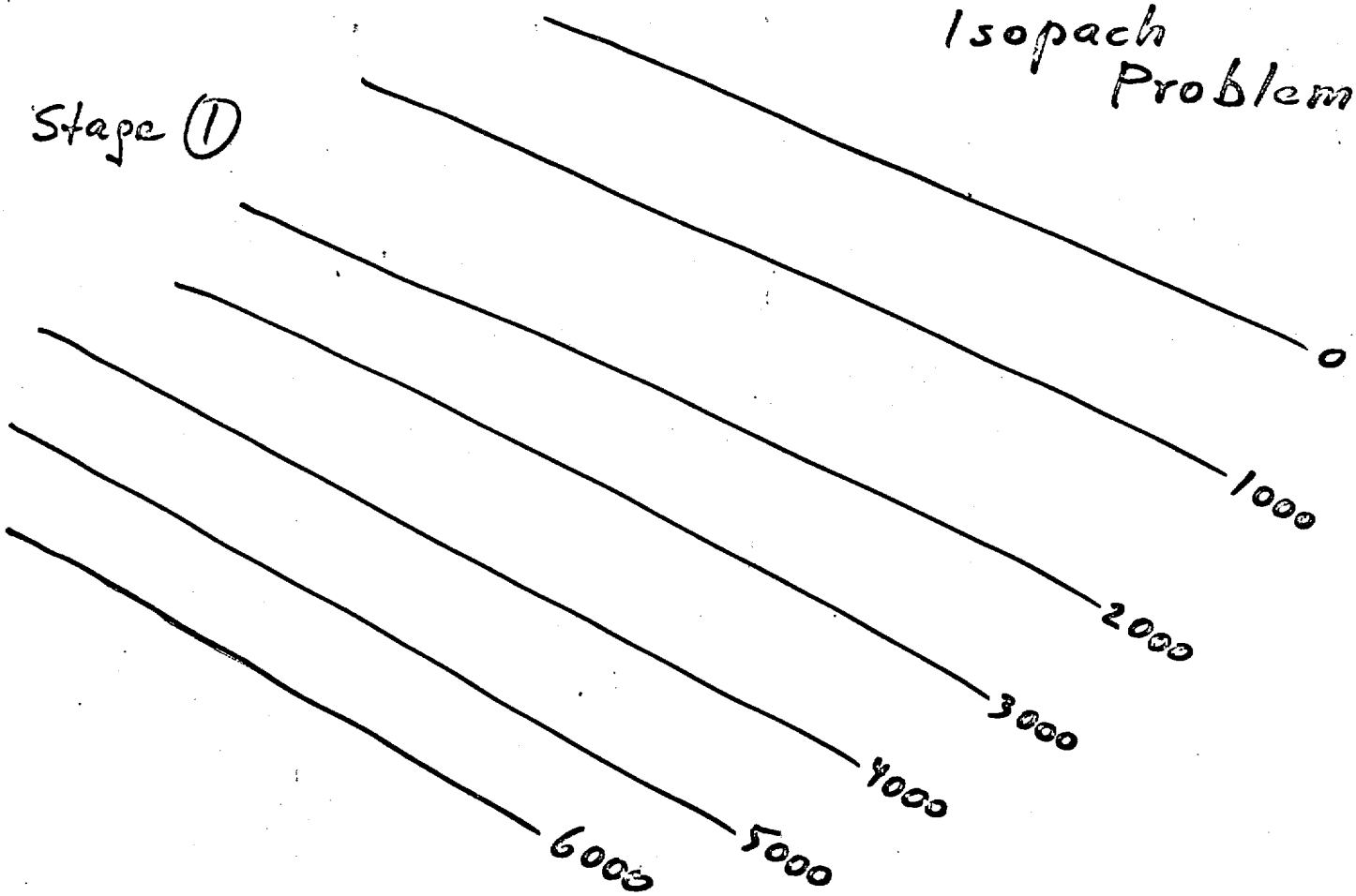
Fig. 5

CALIF.
ARIZONA
0
50
100
150
200
m.y.
T/K
K/J
J/K
S.ANDR. FAULT
COAST RANGE
BAJA CAL.
LARAM.
CATH.
HUNT.
yos.
inyo
Lee VIN.
SIERRA NEVADA
CAN.
AJO.
S. MANUEL
SILVER BELL
Noppes
ARIZ.
Gravity Sliding of Exotic Limestones

Fig. 6

Isopach Problems

Stage (1)



Regional Sketch Maps

Stage (2)

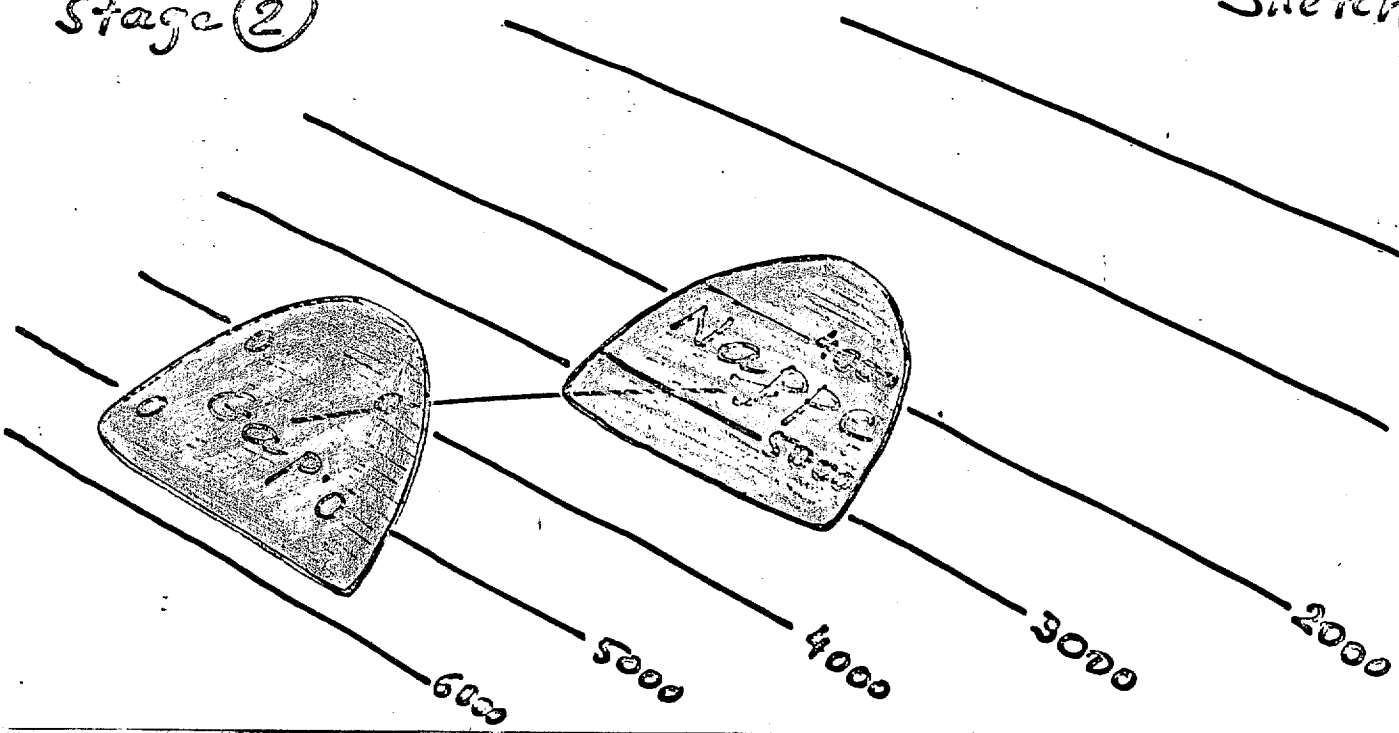
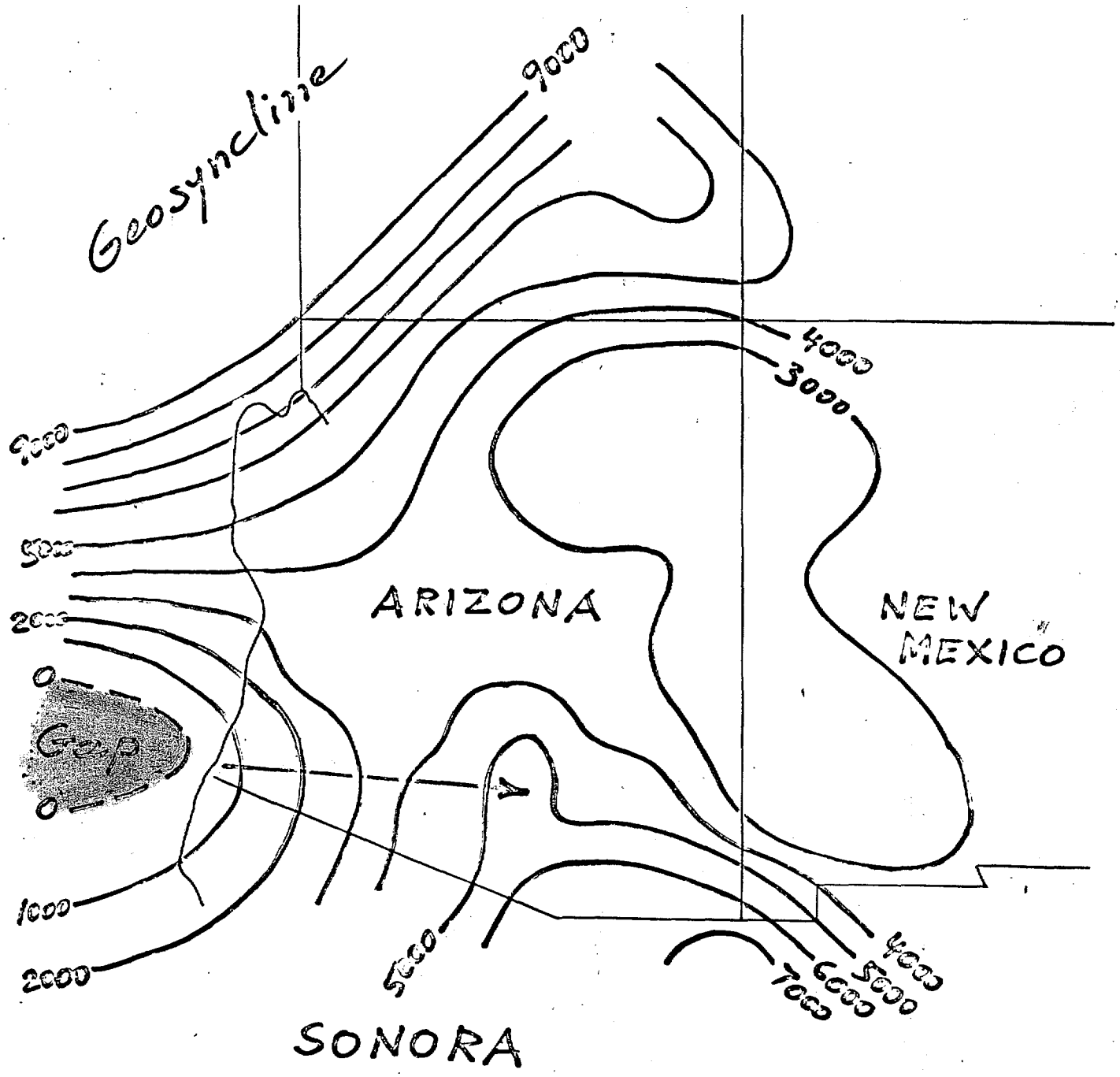


