A SYNOPSIS OF THE GEOLOGIC AND STRUCTURAL HISTORY OF THE RANDSBURG MINING DISTRICT

by

Jeffrey Allen Morehouse

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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To the reader of Jeff Morehouse's thesis:

Jeff Morehouse's life was lamentably cut short by a hiking-rock climbing accident in the Santa Catalina Mountains near Tucson, Arizona, on March 24, 1985. Those who knew Jeff will always regret that accident, not only because it abbreviated what would certainly have been an uncommonly productive geological career but also because it snuffed an effervescent, optimistic, charming personality. He was the kind of guy you would like to have around for your lifetime.

At the time of the accident, Jeff's various professional, social, and political activities included finishing his Master of Science thesis in geology. He had put many months into the Randsburg project, one that seemed to be perfect for him in that it involved his motorcycle, economic geology, structural geology, and significant regional tectonic interpretation-reconstruction. He had tried several versions of his thesis, and had just clearly got in stride when he produced this manuscript. Much more was to come, especially on petrology of the units, on structural fabrics and their interpretation, and especially upon the significance of it all with regard to the Rand Schist interpretation, the Garlock Fault proximity, and the general detachment - metamorphic - tectonic - mineralization interplay of this crossroads district. Several mineralization models were forming in his mind, and his abilities in regional synthesis and implementation of interpretations were developing spectacularly, as is evident in the thesis version presented here.

This thesis copy was prepared only weeks before Jeff's death. I have minimally edited it, being careful neither to change any meanings nor to dilute Jeff's singular syntax. Some phrases are not clear to me, but without Jeff's clarifications they are best left alone. The document will still be invaluable to those active in the Randsburg district, and will probably extend in influence beyond that area. There is no bibliography, the figures and plates referred to are not all included, and there is too little reference in text to the various maps. That was all to come.

His many friends on the faculty of the Department of Geosciences, his innumerable graduate student buddies, and his countless other friends and associates will surely miss him. Special support from his student friends, from George Davis, Bill Dickinson, Spence Titley, Jim Briscoe, Mardee Stewart, and all those cronies in the Randsburg district is part of the paper presented here. I am proud to have been part of it - and Jeff - too.

The Graduate College of the University of Arizona has kindly consented to have this preliminary draft serve as evidence that Jeff Morehouse was certainly a Master of Science in Geology, and has authorized posthumous awarding of that degree.

John M. Guilbert
Professor of Economic Geology
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August 24, 1987

Dr. William R. Dickinson
Head Dept. of Geosciences
and
Dr. George H. Davis
Vice Provost
Administration Building
University of Arizona
Tucson, AZ 85721

Dear Bill and George:

I am airborne as I start this letter. I have just spent a day in the field with Jim Briscoe and some investors from Philadelphia and London and their advisers, and we are zipping back to Tucson by learjet. Our 'target area' was the Randsburg district in Inyo County, California, an area that Briscoe and Associates are about to bring into production as a gold-silver-tungsten property. I am writing this letter because we have just walked over a geologically complex terrain of altered, faulted, sheared, mineralized rocks poking out of a veneer of alluvial cover that must have been exceedingly difficult to map. Mr. Briscoe and I were able to describe the underlying rock type distributions, the structural evolution, mineralization - alteration systematics, and geochronological relationships almost totally as the result of the excellent mapping by the late Jeff Morehouse. Not only were the general distributions of geologic aspects unusually well displayed on his maps, but also we were pleased and amazed to find even the finest geologic details correctly identified and located. Everywhere we went over a complex 5 square kilometer area - up washes, over hills, into adits - Jeff had performed his mapping and analytic functions in an accurate, clear, and professional manner. It was my first visit to Randsburg, and I was gratified to learn that Jeff truly did perform at Master of Science level, if not beyond it.

As you know, Jeff submitted the first draft of his thesis to me, along with a dozen unpolished maps and diagrams, only a few weeks before his lamentable death. As GHD's letter to me of April 29, 1985, indicates, we all feel that Jeff should be awarded a Master of Science degree posthumously. This trip to the Randsburg district - his thesis area - has convinced me that this degree confirmation is richly deserved.

I have been intending to edit and formalize Jeff's draft ever since returning from my sabbatical in July of 1985. I have not done so for a number of reasons, including the magnitude of the task, my own writing responsibilities and commitments, the press of working on other students' work, and so forth. Even more important is the fact that every time I try to edit Jeff's work I feel a sense of infidelity and frustration in that he cannot effectively rebut my rewordings, phrase changes, and interpretations. Jeff had his own style, with sentences like "The elaborate Kelly Fault System was subsequently initiated, but coincident with most of the activity along the Big Horse Fault." It would be tempting to rewrite that in the time frame, with "coincident" replaced by "contemporaneous". But Jeff may have meant that one was later than the other and represents renewed movement along an old fault. Only someone working in the area would know, and it would be too easy to insert errors where only ambiguity now exists. No one has the time to rework the whole thesis (roughly 70 pages), and attempts to do so seem to do horrible violence to some of the sense, phrasing, and style that are part of who Jeff was.

With this letter, I would like to suggest that I be given permission to write a cover letter explaining the circumstances and that we proceed to grant Jeff an M.S. in May 1989, after having prepared his draft essentially in its present form as his thesis, with no editing, no corrections, no rewordings. Anyone working the Randsburg area will be able to work with Jeff's draft, and in fact they will certainly acquire or retain a truer idea of the author than they would were we to 'launder' his writing.

If a special appeal or petition to the Graduate College Council is required, I will be pleased to initiate it. It is certainly time we act.

Sincerely Yours,

John M. Guilbert

JG:kw

James A. Briscoe & Associates, Inc.

Exploration Consultants:
Base and Precious Metals/Geologic and Land Studies/Regional and Detail Projects

James A. Briscoe
Registered Professional Geologist

Thomas E. Waldrip, Jr.
Geologist/Landman

February 6, 1986

John Guilbert
Department of Geosciences
Building #11
University of Arizona
Tucson, AZ 85721-9990

RE: Transmittal of Jeff Morehouse's most recent thesis draft

Dear John:

I have gone through Jeff's notes and papers, and have concluded that the enclosed thesis draft is Jeff's most recent work. The quote from me on the last page was discussed by Jeff and myself only a few days before he was killed.