Fig. 7



Isopach Map of Paleozoic Rocks (in Ft)
by C.A. Anderson
1966

Fig. 8

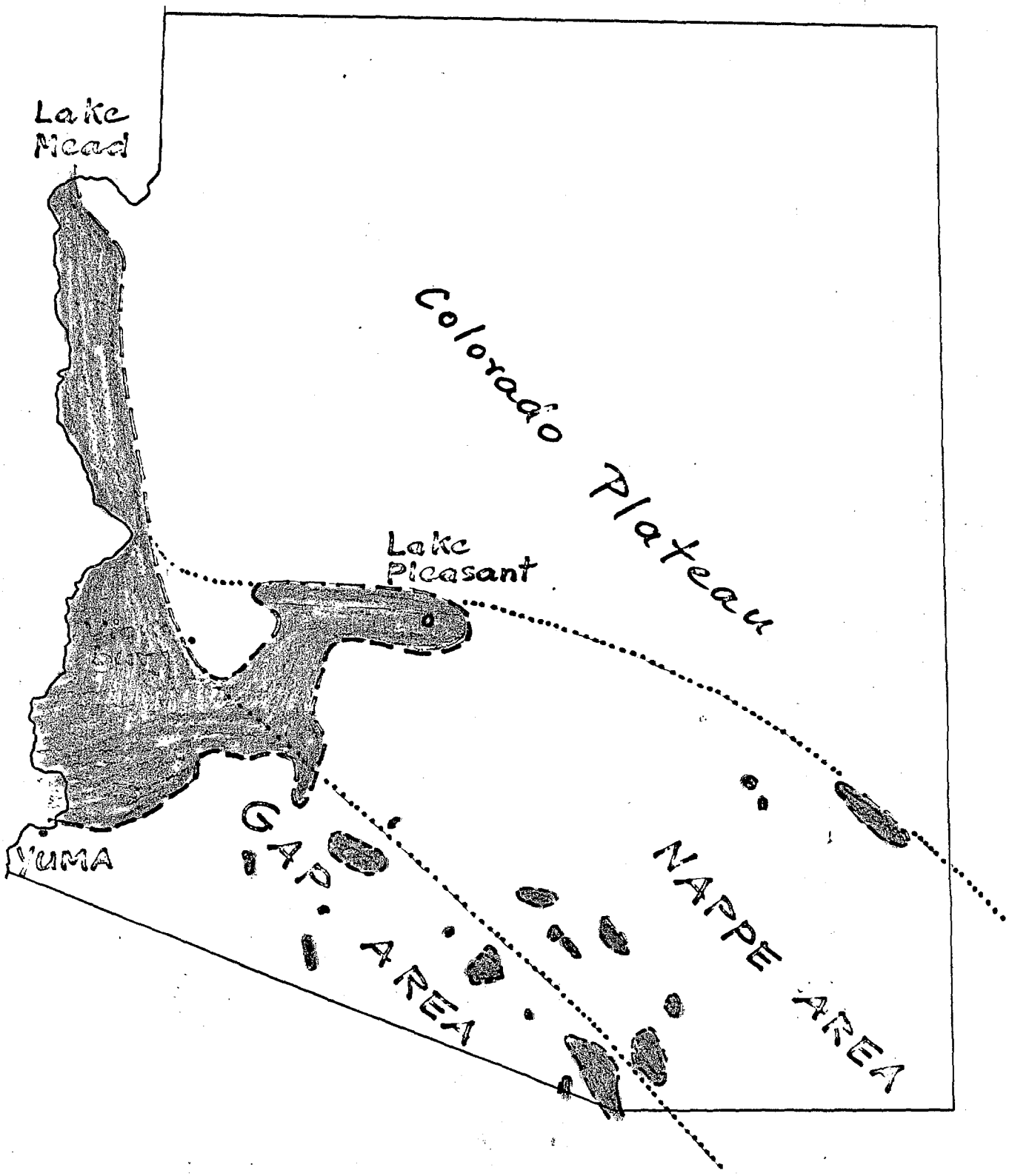
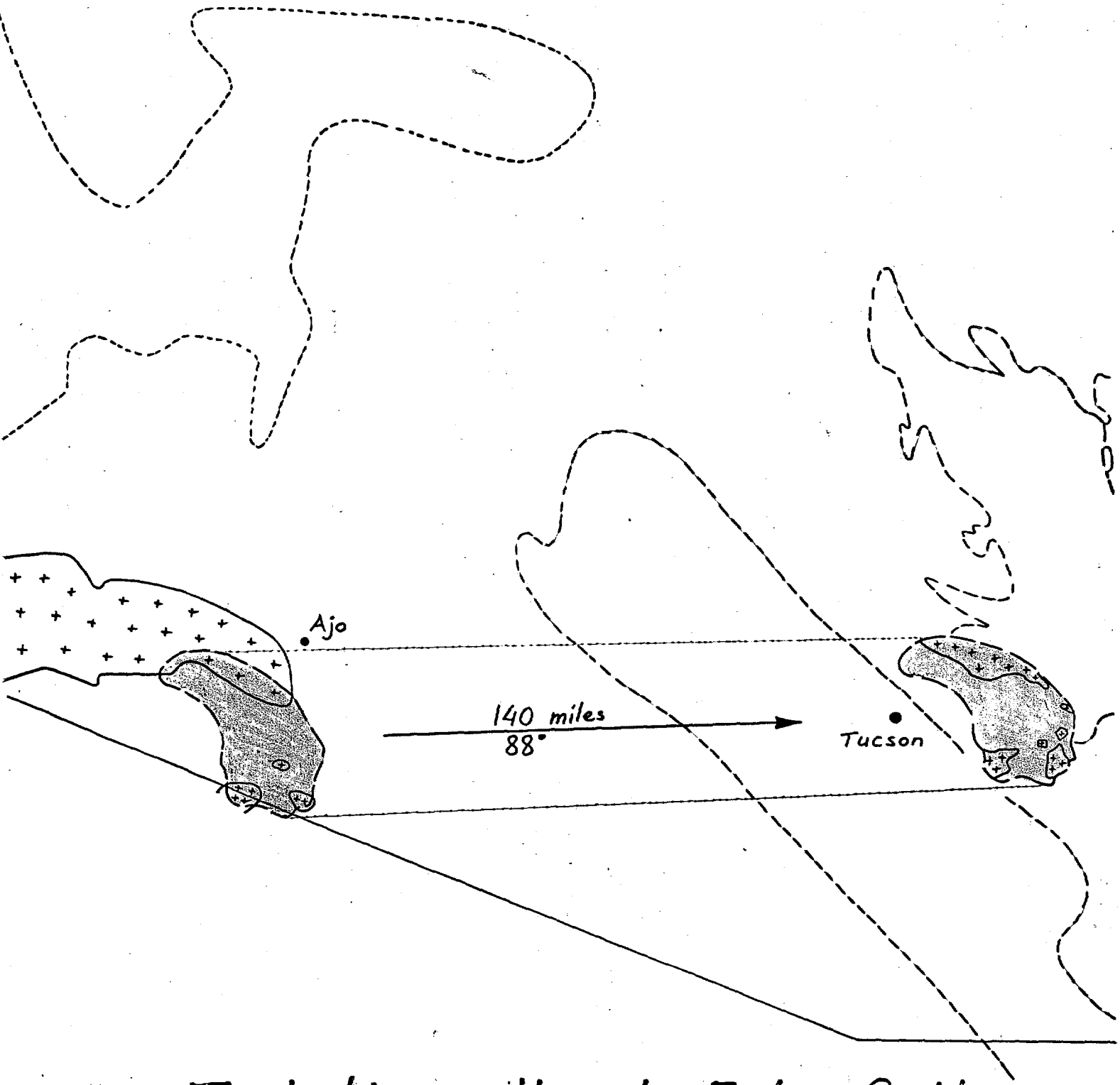
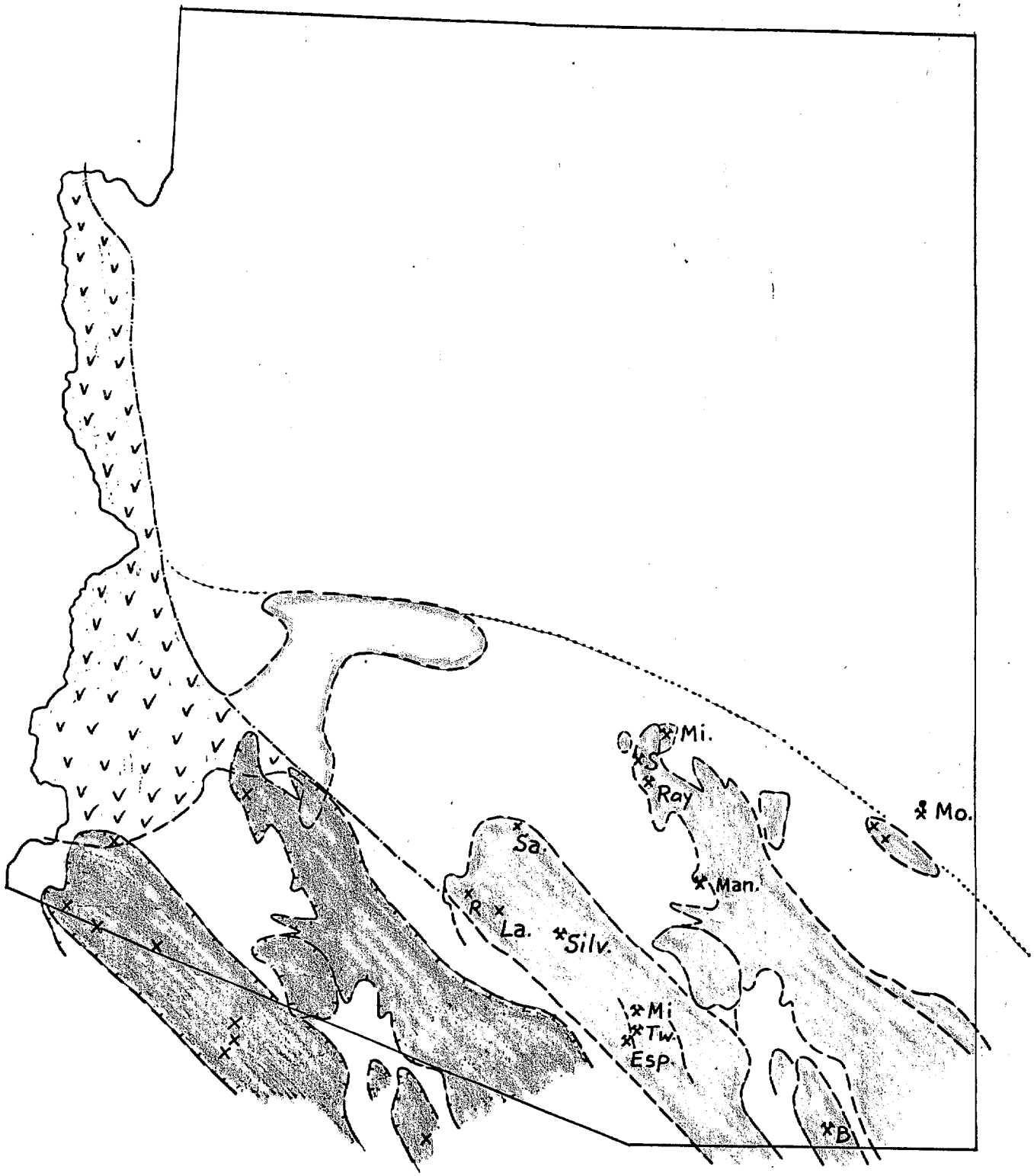


Fig. 9 Regional Distribution of Cretaceous Volcanics



Tentative direct Fit of the Santa Catalina-Rincon Nappe.

Fig. 10



The Source Area of the Nappes.
Tentative partial Solution.

Fig. 11

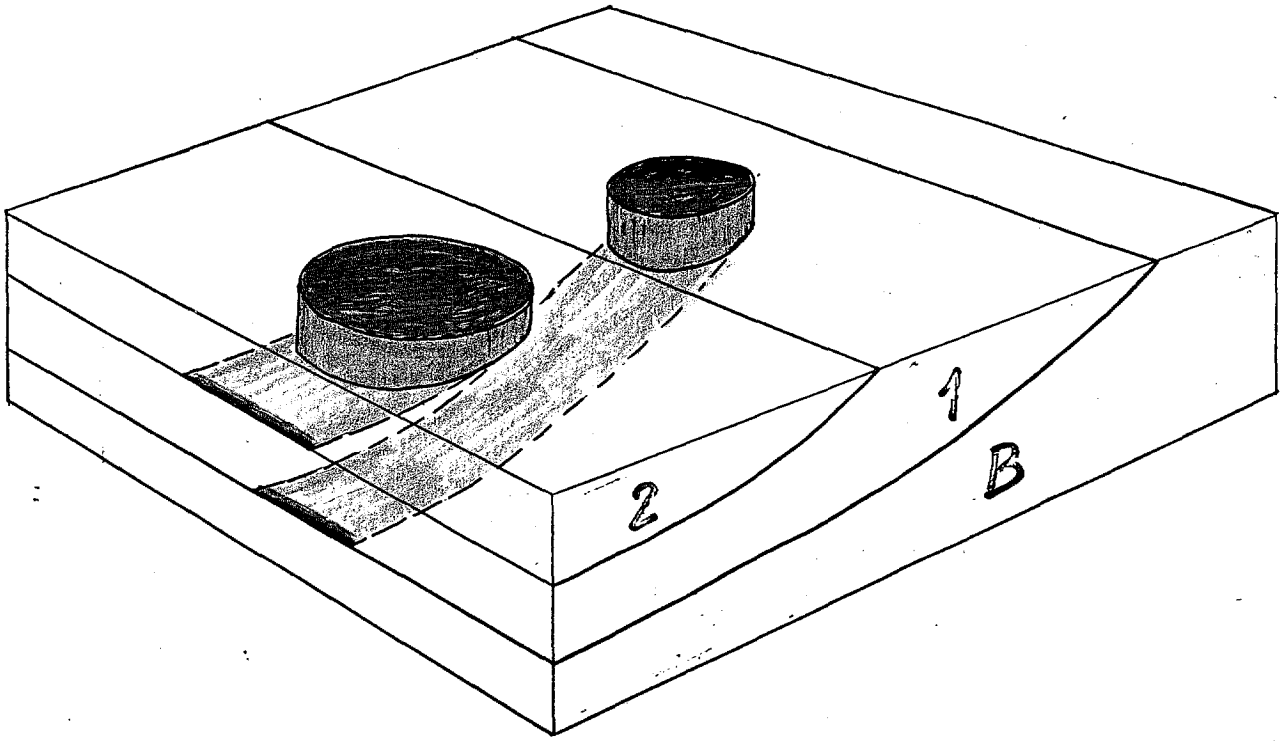
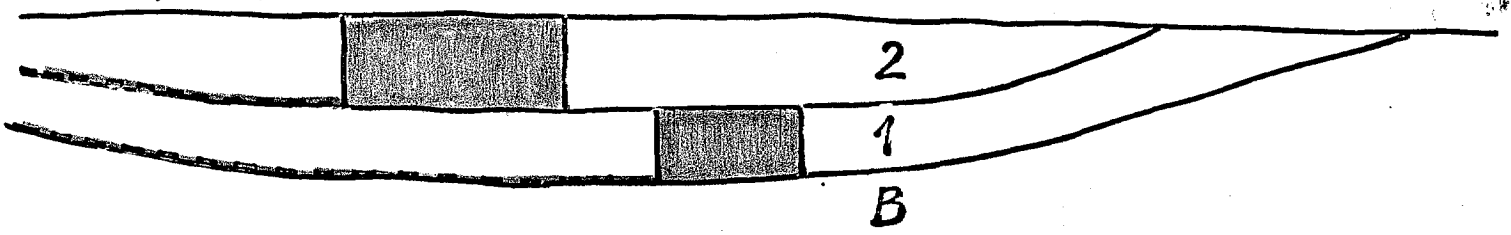


Fig. 12

Idealized Section



Drag Ore only indicative of ore in Hanging Wall Nappe.

No Drag Ore in outcrop of Glide Fault between these two Orebodies!

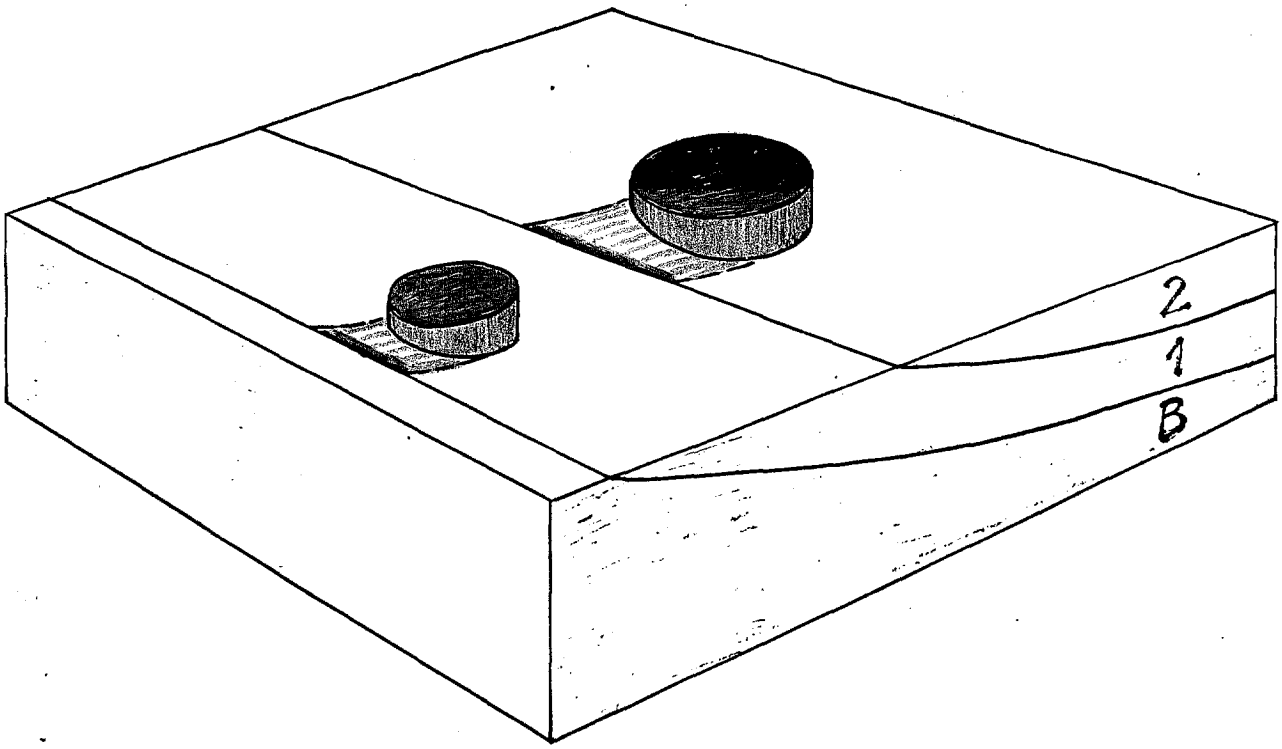
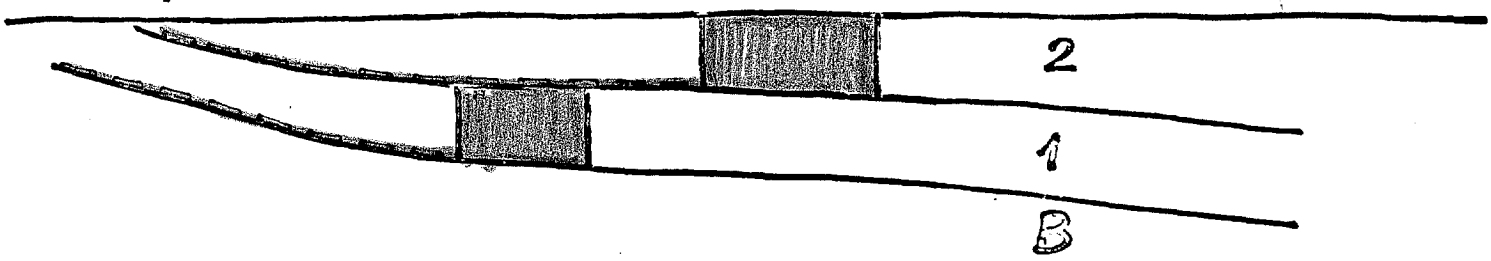


Fig. 13

Idealized Section



Drag ore in outcrop of Glide Fault 1-2 is no Criteria to match these two Orebodies!

Apparent amount and sense of displacement is highly misleading!