I made numerous comments, suggestions and notes, as well as corrections on the first draft. These have been taken into consideration and re-typed on this edition, however, some which have not are included as additional handwritten pages along with Jeff's notes or comments on them. All of this is on a word processing disk, so additions, changes, etc., can be readily accomplished. I am sending a copy of this to George Davis for his review and input.

I also have all of Jeff's field notes, underground maps, drafts of his surface maps, on several different sheets, and so forth. The geologic map will be the most expensive item to prepare in completion of the thesis. We had hopes of completing this using a computer assisted drafting program, which we recently purchased, but have not had the adequate time nor funding to complete it as yet.

I would be happy to get together with you and George to work towards completion of the thesis at any mutually convenient time.

Best personal regards,

James A. Briscoe

JAB/ms

5701 East Glenn Street, Suite 120/Tucson, Arizona 85712/602-721-1375

Enclosure

January 31, 1985
2425 E. Edison
Tucson, Az. 85719

Dear John,

Greetings for the new year from the new world. I certainly hope that your sabbatical work is fruitful and engaging, and that Mary is enjoying the 'continent'. I got a chance to read a letter about the marketplace from you, which Betty had on her desk, Midieval indeed! (spelling is not in my dictionary!)

I contracted a sequential pair of horrible diseases during the fall semester which deprived me of many nights sleep and almost my left eye as well. As an additional distraction to Scabies and Iritis, I taught general geology up at Florence State Prison. Consequently, thesis work lulled until November. Since that time, much has been accomplished and I am sending you a rough draft of the text with illustrations.

The rough draft comes in two parts with some overlap. Part One, A Conversational Outline, indicates what I mean to say about most background subjects. Part Two, A Synopsis of the geologic and structural history of the EMD, highlights my contributions to the general geology and details the results of the structural analysis. I'd like to draw your attention to the segment entitled 'General Considerations on Structural Episodes of Alteration and Mineralization', page 8.

Embellishments and specific details have yet to be added to many subjects. Chapters on Petrography, Fault Plane Geometry, and Tectonic Background still need to be written and incorporated into the text, but you hold the essential substance of what I have to say. Fleshing out an official first draft (by March?) will no more than double the length of the text, I hope.

Jim Briscoe has reviewed the paper twice and some of his suggestions have already been incorporated; more are to follow. I hope that you will have time to examine the manuscript and I eagerly invite your questions, comments and suggestions.

At the Reno GSA in November, I interviewed with Anne Pasch, Geology Professor at Anchorage Community College, about teaching at my old alma mater. I fit the included job description remarkably well, with a Masters Degree (coming up), Alaskan field experience (all over, with slides), and community college teaching experience (TA and Florence). Would you please write "a professional letter of recommendation" for me, to the ACC Division of Mathematics/Natural Sciences and Engineering Technology. It would be best to send the recommendation to me for inclusion with my application.

I wish you the very best of luck with your granites and offer my thanks in advance.

Yours truely,

STATEMENT BY AUTHOR

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SIGNED ____________________

Michael Cusanovich
Vice-Dean
Graduate College

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SIGNED ______________________

Michael Cusanovich
Vice-Dean
Graduate College

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ABSTRACT

The polymetallic gold-silver-tungsten-iron-antimony-arsenic ores of the Randsburg district in the Mojave Desert of southeastern California occupy a complex series of thrust and normal faults. The district is near the Garlock fault and displays a singular metamorphic-core-complex-related origin. A principal host rock, the Rand Schist, is similar to the Pelona and Orocopia Schists. Its schistosity was probably developed at almost 80 my by core-complex phenomena that produced the coeval Rand Thrust.

Extensive isotopic dating and systematic mapping of structural geology, lithologies, alteration, and mineralization in the Randsburg district have unravelled a complex series of ore-forming manifestations that reflect the local geological framework and its response to regional tectonic stresses. The pre-Jurassic Johannesburg Gneiss and 160 my Rand Schist graywacke (?) protolith were intruded by the Atolia Quartz Monzonite batholith at 85 my, cut by the Rand thrust and uplifted at about 80 my ago, and reintruded by the Randsburg stock at 73 my. A series of structural-alteration-mineralization events were generated that are intimately related to Rand Thrust and Rand Schist schistosity development and to a series of steep fault systems that introduced distinctive ore mineral assemblages into progressively more fractured volcanic and intrusive rocks. Atolia District mineralization produced sericite-scheelite in NE to E fractures at 32 my, Yellow Aster mineralization produced gold-enriched ESE veins at 18 my, and Kelly-age silver mineralization occurred in NW-SE to N-S extensional veins with silicification at 1.6 my. All three events are economically significant and warrant further exploration and evaluation.

Geologic evolution of the Randsburg district is an integral part of the plate tectonic history of the region, including the influence of the Garlock fault. A model suggesting that the Rand Schist and related ores and rocks are related to metamorphic core complex genesis and continental decretion is presented.

(by JMG)

A SYNOPSIS OF THE GEOLOGIC AND STRUCTURAL HISTORY OF THE RANDSBURG MINING DISTRICT

JOHANNESBURG GNEISS

The earliest history of the Randsburg Mining District is recorded in rocks of the Johannesburg Gneiss (Plates 1a, 1b). Brief field visits and scanty Rb/Sr isotopic work on the gneiss indicate that it includes Paleozoic through Triassic rocks with a Precambrian provenance and a polymetamorphic history. Component rock types include amphibolitic gneiss, quartzose-feldspathic gneiss, marble, calc-silicates, and quartzite in a heterogeneous package. The inherited(?) Precambrian components indicate that accumulation occurred near the Mojave Precambrian cratonal promontory. Regional and contact metamorphism of Paleozoic rocks throughout the western Mojave Desert occurred in conjunction with the diachronous intrusion of the Great California Batholith during Jurassic and Cretaceous times. This event is surely represented in the polymetamorphic history of the Johannesburg Gneiss. At least one further dynamic metamorphic event is represented by mylonite development during overthrusting of the Rand Schist at 80-70 my. The Johannesburg Gneiss is tentatively correlated with eugeosynclinal Paleozoic and Triassic rocks of the Garlock

Assemblage in the El Paso Peaks and Pilot Knob Valley (Carr, Poole, and Christiansen, 1984) (Plate 3).