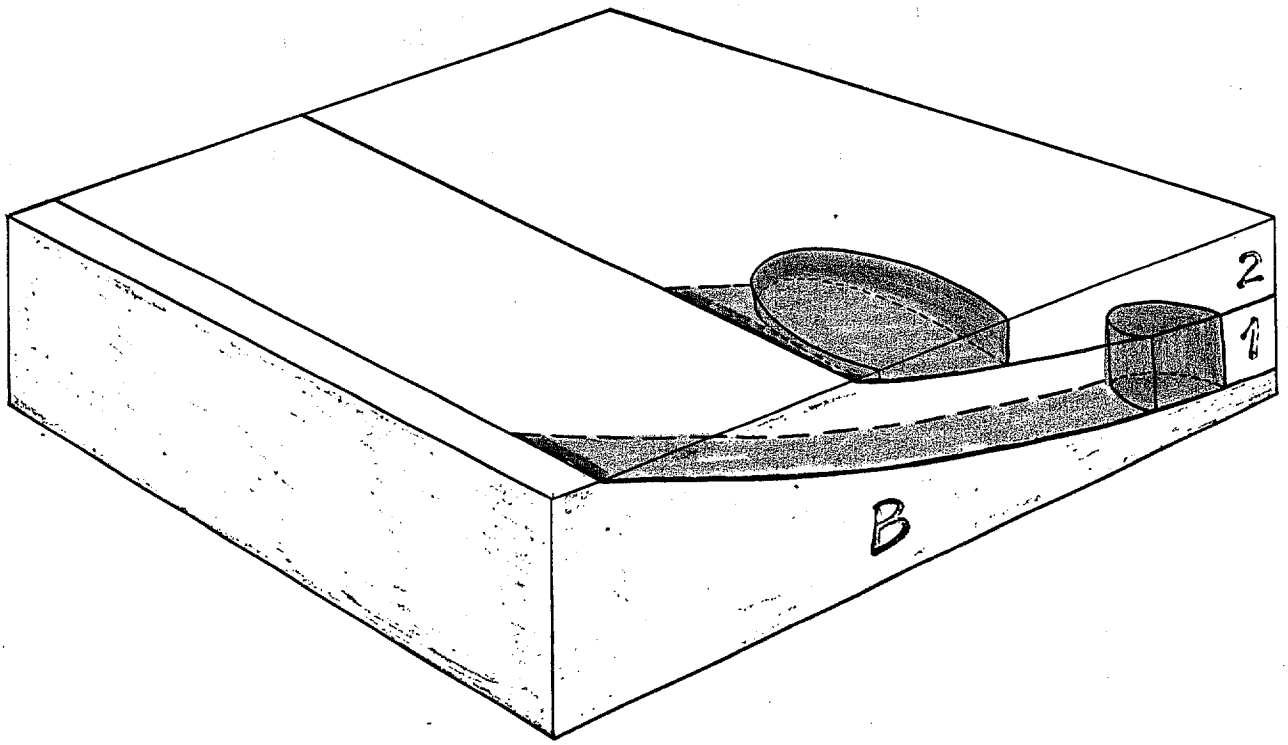
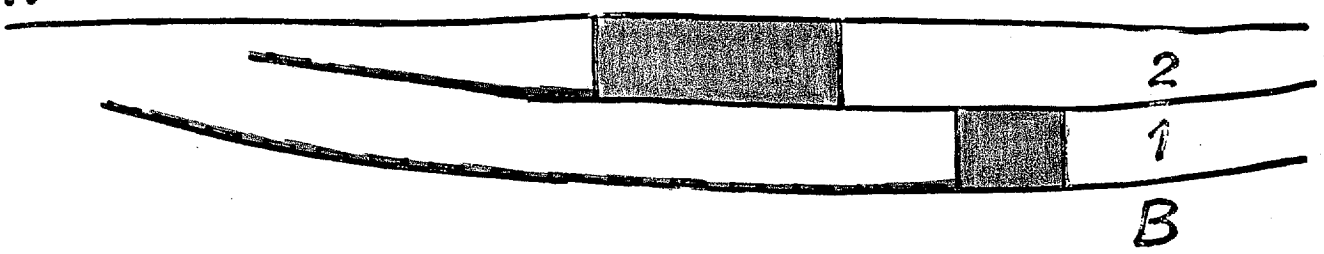


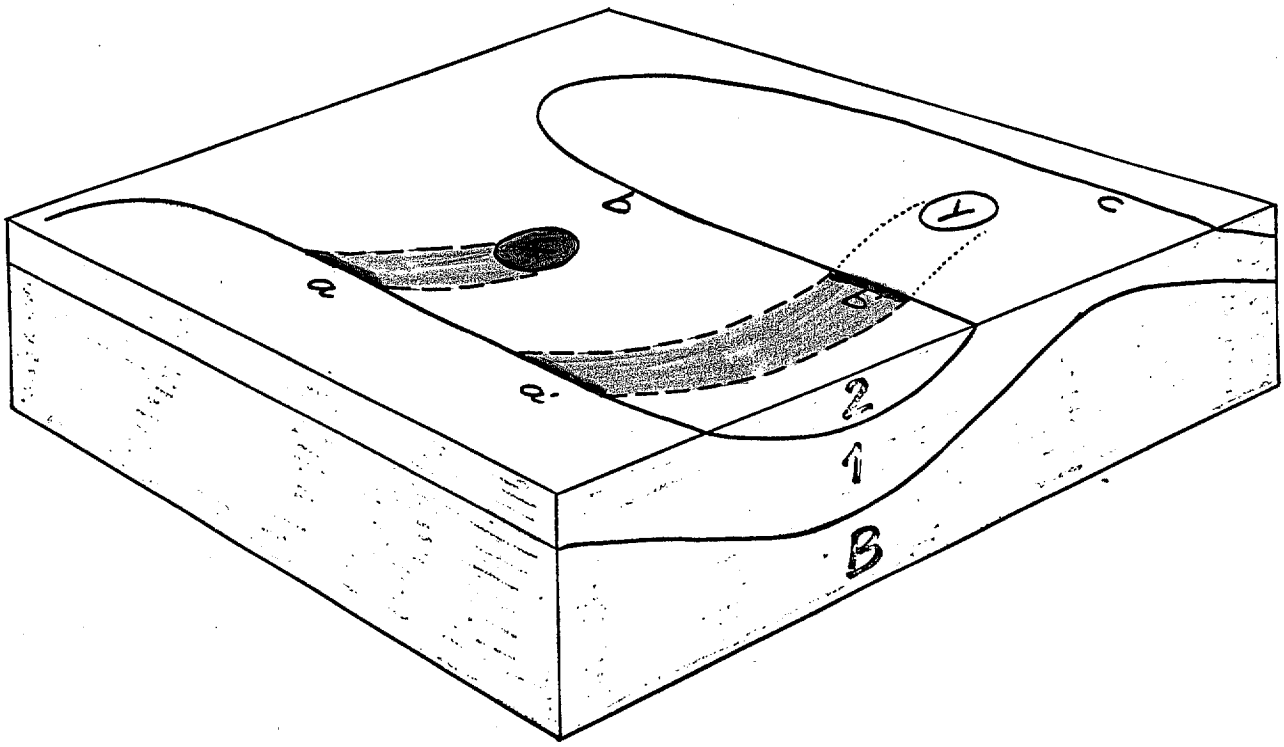
Fig. 14

Idealized Section



Drag Ore in outcrop of Glide Fault B-1 is guide to blind Orebody 1.

Orebodies 1 and 2 are not connected via a trail of Drag Ore. They are independent Exploration Targets!



<u>Case X</u> = Anomaly at <u>a</u>, but none at <u>b</u>.

Target at depth between <u>a</u> and <u>b</u>.

<u>Case Y</u> = Anomalies at <u>a'</u> and <u>b'</u>, but none at <u>c</u>.

No Target exists anymore.

Fig. 15

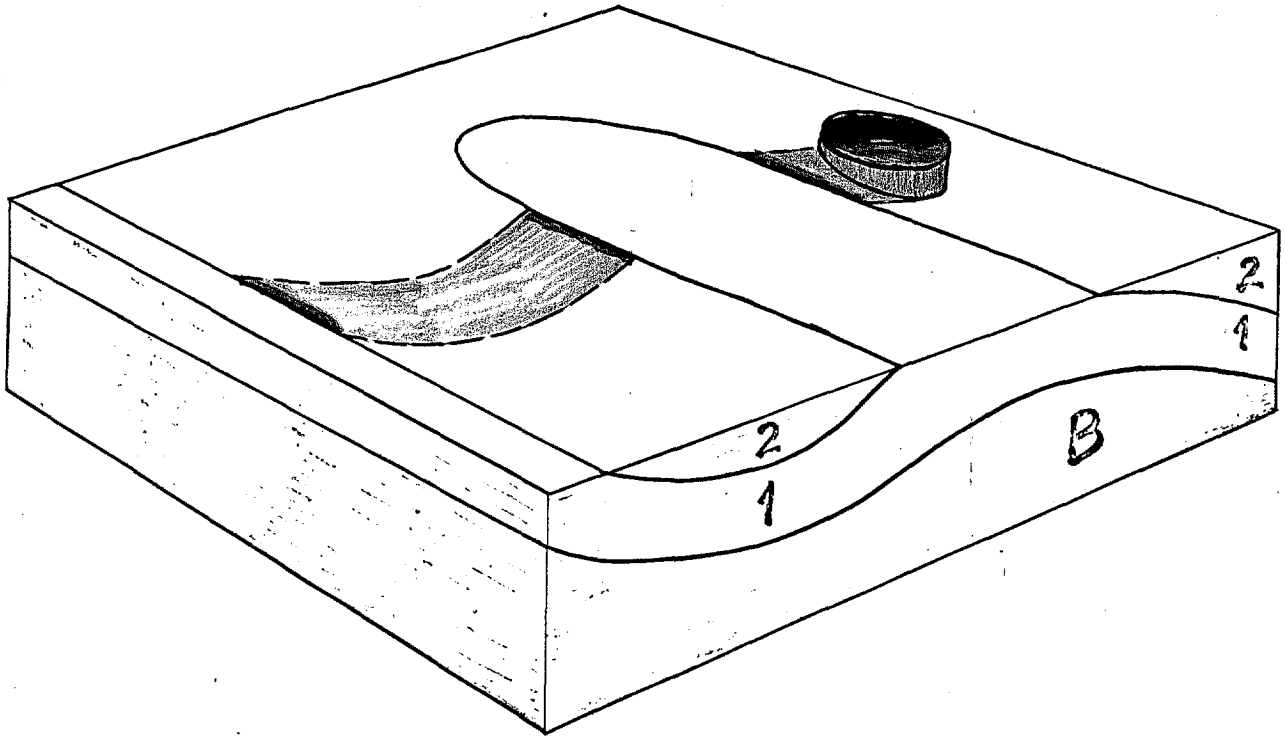
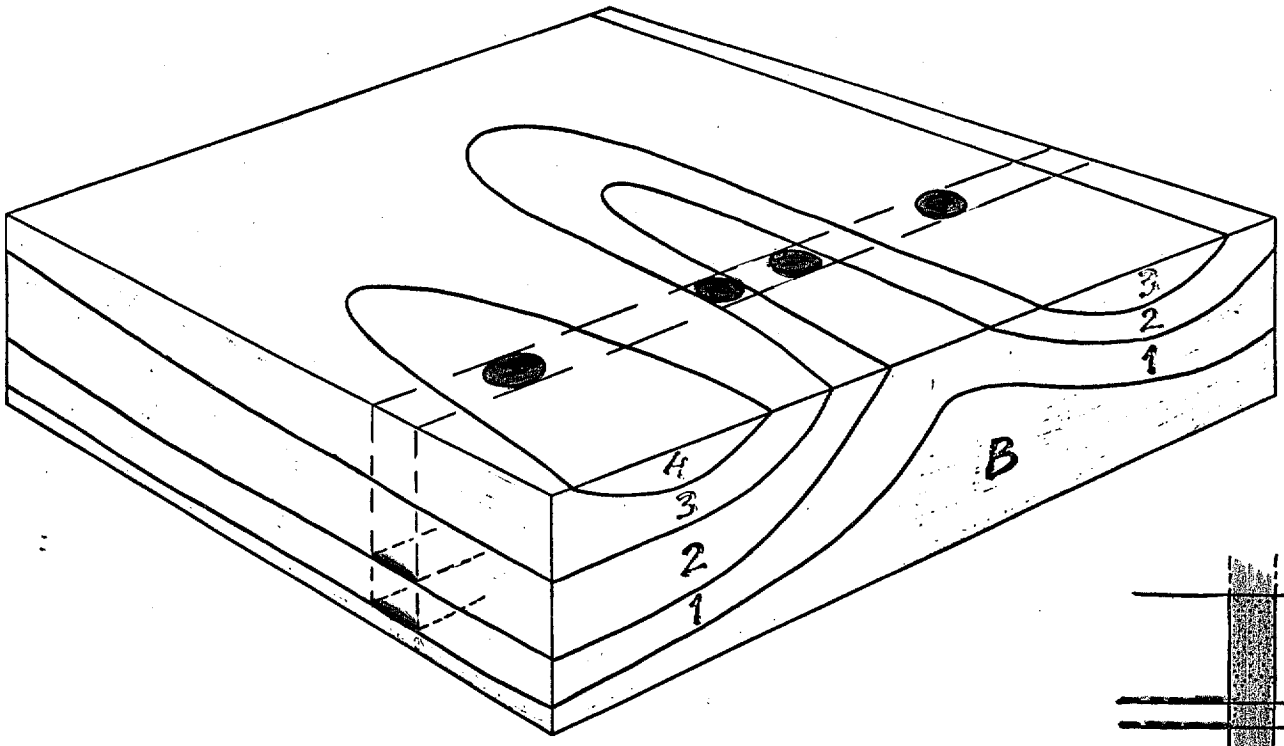


Fig. 16

Drag Ore in outcrops of a Glide Fault can be used as directional Orefinder. Gouge Sampling is needed for the entire length of Fault outcrop. — Reevaluate existing exotic Geochem. anomalies



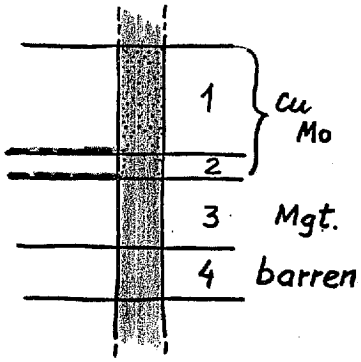


Fig. 17

Idealized Reassembly.

Lineaments, Trends, or "Lines" could result from Nappism: Slicing of an intrusive Pipe, and Spreading along area of Movement.

Reassembly of Pipe must include mineralized and <u>barren</u> portions of pipe!

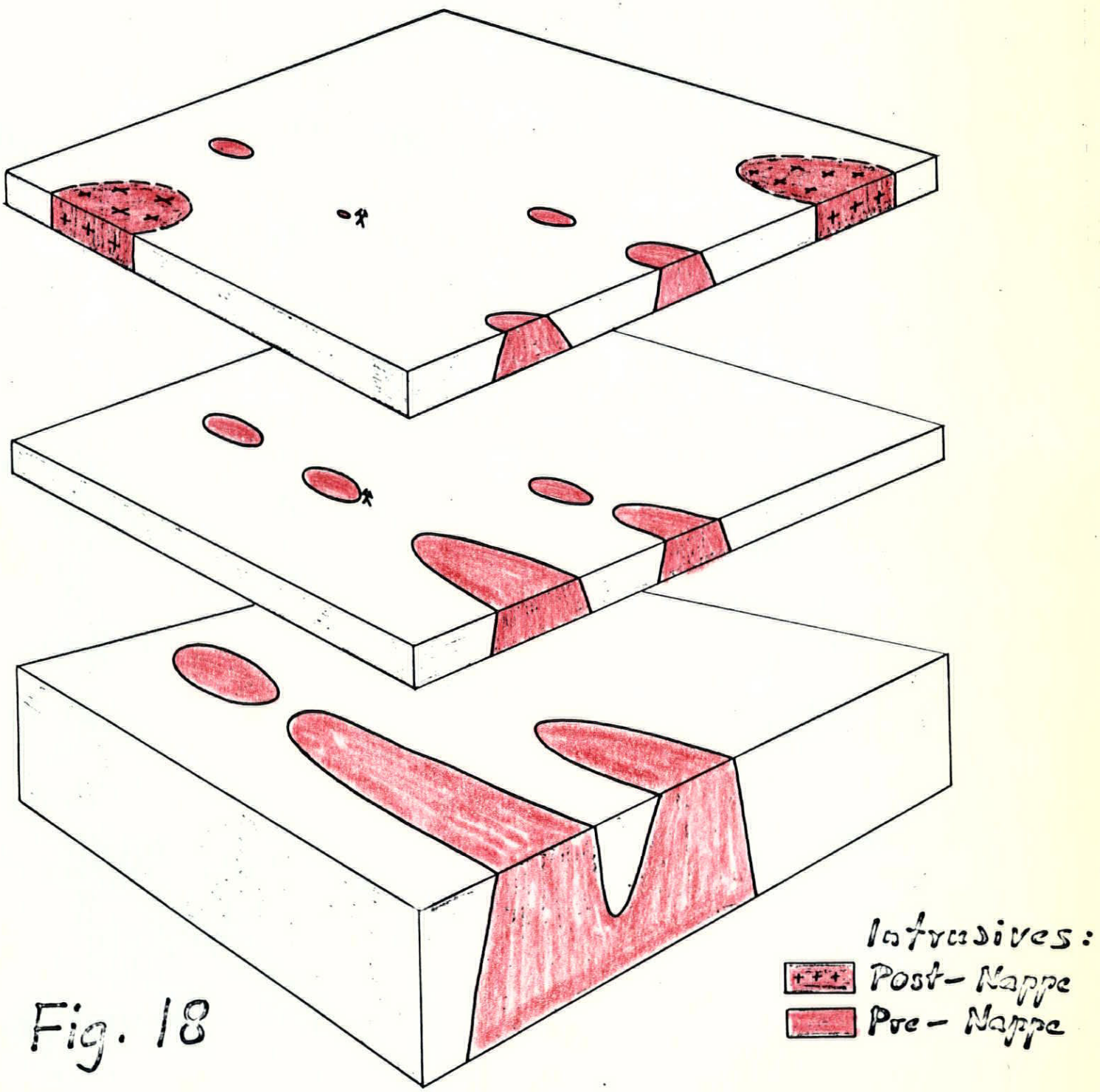
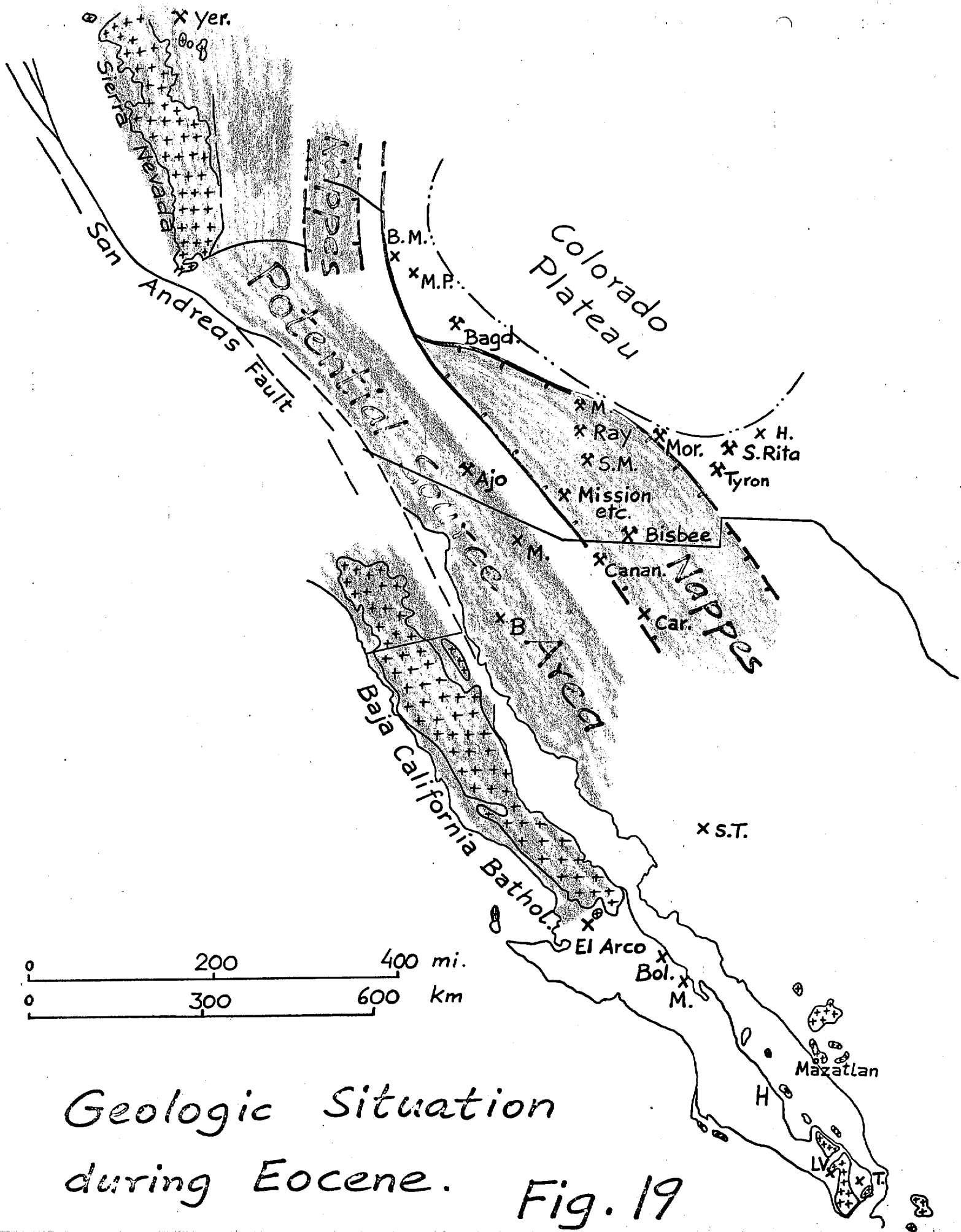


Fig. 18

Nappes restacked. Try to project geological features upwards or downwards.



Geologic Situation during Eocene.

Fig. 19

THE RELATIVE POSITION OF PORPHYRY COPPER DEPOSITS TO BARREN LARAMIDE STOCKS

by J. C. Balla

THE RELATIVE POSITION OF PORPHYRY COPPER DEPOSITS TO BARREN LARAMIDE STOCKS

J. C. Balla

Introduction

In many of the porphyry copper deposits of southwestern North America, there is, in the general vicinity, a large, barren, granitic stock. Little attention has been paid to these stocks, since they are generally totally barren of sulfide mineralization and do not, in some cases, appear to be intimately associated with the porphyry copper mineralization.