ATOLIA QUARTZ MONZONITE

The Atolia Quartz Monzonite is dated at about 85 my. by Silver (1984). It is part of the Great California Batholith and extends south of the Randsburg Mining District until covered by alluvium. It structurally overlies the Rand Schist across the southern margin of the Rand Mountains. In contact with the schist, the Atolia Quartz Monzonite exhibits retrograde dynamic metamorphic mylonite fabrics.

RAND THRUST

The contact of the Rand Schist with Johannesburg Gneiss on the north and the Atolia Quartz Monzonite on the south is interpreted to represent one thrust fault surface, the Rand Thrust. Carbonate mylonites and gneissic rocks sheared into the southern Rand Thrust are probably derived from the Johannesburg Gneiss and help to support such an interpretation. A further exposure of the thrust may occur in the center of the district as discussed in the section on the Randsburg Intrusive Complex.

The larger picture of the tectonic significance of the Rand Thrust is still obscure. It is clearly a regionally significant fault juxtaposing very different lithologies from

CAPSULE CHRONOLOGY OF THE RANDSBURG MINING DISTRICT

Rock or Event Dated	Date	Method	Significance
Johannesburg Gneiss	PC-Pz-Tr?	Rb/Sr	Components of lithology or Provenance
Rand Schist	160±25my	Rb/Sr	Lithification of greywacke protolith?
Atolia Quartz Monzonite	85 my ±	U/Pb (Silver)	Batholithic emplacement
Rand Thrust	70-80 my	K/Ar Structure	Thrusting and Metamorphism
Randsburg Stock	73±3 my 74.2±1.9my	U/Pb (Silver) K/Ar (Kistler)	Intrusion into Rand Schist Hornblende cooling age
Rand Schist	70.8±1.6 my	K/Ar	Cooling age of Mariposite Schist
Stringer District Alt	50±1.6 my	K/Ar	Hybrid muscovite/sericite age? Ankerite/mariposite faulting?
Atolia District Minz	32.3±.8my	K/Ar	Sericite associated with Scheelite
Butte Diabase	19.5±.5my	K/Ar	Extensional intrusion and faulting
Randsburg Quartz Monzonite Alteration	18.9±.4my	K/Ar (Suppe)	Hydrothermal alteration
Yellow Aster Minz	18.3±.4my	K/Ar	Extensional fault sericite with gold
Randsburg QM Alteration	18.2±.5my	K/Ar (Kistler)	Hydrothermal alteration of biotite
Operator Divide Minz	17.6±.4my	K/Ar	Extensional fault sericite with gold
Red Head Rhyolite	17.4±.4my	K/Ar	Felsic Eruption
Long Dike Rhyolite	15.1±.4my	K/Ar	Intrusion of E-W Dikes ± alteration
Triplet Diabase	15.3±.4my	K/Ar	E-W Diabase which cross-cuts rhyolites
Kelly Minz	11.6±.3my	K/Ar	Left-lateral shear, NW-SE extension, silicification and sericite with silver
Propylite Lava Alt	7.49±.2my	K/Ar	Propylitization in andesites
Red Head Andesite	6.43±.2my	K/Ar	Uppermost Red Mountain Lavas
Subpropylite Lava	4.22±.12my	K/Ar	Young andesites ± alteration

Plate 3. Capsule chronology of the Randsburg Mining District.

different environments of formation. It is tempting to correlate the Rand Schist with Pelona and Orocopia Schists. They share similar ages, lithologies, metamorphic styles and histories, and modes of exposure in thrust windows near major transcurrent faults. If the thrust faults are correlated, the thrust surface becomes a regionally extensive sub-crustal horizontal suture underlying a minimum of 80,000 square miles of southern California and western Arizona.

The COCORP seismic team has identified a reflector as the Rand Thrust in the subsurface to the southwest of the Rand Mountains. It is terminated as a reflector by a younger, low angle fault 15 miles to the southwest, as shown on Plate 8.

The tectonic implications of the Rand Thrust are necessarily profound but highly uncertain at our current state of knowledge. The major uncertainty is the sense of shear across the thrust fault. Lineations and mullions constrain the direction of motion to NE-SW but direction of overthrusting is still uncertain. (See Page 57).

RAND SCHIST

The Rand Schist is considered to have been metamorphosed coincident with thrusting. Schist foliation is sub-concordant with the thrust surface and metamorphic grade increases upwards towards the thrust (Ehlig 1968, Graham and England, 1976). A crude Rb/Sr isochron suggests that the protolith of the Rand Schist accumulated at 160±25 my. A K/Ar age of 70.8±1.6 my. on metamorphic mariposite gives a minimum cooling age of metamorphism of the schist. The schist is now arched into an anticlinorium subparallel to the Garlock Fault. The anticlinorium is best defined by the thrust planes which dip 40-60 degrees north on the north and 10-30 degrees south on the south.

The Rand Schist is largely composed of a quartz-albite-muscovite schist. Ehlig (1968) and others believe that the protolith was greywacke. Large areas of more chloritic schist occur on the western end of the Randsburg Mining District. Small amounts of actinolite-epidote-chlorite-talc schist are presumed to have mafic igneous protoliths. The schist is said to have "oceanic" affinities.

RANDSBURG INTRUSIVE COMPLEX

The Randsburg Intrusive Complex intruded the Rand Schist along the axis of the schist anticlinorium. It is a misnomer to refer to this body as the Randsburg Quartz Monzonite. It is composed of several Quartz Monzonite intrusions and a broad succession of finer grained porphyries and felsites which comprise the complex. Silver (1984) gives a U/Pb date on the Quartz Monzonite in the complex of 73±3 my. Kistler (1978) has a hornblende cooling age of 74.2±1.9 my on Quartz Monzonite. The succeeding units are undated but they are expected to document the uplift and unroofing of the complex well into Tertiary time.

The Rand Intrusive Complex includes large and small pendants of Rand Schist and structurally anomalous Johannesburg Gneiss. Discrete portions of the Quartz Monzonite are intensely foliated. It may be that foliation was imparted to the early Quartz Monzonite during the late stages of Rand Schist dynamic metamorphism, due to the movement of the Rand Thrust. The writer's preferred hypothesis explains both the presence of large bodies of Johannesburg Gneiss and the foliated Quartz Monzonite. This hypothesis asserts that part of the Rand Thrust is exposed in the Big Dyke and Butte mine areas. It has been intruded and deformed by Randsburg Intrusive Complex but still exhibits partly mylonitized Johannesburg Gneiss sandwiched between Rand Schist and mylonitically foliated Atolia Quartz Monzonite.