As part of the writer's work in the area between Casa Grande and Miami, Arizona, a spatial pattern emerged between these barren granitic stocks and porphyry copper deposits. A review of the geology of nearby districts seems to strengthen the possibility that there is a spatial and genetic relationship between these two entities. Specifically, it appears that some, if not all, porphyry copper deposits are derived from an associated barren granitic stock. The porphyry copper deposits are, in essence, the final magmatic event, or the last magmatic event, which occurred from a large, crystallizing magma.

Mapping of these barren granitic stocks shows that they are not randomly shaped but appear to be elongate in a specific direction. The elongate, or ellipsoidal shape is a function of the regional structure along which the stock was intruded. The long axis of the stock is parallel to the regional structure. The ends of these elongate stocks are zones of strong cross fracturing, and it is in these zones that porphyry copper deposits are most likely to occur.

As an example of the above, the geology of several porphyry copper districts will be reviewed below. The location of these districts is shown in Figure 1.

Cananea Mining District, Sonora, Mexico

The Cananea mining district is located a few miles south of the Arizona border. The geology has been described by Velasco (1966). Figure 2 is modified from a map published by Valentine (1936). The Cananea district is located along a northwesterly trending mountain range. According to Velasco (1966); "The most heavily mineralized and most productive zone is in the central and southeastern parts of the district. The entire mineralized area is about 3.5 km. wide by 10 km. long and trends northwesterly-southeasterly."

The general geology consists of a series of Paleozoic sediments and Mesozoic volcanics which were intruded by a series of granitic stocks, which lie north of the district. The exact ages of these stocks are unknown. The Cananea granite appears to be the youngest, pre-mineral, granitic stock.

The sediments and the volcanics dip away from the Cananea granite, suggesting that the granite forms the center of a large, elongate, dome with the long axis of the dome being the long axis of the Cananea granite. Considerable faulting complicates the geologic picture.

Apparent differentiates off the Cananea granite are the quartz porphyries, which are shown in red, and breccia pipes, shown in yellow, in Figure 2. Velasco (1966) states that the "Characteristic distribution of these intrusives (quartz porphyries) is along a general northwest-southeast striking trend. The striking alignment of the quartz porphyry intrusives to the southeast of the Capote basin follows the assumed general trend of the fault (ricketts fault). These intrusive rocks may be the upper fingering of a deep-seated southeast-plunging granitic mass." (Underlining by J.C.B.)

Thus, we see a picture of a large, elongate, barren granitic stock which has domed up the sediments into which it has intruded. Only the top of the intrusive is exposed. There are geological reasons for believing that the granite extends southeasterly, under it's roof rocks, and that in these roof rocks, along the general regional trend, quartz porphyry intrusives, and breccia pipes, are found. Widespread pyritization surrounds the granite, and its southeast projection. However, economic concentrations of copper occur only in the quartz porphyry "differentiates."

Except for the La Colorada breccia pipe, no molybdenum occurs in the district. Considering the normal zoning pattern in porphyry copper deposits, an increase in molybdenum content with depth can be expected.

Bisbee Mining District, Arizona

The Bisbee district has been described by Ransome, (1904) and Bryant, (1966). Figure 3 is part of Plate II, by Ransome (1904). The Bisbee mining district is centered around the Sacramento stock.

The older Precambrian Pinal schist has been covered by a thick sequence of Paleozoic limestones. Intruded into these rocks was a post-Paleozoic, pre-Cretaceous granitic stock called the Juniper Flat granite. This stock, according to Bryant (1966), is in the form of a northwest trending, elongate stock. Two facies are present, a coarse grained one and a finer grained porphyritic one. The areal distribution of these two units is not discussed.

The Escabrosa zone of dikes is composed of dikes which are believed to be genetically related to the Juniper Flat granite. Bryant (1966) states that:

"In the Warren mining district, the important igneous rocks were intruded during the post-Paleozoic-pre-Cretaceous interval. Although these intrusives differ in form, size, texture, and geologic environment, the similarities of granite composition and age indicate a probable comagmatic origin. The intrusive rocks are grouped into two geologic classifications on the basis of the extent of hydrothermal activity. Northwest of Bisbee the first group, including the Juniper Flat Granite and the Escabrosa Ridge dikes, is not appreciably altered. The second group, which includes the Sacramento stock and the "underground" porphyries, is intensely altered and intimately associated with mineralization."

Covering these rocks is the Cretaceous Bisbee group of limestones. These rock have a gentle dip to the northeast.

According to Bryant (1966):

"The Paleozoic beds have a gentle to moderate dip away from, and more or less normal to, the southwestern side and ends of the Juniper Flat Granite, suggesting northwest-southeast anticlinal doming related to its emplacement. (Underlining by J.C.B.) The production area of the Warren mining district consists of about 3 square miles situated on the southeastern end of the anticlinal dome. The nearest ore of consequence is about 1-1/4 miles from the southern end of the granite mass. (underlining by J.C.B.) The relative ages of the granite intrusive and ore deposition imply a genetic relation between the two."

Thus, as at Cananea, there is a similar picture of an elongate, barren, granitic stock, in a domal environment, with porphyry copper mineralization at one end of the stock.

Pima Mining District, Arizona

The Pima mining district is located southwest of Tucson, Arizona, and includes the Esperanza, Sierrita, Twin Buttes, Pima and Mission copper deposits. The geology of the district has been described by Cooper (1960) and in Titley & Hicks (1966).

As shown on Figure 4, the Esperanza-Sierrita mines occur at the south end of a large, barren stock called the Ruby Star granodiorite. According to Lovering, et al, (1970), the Ruby Star granodiorite consists of two granodiorite facies and, near the Esperanza-Sierrita area, a quartz monzonite facies (Figure 4).

The border phase is an equigranular, medium-grained rock, while the core phase in a porphyritic rock, distinguished by large, K-feldspar phenocrysts which are 1/2" to 3" long.

The quartz monzonite phase consists of several different quartz monzonite intrusive stocks, which, because of gradational contacts, are known to be genetically related. The ore bodies of Sierrita, West Esperanza and Esperanza are in the quartz monzonite complex. The Twin Buttes mine appears to be related to an apophysis off the main granodiorite stock.

As shown in Figure 4, the Ruby Star granodiorite is elongate in a north-northwest direction. At the southern end, in the different pits, strong east-northeast trending fracturing is important.

Figure 5 is a structure map prepared by Lutton (1958). When the Ruby Star granodiorite is located on the map, Figure 5, the strong east-northeast fracturing becomes evident. It should also be noted that within the stock, the principal fracture direction is parallel to the long axis of the stock. These are probably cross joints (Balk, 1937).

It is interesting to note that if a large stock was rotated by post-intrusion tectonics, and if this rotation was around an exis which was horizontal and perpendicular to the long axis of the intrusion, then gravity sliding at the elevated end, along these joints (which would form horsts and grabens) could be accomplished quite easily. In the two porphyry copper deposits known by ASARCO to have slid substantially (Sacaton, Mission), both slid parallel to the long axis of the intrusive (Three Peaks, Ruby Star), and parallel to the regional structure (East-northeast, North-northwest).

Globe-Miami Mining District

The Globe-Miami district is a most interesting district, since it is more complicated than the previous districts discussed. The district geology is discussed by Peterson (1962) and in the Titley & Hicks volume (1966).

As shown in Figure 6, the barren Laramide Schultze granite has an irregular shape. It is elongate in a east-northeast direction, with a secondary elongation in a northwest direction. The dominant structural direction of the mineralization in the district is northeast.

The Schultze granite is not a zoned, composite intrusive, but is more or less uniformly a medium grained, porphyritic rock. The phenocrysts are orthoclase, ranging in size from 1" to 4" long. There is no border phase, except the granite porphyry, which is a differentiate off the Schultze granite, and which is associated with the ore deposits.

As noted on Figure 6, the Miami-Inspiration deposit is located on the northside of the eastern lobe, while the Santa Anna deposit is on the southern lobe. The southwest lobe of the Schultze granite is covered by post-mineral dacite, and is currently being explored by ASARCO.

North of the Schultze granite by a couple of miles are two porphyry copper deposits, Castle Dome and Copper Cities. These two deposits are along a east-northeast trend that is a part of the Globe-Miami trend. The deposits are thought to be genetically related to the Schultze granite (Simmons & Fowells, 1966). However, J. D. Sell (personal communication) thinks otherwise. It is interesting to note that the Copper Cities and Castle Dome deposits are of the same age, but are distinctly older than the Schultze granite, (Figure 7), suggesting that Sell may be correct. It has been suggested that the two deposits are actually one deposit that has been cut in two by faulting.

General Model

Figure 7 is a table comparing some of the features discussed so far. From previous discussion, and Figure 7, a general "model" can be constructed which is shown in Figure 8.

It is noted that these barren, Laramide granitic stocks are elongate in a specific direction. This elongation is presumably due to intrusion of the magma along a lineament or major fracture. The intrusion of the magma forms an elongate dome. If the roof rocks of the stock are still preserved, then we may see numerous porphyry intrusions and breccia pipes with widespread pyritization. Copper Mineralization would be associated with the porphyries, as at Cananea.

If the roof rocks are eroded away, then a situation similar to the Bisbee or Pima mining districts may exist. The porphyry copper deposit may exist immediately adjacent to one end of the stock, or a couple of miles from the end, as at Bisbee. Erosion of the stock will have progressed into the interior of the barren stock, where the different internal zones of the stock may be exposed.

As erosion continues deeper into the stock, the stock may grade from a composite, zoned stock, into one which is merely very coarse grained, without different zones, such as the Schultze granite.

Exploration Potential

The exploration potential of the above concept can be demonstrated in two district where ASARCO has considerable knowledge; the Sacaton and Florence mining districts.

Sacaton Mining District

The Sacaton-Santa Cruz deposits were found by first finding a small altered hill of Precambrian granite. Finding the hill led to the discovery of the Sacaton deposit, and then Santa Cruz. Assuming that the hill was not exposed, could the presence of Sacaton or Santa Cruz been predicted?

Consider Figure 9. There are two Laramide stocks, Three Peaks and Sacaton Peak. Both are zoned, composite granitic stocks. Radiometric ages of the stocks, and the Sacaton deposit, are shown in Figure 7.

Due to alluvial cover, it is difficult to be sure which stock is the one associated with the Santa Cruz deposit. The Three Peaks stock is the one chosen, based on proximity, Union Oil's drilling, and age. The Three Peaks stock is oriented along the regional trend of about N45°E. There is no sulfide mineralization in the stock, with the exception of the southwestern corner of the western border phase. In this area, copper occurs in veins, parallel to the trend of the stock. There is a distinct increase in copper mineralization in a southwesterly direction in the border phase. Drilling by Union Oil in alluvium southwest of the mineralization found the border phase. Further drilling in a southwesterly direction, looking for the southwest end of the stock, would have encountered the sulfide system at Santa Cruz. Hence, using the "model" proposed, exploration would have found the Santa Cruz deposit.

Florence Mining District

Figure 10 is a map of the area around Poston Butte. It is assumed that the mineralized Precambrian granite which led to the discovery of the Poston Butte deposit is covered by alluvium.