The duration of intrusive activity related to the Randsburg Intrusive Complex is not constrained by radiometric ages on its younger end. Porphyritic latites(?) cut by the Jupiter Fault at the Yellow Aster Mine are interpreted to predate the 32 my E-W trending Atolia Fault episode.

The Rand Schist anticlinorium and its axial intrusive complex have acted as an elongate diapir. Such a description fits the schist occurrence in a thrust window but it also helps to understand the geometry of the subsequent mineralizing episodes. The upwelling diapiric nature of the Rand Schist has focused extensional events near its axis. Even when the event was more regional in extent, as with the detachment fault episode, the more numerous faults and greater displacement occur along the schist diapir axis. Consequently, effects seem to die out or diminish rapidly away from the axis.

GENERAL CONSIDERATIONS ON STRUCTURAL EPISODES OF ALTERATION AND MINERALIZATION

Detailed structural and macroscopic alteration mapping of the Randsburg Mining District, accompanied by carefully selected age determinations on key kinematic and lithologic structures, has succeeded in defining a precise sequence of four discretely superposed structural and mineralizing episodes between 32 and 10 my. The three kinematic structural episodes are named after the major mines or districts localized in structures of each uniquely mineralized trend. The Atolia Episode started at about 32 my and saw scheelite emplaced into structures striking about an azimuth of 80 degrees and dipping variably northward. The Yellow Aster Episode ranged from 20 to 17 my. while gold was emplaced into back-to-back extensional faults striking northwestward and dipping at low to moderate angles northeastward. The Osdick Rhyolite Episode ranged from 17 to 15 my. It saw emplaced a swarm of E-W striking, pyrite bearing rhyolite dikes around a complex volcanic edifice. During the Kelly Episode, from about 15 to less than 11 my, silver was locally emplaced into a suite of normal left-lateral en echelon faults striking northeast and dipping southeast at moderate to high angles. These are linked by tensional faults striking N-S and dipping both east and west.

The Atolia Episode attests to activity on the Garlock Fault as long ago as 32 my. The Garlock Fault has been the predominant influence on stress and strain in the Randsburg Mining District since at least that time. However, a major stress perturbation occurred at 20 my ago with the northward passage of the Mendicino Fracture Zone. A suite of radiometrically dated back to back normal faults and diabase dikes trending NNW to WNW documents NE-SW extension during this time. Glazner and Supplee (1982) correlate this episode with the "mid-Tertiary detachment fault episode" which occurred throughout southern California and western Arizona.

During and after the passage of the Mendicino Fracture Zone, the Garlock Fault reasserted its left lateral stress regime over the Randsburg Mining District. This led to a nearly 180 degree counterclockwise rotation of the stress ellipse between 20 and 10 my ago. Structural elements documenting the strain associated with the rotating stress ellipse are dated and depicted on the chart entitled "Evolution of Stress Ellipses during Mineralizing Events, Randsburg Mining District" (Plate 4).

Several of the stress ellipses depicted on this chart are dashed due to a lack of radiometric information on their absolute ages. Indeed, initiation of the Stringer District Faults is reassigned to the Atolia Episode from the Yellow Aster Episode as previously interpreted (Morehouse Status Reports, 1984).

Initiation of the Yellow Aster Episode is interpreted to have begun with NNW-trending faults because a few crosscutting relations within the Yellow Aster Episode seem to indicate that NNW-trending faults are cross cut by WNW-trending faults.

The Big Horse Fault is placed at the inception of the Kelly Episode because it shows the greatest recognizable offset and it was involved with both early Kelly Episode alteration at the end of the Osdick Rhyolite Episode and late alteration associated with the N-S tension linkages of the Kelly Episode.

Strain response symbols are placed on the hanging wall of oriented normal faults related to the various stress

Evolution of Stress Ellipses During Mineralizing Events, RMD.

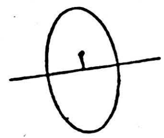
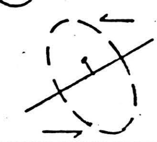
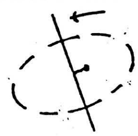
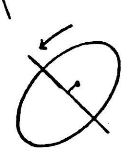
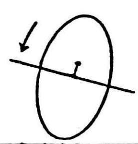
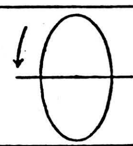
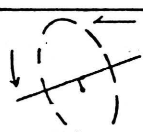
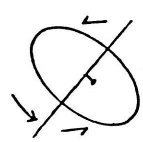
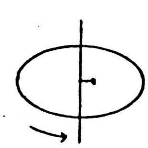
Structural Episodes	Stress Ellipse, Rotation, and Strain Response	Azimuth of Fault or Dike Set	Age (my)	Example Structures (* Dated)
ATOLIA		80	32.3±.8	* Atolia District Stringer District Yellow Aster Jupiter Faults Rand Border Faults
		60	32-20 ?	Stringer District Rand Border Faults
MENDICINO FRACTURE ZONE STRESS PERTURBATION				
YELLOW ASTER		160	20 ?	Big Dyke Faults Windy Faults Dogpatch Fault?
		135	19.5±.5	* Butte Diabase Butte Faults
		105	18.3±.4 17.6±.4	* Yellow Aster Fault Intermediate Diabase * Operator Divide Faults King Solomon Fault
			17.4±.4	* Read Head Rhyolite Bx.
OSDICK RHYOLITE		90	15.1±.4	* Long Dike Rhyolite
		70	15-11 ?	Big Horse Fault
KELLY		40	11.6±.3	* Kelly Footwall Fault
		0	<11	Kelly Tension Veins Hybrid Fault Silicap Stockwork Red Mountain Andesites?

Plate 4. Evolution of stress ellipses during mineralizing events in the Randsburg Mining District.

ellipses. Shear couples are also depicted on lateral faults where indicated by field data. It is interesting to note that the Osdick Rhyolite Episode is not accompanied by a down-drop side (although the Stringer District may have been reactivated again). The Rhyolites occupied a neutral period while the down-drop side of the ellipse switched sides to remain towards the east in spite of stress rotation. Counterclockwise rotation consistent with left-lateral shear is indicated by a single curved arrow outside the rotating ellipses.

It is important to note that each of these discrete episodes has variably affected structures from preexisting episodes. The Yellow Aster Mine, for instance, has participated directly in each of the four episodes and owes its structural receptivity in part to a long and active kinematic history. Similarly, the Atolia Episode faults in the Stringer District have been overprinted by pyritic alteration associated with the Yellow Aster and Osdick Rhyolite Episodes.

Notwithstanding evidence for reactivation, the kinematic structures in the Randsburg Mining District are considered to be fault-veins or fissure-veins which were active during their episode of mineralization. Away from reactivated areas, alteration episodes are discretely unique and mineralization is partly sheared into the fault plane suggesting contemporaneity of motion and mineralization. Field work shows that preexisting structures were only used as conduits for overprinting alteration when their orientations were subject to reactivation under a later stress field. Preexisting structures misaligned to the later stress field remained almost universally impervious to later hydrothermal solutions.

ATOLIA EPISODE MINERALIZATION

Sericite associated with scheelite mineralization in the Atolia District has been dated at 32.3±8 my with K/Ar. The Atolia Fault Zone is a high angle north dipping zone of structures of about 80 degrees azimuth, subparallel to the Garlock Fault. The simple alteration and mineralization suite on these faults includes sericite + clays with quartz and calcite as gangue to massive scheelite. Slickensides reported by Hulin (1925) in the mines are usually horizontal indicating strike-slip motion. He suggested that motion was probably left-lateral, sympathetic to the Garlock Fault.

Other high angle faults in the Randsburg Mining District have similar trends. The Sunshine and the Jersey Lily faults in Rand Schist are known to contain scheelite mineralization. These faults are considered to have been broadly coeval with the Atolia Fault Zone.

Additionally, numerous faults subparallel to the Garlock with high to moderate northward dips throughout the district and especially in the Stringer District exhibit 75% of the recorded scheelite occurrences listed in the Kern County Report (Troxel and Morton, 1962). They are considered to be normal or oblique faults also broadly coeval with scheelite mineralization in the Atolia District. The Hawk Scheelite mine on the north side of the Randsburg Mining District is part 80 degree in trend and part 50 degree in trend. Because it is a splay of the Rand Border Fault bordering the Fremont pull-apart basin it is likely that these sympathetic normal, oblique, and left-lateral faults of the Atolia Episode indicate a minimum age of initiation of transtension along the Garlock Fault and in the Randsburg Mining District. The 32.3$\pm$8 my date from the Atolia District is the only absolute control we have on this sequence of events. The suite of E-W- to NE-striking, N dipping structures correlated with Atolia Episode activity should have been diachronous through time as a transtensive regime established itself in the region. Thus, 32 my is considered to be near the beginning of the Atolia Episode which continued until about 20 my.

YELLOW ASTER EPISODE MINERALIZATION

A major perturbation in the Garlock-controlled stress regime of the Randsburg Mining District occurred between 20 and 17 my. Glazner and Supplee (1982) have documented passage of the Mendicino Fracture Zone (MFZ) under North America at this time. "The MFZ theory holds that this moving, east-west zone of stress triggered volcanism, detachment faulting, and basin formation in the southwest". K/Ar dates from dikes, volcanic rocks and the alteration of NW trending faults in the Randsburg Mining District support this theory.

COCORP seismic work offers support for this theory also. The COCORP survey has identified a low angle structure dipping southwestward away from the Rand Mountains (Plate 8, horizon B), that is interpreted to be the detachment surface into which the Yellow Aster Episode lystric faults root at depth. The detachment is about three kilometers beneath the surface of the Rand Mountains. It truncates the highly segmented Rand Thrust 15 miles to the SW. The detachment itself is rarely offset by the same faults which segment the thrust. Although the detachment now dips SW, the high angle normal faults drawn by COCORP dip eastward into the detachment as do the Yellow Aster Episode faults. Later high angle lateral faults synthetic to the San Andreas Fault cut both the thrust and the detachment.

The earliest dated expression of the Yellow Aster Episode is a prominent diabase dike, the Butte Diabase, dated at

19.5±0.5 my. It is located to the NE of the village of Randsburg. The dike is over two miles long and up to 500 feet wide in places. It trends at about 135 degrees. The Butte Diabase forms the hanging wall, in large part, for the Butte Fault Zone and dips in the plane of the fault at about 45 degrees NE, according to Cap Romp who is currently mining the Butte (personal communication, 1984). The Butte, Middle Butte, and Little Butte gold mines are located along the dike and fault.

The Operator Divide, the Windy, the Big Dyke, the Dogpatch, the Buckboard, and other mineralized fault zones also have parallel trending diabases involved with or near the fault zones. These diabases are never significantly offset by the NW faults although they are brecciated and mineralized. They are considered to be generally coeval with Yellow Aster Episode faulting and may be important local contributors to ore grade gold values.

The Yellow Aster Episode faults are widespread throughout the Randsburg Mining District. They include faults with strikes varying from 180-105 degrees dipping E to NE at moderate low angles. The faults are composed of a rusty gray gouge with minor development of sericite and clays in granular quartz. Gold has been produced or detected in all of these faults. Pyrite, stibnite, and arsenopyrite are present in small amounts beneath the zone of oxidation (Hulin, 1925).

Due to variations in trends, many of these faults illustrate an anastomosing map pattern, particularly the composite Big Dyke, Butte, King Solomon, Windy, Snowbird, and Operator Divide Fault System. The anastomosing pattern may result from the crosscutting of structural elements through time as the stress regime rotated counterclockwise. This interpretation is followed on the Evolution-of-Stress-Ellipses chart.

The more northerly trending Big Dyke faults and their companion diabase may be the earliest event in the Yellow Aster Episode just because they fit best on the early end of the counterclockwise stress rotation diagram (despite the circular reasoning that they fit on the diagram because they fit on the diagram). Many steep faults west of the Yellow Aster, trending about 160 degrees, appear to be older faults with limited displacement and uncertain timing.

In addition to the first 135-degree Butte Diabase, and many subparallel diabases with or without companion fault zones, there are only two other long diabase dikes that have different trends. They testify to a well defined rotation of the stress regime during their emplacements. The Intermediate Diabase originates at the same point as the

Butte Diabase where they are truncated by the Big Horse Fault. It extends discontinuously for a mile south of Randsburg at 105 degrees. It is intermediate in space and trend between the older Butte Diabase and the younger Triplet diabase so it may be intermediate in age as well.