There are two known facies to the Walker Butte stock, as shown on Figure 10. The small isolated outcrop of the core facies of the Walker Butte stock (Cholla Butte) carries numerous quartz veinlets that are aligned about N70°E. There are also a number of cupriferous veins, also aligned in that direction.

Where the border phase and the core phase appear to merge, on the eastern end of the large outcrop area, considerable copper exists associated with basic dikes. There is also copper, in veins, along the contact between the border and core phase.

Again, using the concept described above, the eastern end of the Walker Butte stock would be an area of considerable interest due to above described mineralization. I.P. and/or wildcat drilling, east of the outcrop, would have found the Poston Butte deposit.

General Utilization

The concept developed above can be used in porphyry copper exploration in several ways. Sampling of the biotite in these stocks (a la F. Graybeal and J. King) appears to be a useful tool.

These different facies of the intrusives show up on the ASARCO low attitude aeromagnetics, and hence, the aeromagnetics can be used in covered areas, once the geology makes the aeromagnetics "interpretable".

Also, utilizing the geologic drill would provide information on the extend a barren, Laramide intrusive stock extends under alluvium. Wildcat drilling could be done, looking for a buried end of the stock.

In conclusion, it appears that the above concept is valid and can be utilized to look for porphyry copper deposits totally covered by alluvium.

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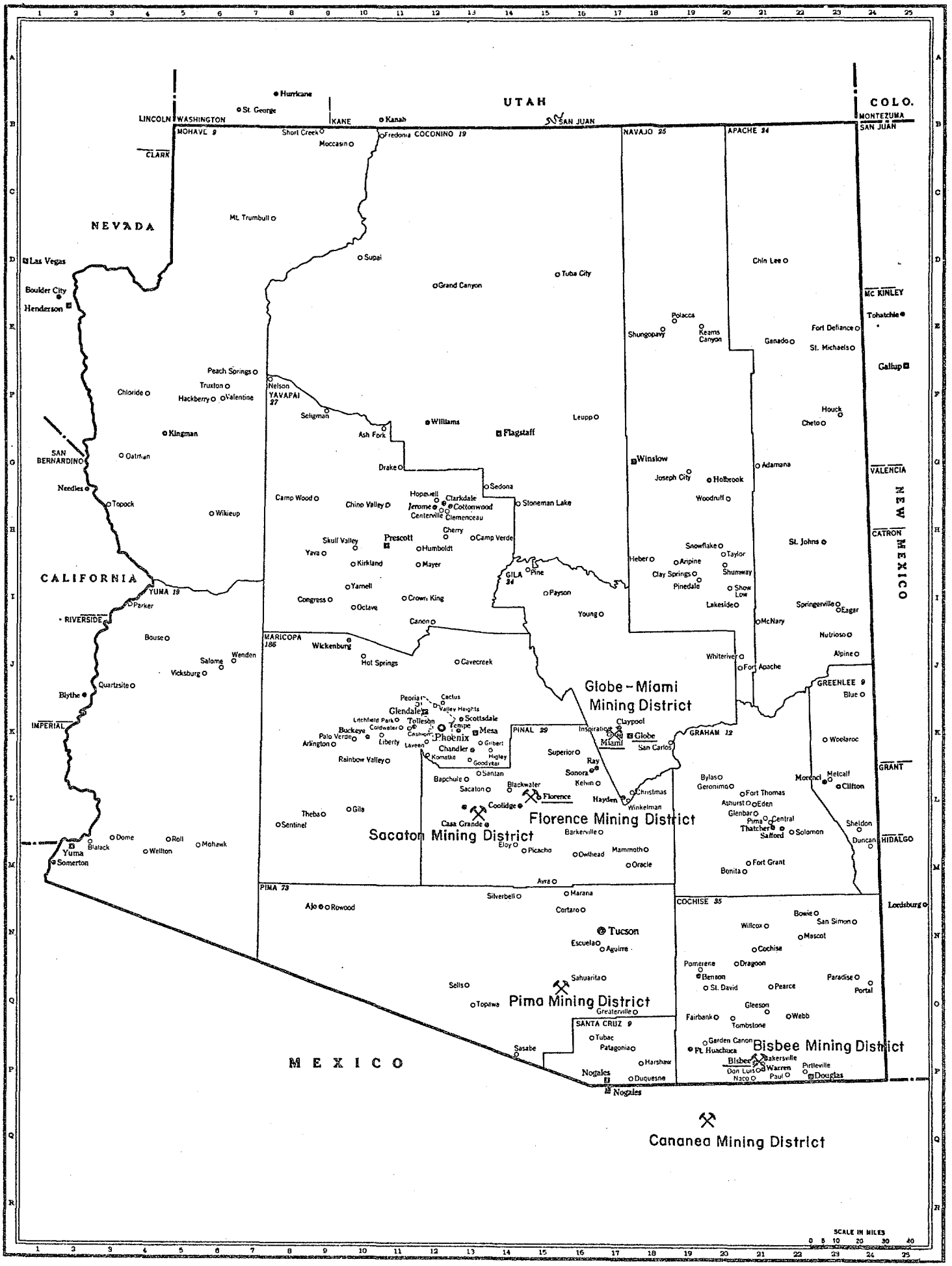
FIGURE 1

ARIZONA



LOCATION MAP

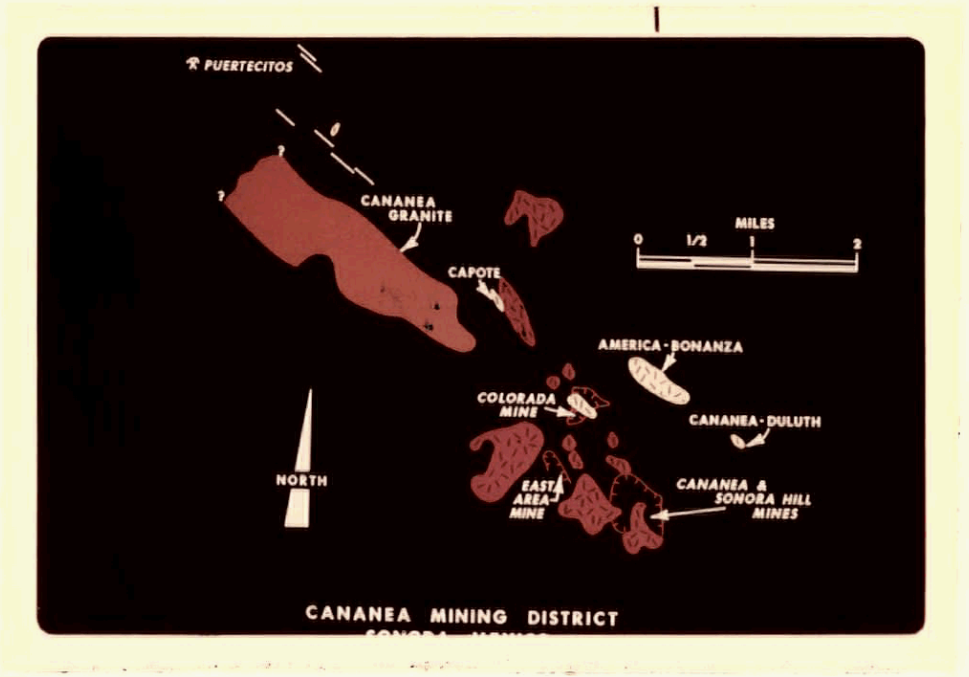

PUERTECITOS
CANANEA GRANITE
CAPOTE
MILES
0 1/2 1 2
AMERICA-BONANZA
COLORADA MINE
CANANEA-DULUTH
NORTH
EAST AREA-J MINE
CANANEA & SONORA HILL MINES
CANANEA MINING DISTRICT

Fig. 2

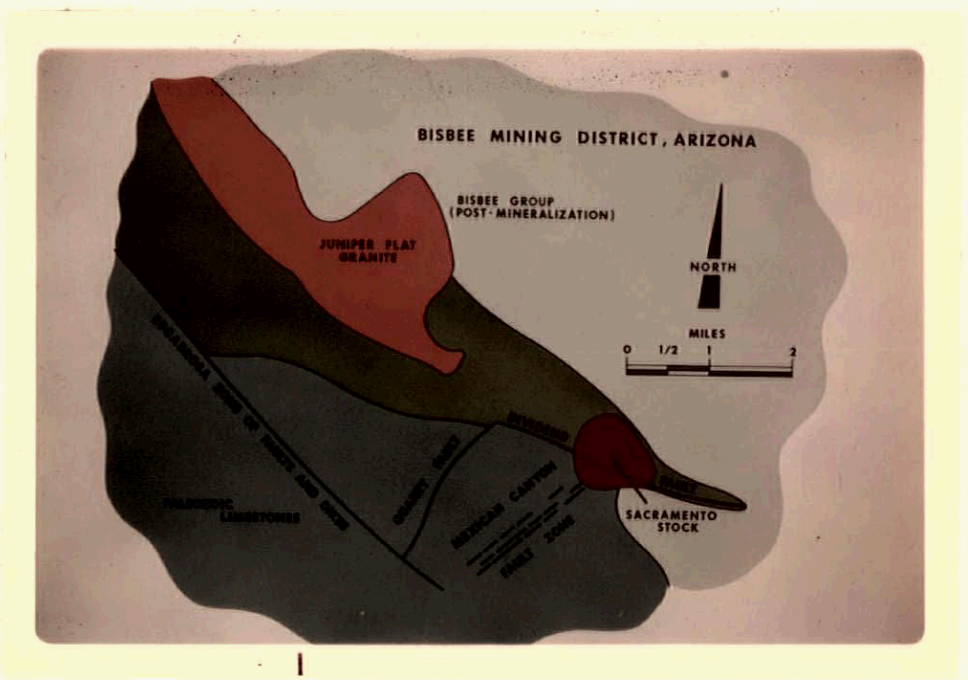

BISBEE MINING DISTRICT, ARIZONA
BISBEE GROUP (POST-MINERALIZATION)
JUNIPER FLAT GRANITE
NORTH
MILES
0 1/2 1 2
SACRAMENTO STOCK

Fig. 3

COBB FACIES
UPPER PLATE ROCKS
BORDER FACIES
PUDY STAR GRANODIORITE
NORTH
MILES
QUARTZ MONZONITE COMPLEX
BORDER FACIES
TWIN BUTTES MINE
SIERRITA MINE
WEST ESPERANZA MINE
ESPERANZA MINE
LOWER PLATE ROCKS
PIMA MINING DISTRICT