The Triplet Diabase extends at 90 degrees for three miles through the center of the district, south of the other two diabases. It is offset twice by later faults but its continuity can be confidently established by its relationship to distinctive clusters of rhyolite dikes in the Central Rhyolite Swarm. The diabase cross cuts one rhyolite dike at a very low angle. A sister rhyolite in the swarm has been dated at 15.1±4 my. This age may be slightly affected by alteration. An age of 17.4±0.4 my on fresh extrusive rhyolite from the Red Head area confirms that these rhyolites postdate the first Butte Diabase and predate the last Triplet Diabase. One diabase dike at 165 degrees in the Big Dyke area is cut by the Big Dyke Rhyolite. The diabases serve to document a counterclockwise rotation of stress from 20 to 15 my. They overlap the Yellow Aster and Osdick Rhyolite Episodes.

THE OSDICK RHYOLITE EPISODE

During the emplacements of the various diabases, several swarms of rhyolite dikes and a central rhyolitic extrusive event occurred. These rhyolitic events occur mostly within a swath five miles long striking between 70 and 80 degrees, and are herein named the Osdick Rhyolites. To the east they include fresh intrusives and extrusive flows and breccias, dated at 17.4±0.4 my on feldspar, occurring SW of the Red Head of Red Mountain.

In the center, the Osdick Rhyolitic Complex includes the hills of the Breccia Cap on the east and the Silicap on the west. The Breccia Cap is composed of small plugs, an extrusive breccia, and fine tuffs intruding and overlying the Randsburg Intrusive Complex and grusy sediments. The Silicap is comprised of thoroughly silicified sediments and hydrothermal(?) breccias overlying Randsburg Intrusive Complex and grusy sediments which are laced with a large stockwork of striated quartz veins. Both hills are intensely clay-altered, making units difficult to distinguish. Montmorillonite, kaolinite, and sericite are all abundant in thin section.

The rhyolite dikes form three major swarms. The Joburg Swarm trends NNW out of Johannesburg. It includes two main dikes which splay into left-stepping en echelon dikes northward. This trend is anomalous to stress directions dictated by presumably coeval E-W dikes. This trend is attributed to radial stresses associated with the volcanic complex. Another single dike radiating SSW away from the volcanic complex in the Dogpatch area is similarly controlled. The Operator Divide Fault Zone is intimately associated with the Joburg Swarm, and would have been reactivated and mineralized by intrusion of the swarm.

The dikes of the Randsburg Swarm trend at 90 degrees and occur just north of Randsburg in the right-stepping en echelon pattern. The Central Swarm is almost three miles long on an E-W trend through the center of the district between the Intermediate and Triplet Diabases. One partially altered dike (the Long Dike, cluster C) has been dated at 15.1±0.4 my.

The Central Swarm is divisible into four individual dikes or clusters of dikes which are offset by crosscutting faults of the Kelly Episode. The persistent Triplet Diabase (Cluster D) is post-rhyolite and pre-faults and serves to earmark these clusters and define their apparent offsets.

At the western end of the Central Swarm on the Long Dike (Cluster C) is a thick radial splay of dikes which indicates something of an intrusive center. Many of the rhyolite dikes especially on the west are impregnated with limonite after pyrite cubes.

KELLY EPISODE MINERALIZATION

The rotation of the stress ellipse is continued after 15 my as documented by faults of the Kelly Episode. The Kelly Episode is characterized by an evolving en echelon normal left-lateral shear system which developed in several stages. The geometry of the overall system forms an E-W band of NE to N-S striking, SE to E dipping brecciated, silicified, sericitized, and clay-altered fault and fissure veins. The band is three (or four?) miles long and one and one half miles wide. This band is depicted and interpreted on the "Line Drawing of Kelly Episode Silicified Fault and Fissure Veins" (Plate 5).

It is tempting from a theoretical viewpoint to consider these en echelon faults as composed of three ordered elements. The first order element is the shear couple, an E-W band of left lateral shear defined by the overall geometry. The second order elements are the synthetic normal left-lateral en echelon fault veins which strike NE and dip SE. The third order elements are the N-S striking E and some W dipping normal fault and fissure veins.

To a first approximation such an image is informative and useful. However, it is important to recognize that both the second and third order structural elements demonstrate both unmoved fissure veins and distinctly offset oblique fault