Fig. 4

ASH CREEK FAULT ZONE
FAULT
ZONE
TASCOYLA
SIERRITA FAULT
COMMON WASH FAULT ZONE
DUVAL FAULT

Fig. 5

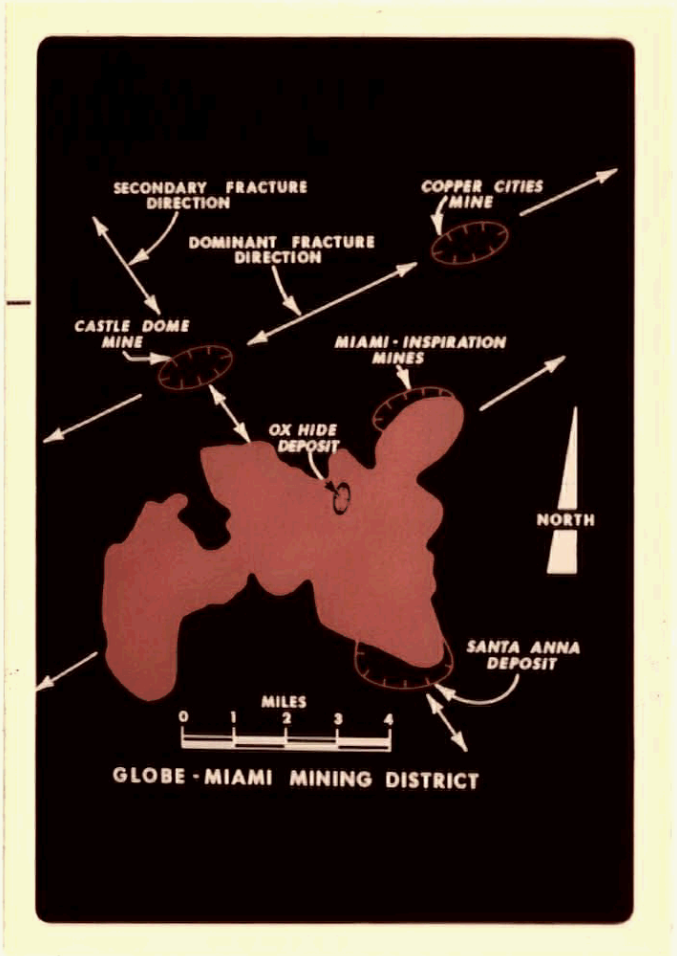


Fig. 6

RELATIONSHIPS OF BARREN STOCKS TO MINERALIZED STOCKS

NAME OF DISTRICT	NAME OF MINE(S)	NAME OF BARREN STOCK	AGE OF MINERALIZED STOCK	AGE OF BARREN STOCK	ORIENTATION OF BARREN STOCK	STOCK IS INTERNALLY ZONED	DISTANCE OF MINERALIZED STOCK FROM BARREN STOCK	BRECCIA PIPES PRESENT?	SHAPE OF BARREN STOCK (PLAN VIEW)
CANANEA	LA COLORADA SONORA HILL	CANANEA GRANITE	58 M.Y.	LARAMIDE	N 50° W	UNKNOWN	1.3 MILES 2.5 MILES	YES	ELLIPSOIDAL
BISBEE	LAVENDER PIT	JUNIPER FLAT GRANITE	PRE-CRETACEOUS	163 M.Y.	N 40° W	UNKNOWN	2 MILES	YES	ELLIPSOIDAL
PIMA	SIERRITA ESPERANZA TWIN BUTTES	RUBY STAR GRANODIORITE	61 M.Y. 54 M.Y.	59 M.Y.	N 25° W	YES	0.5 MILES 0.8 MILES 3 MILES	NO	ELLIPSOIDAL
SACATON	SACATON	THREE PEAKS SACATON PEAK	65 M.Y.	71 M.Y. 61 M.Y.	N 50°E N 55°E	YES	3 MILES(?)	NO	ELLIPSOIDAL
POSTEN BUTTE	POSTEN BUTTE	WALKER BUTTE	LARAMIDE	62 M.Y.	N 85°E	YES	3 MILES(?)	NO	ELLIPSOIDAL
GLOBE-MIAMI	INSPIRATION-MIAMI COPPER CITIES CASTLE DOME	SCHULTZE GRANITE	58 M.Y. 63 M.Y. 62 M.Y.	58 M.Y.	N 60°E N 40°W	NO	ADJACENT 2.3 MILES 1.5 MILES	NO	IRREGULAR

Fig. 7

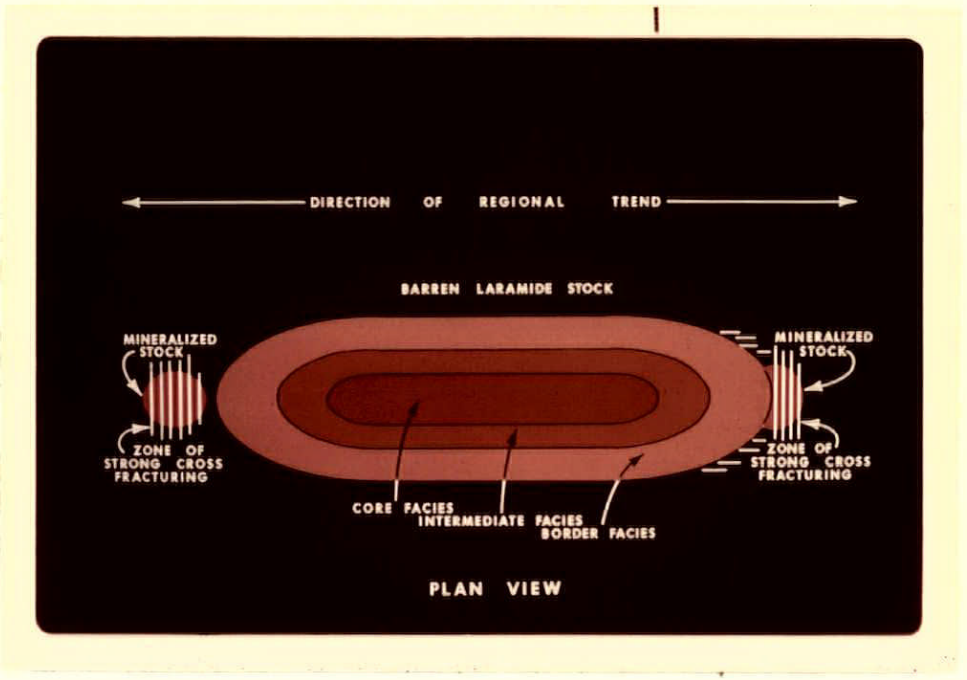

DIRECTION OF REGIONAL TREND
BARREN LARAMIDE STOCK
MINERALIZED STOCK
ZONE OF STRONG CROSS FRACTURING
MINERALIZED STOCK
ZONE OF STRONG CROSS FRACTURING
CORE FACIES
INTERMEDIATE FACIES
BORDER FACIES
PLAN VIEW

Fig. 8

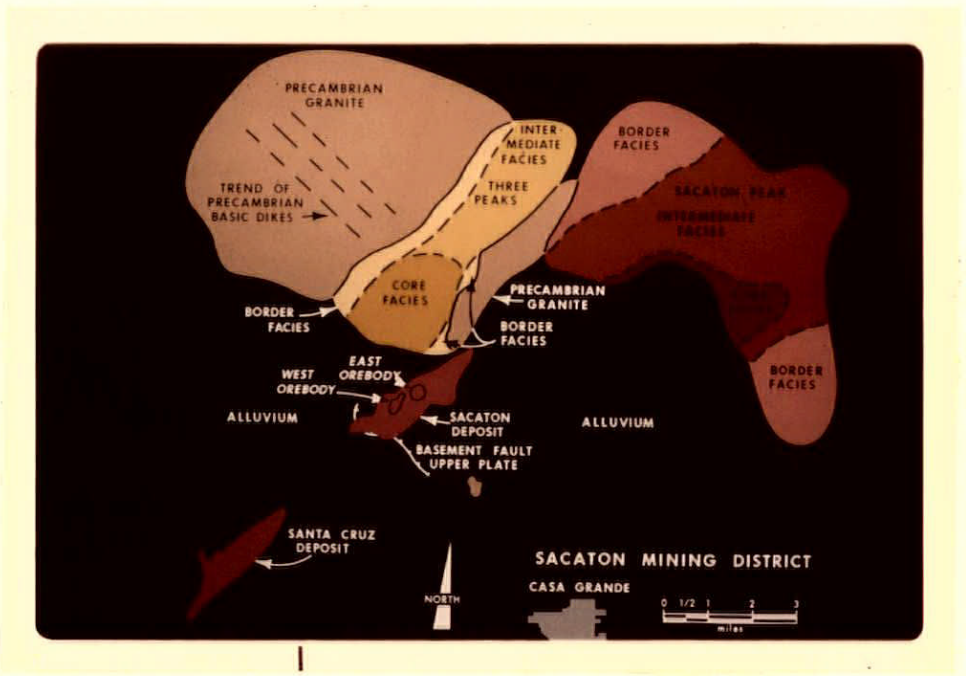

PRECAMBRIAN GRANITE
TREND OF PRECAMBRIAN BASIC DIKES
INTER MEDIATE FACIES
THREE PEAKS
BORDER FACIES
SACATON PEAK
INTERMEDIATE FACIES
CORE FACIES
BORDER FACIES
PRECAMBRIAN GRANITE
BORDER FACIES
EAST OREBODY
WEST OREBODY
ALLUVIUM
SACATON DEPOSIT
BASEMENT FAULT UPPER PLATE
ALLUVIUM
BORDER FACIES
SANTA CRUZ DEPOSIT
NORTH
SACATON MINING DISTRICT
CASA GRANDE
0 1/2 1 2 3
miles

Fig. 9

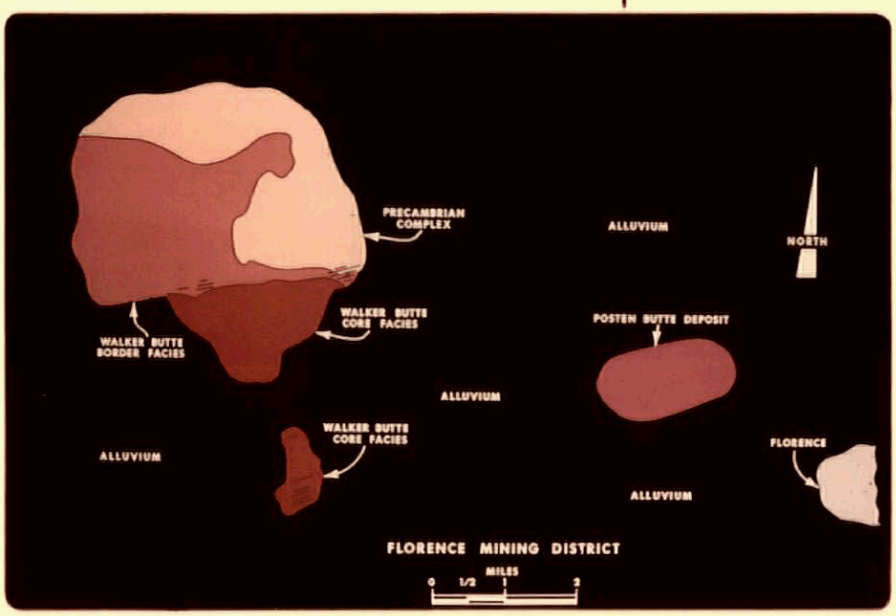

PRECAMBRIAN COMPLEX
ALLUVIUM
NORTH
WALKER BUTTE CORE FACIES
WALKER BUTTE BORDER FACIES
POSTEN BUTTE DEPOSIT
ALLUVIUM
WALKER BUTTE CORE FACIES
ALLUVIUM
FLORENCE
ALLUVIUM
FLORENCE MINING DISTRICT
MILES
0 1/2 1 2

Fig. 10