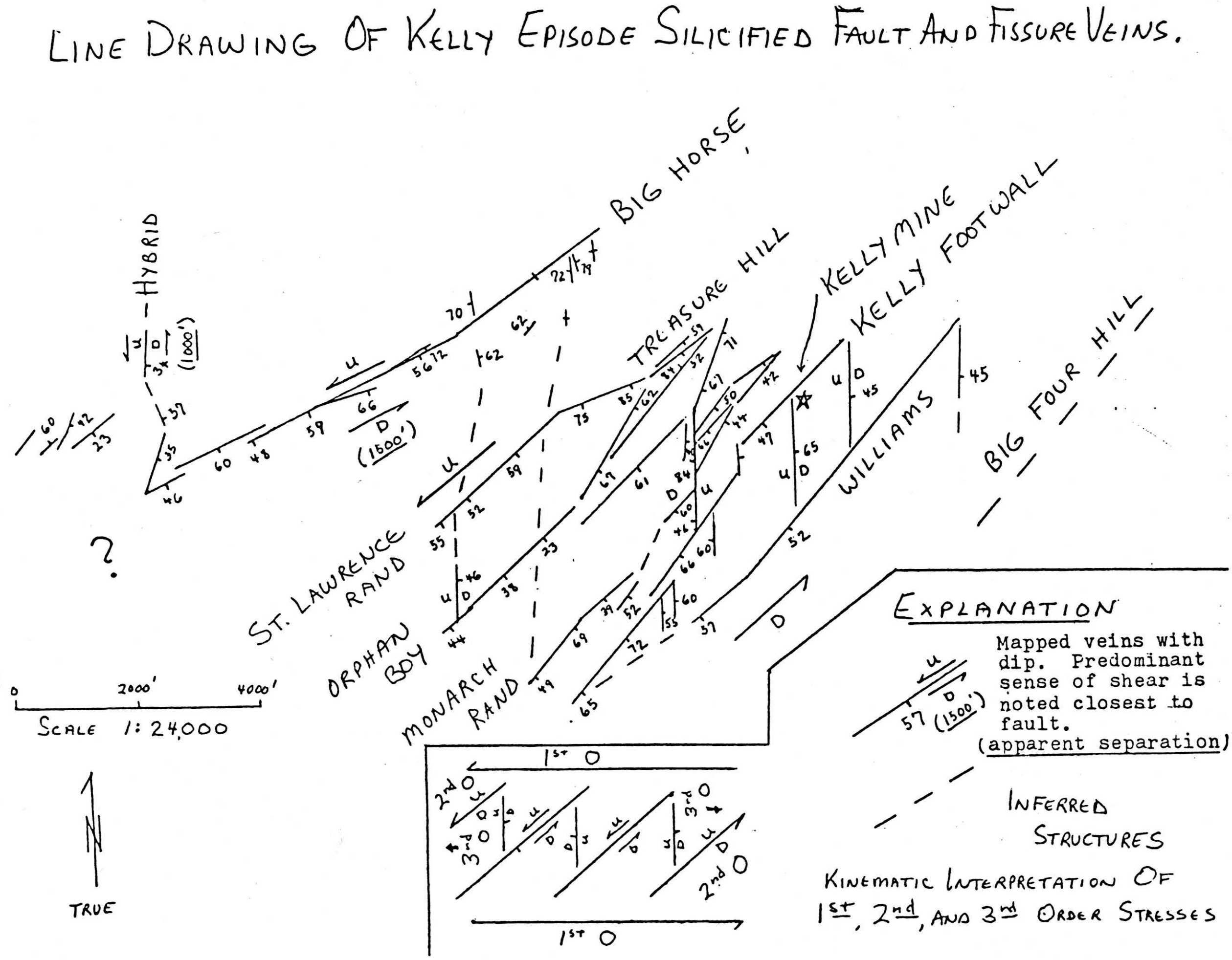


Plate 5. A line drawing of Kelly Episode Silicified Fault and fissure veins.

veins. Movement on all elements is in large part contemporaneous. Indeed the roles of these ordered elements would have been upgraded through time due to rotation of the stress ellipse.

The Big Horse Fault is probably the earliest manifestation of the Kelly Episode. It demonstrates an apparent normal left-lateral separation of 1500 feet across the Triplet Diabase. It trends at 70-50 degrees and changes its character along strike. To the SW at 70 degrees in Rand Schist it is a topographically positive silicified fault plane much like the well known Kelly Footwall. To the NE at 50 degrees in Randsburg Intrusive Complex, the continuous silica vein vanishes and the fault zone is characterized by strongly clay-altered rocks with steeply discordant discontinuous quartz veins.

The elaborate Kelly Fault System was subsequently initiated, but coincident with most of the activity along the Big Horse Fault. The Kelly System exhibits perfectly consistent slickensides etched into silicified fault planes on all strands of the anastomosing system. The slickensides indicate normal left-lateral motion across the system. Unfortunately, no unique markers are recognized to help quantify actual slip across the system. A K/Ar date on sericite from the Kelly Footwall Vein gives a date of 11.6±0.3 my.

The NE striking, SE dipping veins are second order elements of the Kelly Episode. These elements include fault veins with apparent slip of up to 1,500 feet and subparallel fissure veins with little or no offset. Fourteen subparallel veins are recognized as elements of this trend, and others are postulated. Aside from the Big Horse, they strike at 50-25 degrees. The longest veins are nearly two miles long.

One postulated fault lies just east of the Big Four Shaft on the east end of the Kelly System. The area is covered with andesite regolith and the fault is suspected on geomorphic, lineament, and theoretical grounds. If it exists and is related to the Kelly Episode it would extend the band of Kelly Episode en echelon faults to over four miles long.

Activity on Kelly Episode faults was recurrent. In several places, early formed high-temperature (glassy) silica is brecciated and cemented by lower temperature (ceramic) silica. With the exception of the Silicap, the breccias in the Kelly Episode faults are considered to be tectonic fault breccias. The Silicap itself will be discussed at some length as an exploration target.

The N-S-striking third order elements dip mostly eastward and demonstrate oblique normal and left-lateral motion.

Several strands dip westward though, and some strands indicate local right-lateral components of motion. These facts suggest an overall extensional, horst and graben type kinematics with an oblique left-lateral skew. Eight of these elements are recognized on the surface and in the Kelly mine underground workings. Many others are expected to exist. They serve to link NE-striking elements and are as much as 1,000 feet long or more.

The third order N-S structural trend might appear to have been merely a local response to en echelon shear and consequently undeserving of a place on the district-wide chart of stress ellipse rotation. However, similar trends in major andesite dikes at a similar time in the Lava Mountains suggests that this trend represents an independent event. This orientation of the stress ellipse served to obliquely reactivate the Yellow Aster Episode faults. These faults, therefore, demonstrate some of the youngest cross cutting relations in the district, especially at the Yellow Aster Mine (Taylor, personal communication, 1984).

OTHER STRUCTURAL EVENTS

Several structural events of potential economic importance have been excluded from this discussion because their timing remains poorly understood. Ankerite-mariposite veins of irregular trend and distribution occur widely on the western end of the Randsburg Mining District. Several efforts have failed to yield mineral separates of mariposite for radiometric dating. A variety of styles of faulting and veining characterize these veins and suggests that they may range widely in age. For instance, an ankerite-mariposite vein subparallel to the Buckboard-Gorman fault zone has been reactivated during the Yellow Aster Episode. Yet the Sidney Peak Fault, a N-S-striking, W-dipping major fault west of the Randsburg Mining District is an important young feature which cuts all structures along its 2 (to 4?) mile length. The Sidney Peak Fault exhibits ankerite-mariposite vein material and silicification which records normal right-lateral slickensides (Postlethwaite, 1983). Mariposite and similar exotic micas have been intimately associated with gold in other districts such as the Mother Lode and many Canadian deposits.

The Stringer District has a complex history and has not been confidently dated. Further effort to do so must await another trip to the field for carefully chosen samples. The Stringer District has been logically incorporated with the Atolia Event into an evolutionary structural scenario for the Randsburg Mining District but substantiating radiometric ages would be comforting. The Stringer District faults were weakly overprinted and reactivated as tear faults and oblique faults during the Yellow Aster Episode. They have been further activated and mineralized during emplacement of the parallel Osdick Rhyolite Episode dikes just to the north.

The Mud Wall Fault exposed in the Kelly Mine is a particularly important feature that is not yet understood. Its geometry, extent, age, and economic significance are all debatable, but potentially resolvable topics, which might serve as particularly profitable catalysts for discussion on any joint field trips to the district. Discussion could center around a beautiful exposure of Red Head Rhyolite Breccia overlying profoundly disturbed Bedrock Springs arkoses exposed near the Red Head of Red Mountain, almost on strike with the Kelly Footwall Vein. This contact may or may not represent the Mud Wall Fault.

BEDROCK SPRINGS SEDIMENTS

Nonmarine sediments mapped as Bedrock Springs Formation by Dibblee (1957) occur in the area of the Kelly Mine and the Osdick Rhyolitic Complex and extend eastward through the Lava Mountains. The Bedrock Springs Formation has been described as a coherent basinal deposit, dated with mammalian fossils as middle Pliocene by Smith (1964). His fossil collections were taken from areas near the type section in the eastern Lava Mountains. Within the core study area of the Randsburg Mining District, however, the local sedimentary accumulations have been shown to date back at least to the Osdick Rhyolite Episode at 17.4±0.4 my. It seems probable that many of the classic Bedrock Springs Formation sections are sedimentary accumulations in local basins of arkosic deposition produced during tectonic jostling of the Rand and Lava Mountain areas. Local ages may then vary significantly from place to place.

The actual age of the Bedrock Springs Formation in the Randsburg Mining District and Red Mountain areas is of great importance. Arkosic sediments are cut by the Mud Wall Fault in Red Mountain townsite and perhaps near the Red Head of Red Mountain. If these sediments were of mid-Pliocene age as Smith supposed, then the Mud Wall would clearly post-date Kelly Episode activity. If the sediments are older than the Osdick Rhyolite Episode, however, then the Mud Wall could be the pre-mineral fault that Hulin (1925) envisioned it to be. It is unlikely, but possible, that dateable fossils might be obtained from a limestone marker bed in the Bedrock Springs Formation west of Red Mountain.

The major lithology of the Bedrock Springs Formation is poorly sorted, graded, and often cross-bedded arkosic sandstone. Conglomerate, limestones, mudstones, and tuffs also occur. The Bedrock Springs Formation arkoses occur in several colors in different areas. Commonly it is a bright maroon red in color especially west of Red Mountain, thought to be due to pyrite oxidation to hematite. Above the Mud Wall Fault in the Red Mountain townsite, and south of the Mountain Wells area east of Red Mountain, silicified Bedrock Springs Formation is a rusty golden color attributed to pyrite oxidation to limonite and jarosite. Chip boards from drill holes in the Bedrock Springs Formation west of Red Mountain exhibit abundant fine pyrite cubes beneath the zone of oxidation (Briscoe, personal communication, 1983). This pyrite must have been introduced by hydrothermal activity and widely disseminated into the porous sediments.

ALMOND MOUNTAIN VOLCANICS

The Almond Mountain Volcanics occur from Red Mountain northeastward throughout the Lava Mountains. They intrude through and bury the Bedrock Springs Formation in large part. The intrusive style on the east flank of Red Mountain is remarkably dike-like, as depicted on maps and cross sections by Tom Dibblee (1967). Dike-form intrusions trend about 10 degrees east of Red Mountain, and swing to as much as 30 degrees in the propylite zone. These are andesites which underwent a major propylitization event, dated at 7.5 my, near the Steamwell. The older lavas of Red Mountain and the Lava Mountains probably extruded from these dikes as fissure eruptions prior to propylitization.

The age of these andesites is not tightly controlled on their older end. The dike-form intrusions are subparallel to N-S structures in the Kelly Episode which post date 11.6 my, so they may be broadly coeval. Indeed, the andesite dikes may have been similarly controlled by a lateral shear couple on faults NW and SE of Red Mountain.

Andesite in the Lava Mountains (including Red Mountain) occurs as intrusives and extrusive flows, agglomerates, breccias, and pyroclastics. All andesite compositions are remarkably similar according to Smith (1964).

A large (6 square miles) NE-trending ellipse NW of the Steamwell is thoroughly altered to a propylite reminiscent of the type Comstock Lode propylite. A date of 7.49±0.2 my has been obtained for albitization of feldspars during propylitization. Surrounding the propylite are areas of sub-propylite as reported by Hulin (1925).

LAVA MOUNTAINS STRUCTURAL GEOLOGY

Structural activity younger than the Kelly Episode in the Randsburg Mining District is difficult to demonstrate. To the east in the Lava Mountains, however, tectonic breccias and veins in young andesites indicate that tectonism has continued. Structurally controlled alteration and mineralization may continue to this day beneath high geothermal gradients around the Steamwell in the Randsburg KGRA (Known Geothermal Resource Area).

The structural geology of the Lava Mountains is less well expressed than that in the Randsburg Mining District. Part of the reason is simply that the rocks are much younger, probably 10 my or less, and thus they have not enjoyed as much deformation. Secondly, the geology and chemistry of the andesites and sediments respond quite differently to deformation and alteration than do the crystalline rocks of the Rand Mountains.

The Lava Mountains appear to be structurally down dropped an unknown amount with respect to the Rand Mountains. The basement for the Lava Mountains is expected to comprise crystalline rocks similar or identical to those in the Rand. Complex fault networks like those of the Kelly Episode may underlie "mud basin" development in the overlying volcanics and sediments.

The structure NW of Red Mountain is called the Red Neck-Steamwell zone. It is an 'air photo lineament' that exhibits hydrothermally altered tectonic breccia zones where it is best exposed. Carbonate, silica, and mixed silica and carbonate veins occur sporadically along sharp fault planes throughout the area. Yet, large areas are characterized by broad zones of tectonic brecciation and variably pervasive alteration without discrete planar fault features. This phenomenon culminates in local, distinctively colored, recessive weathering, clay alteration zones referred to as "mud basins". These are easily identified on color air photos. Investigations within the mud basins reveal veins and sheared joints in complex patterns. Predominant structural trends are NE, NW, and N-S. Low angle structures are also important. SE of Red Mountain is a less investigated area which demonstrates many of the same features.

Mapping by Smith (1964) shows that en echelon left-lateral shear like that of the Kelly Episode has continued in the young volcanics of the Lava Mountains. Several areas of silica sinter are exposed along the Red Neck-Steamwell Zone. Sinter is especially well developed in faults bordering the Golden Valley Graben on the north. One silica sinter apron at Turtle Mountain is 15-20 feet thick and acres in extent. Brecciated veins with sulfides occur in the huge mud basin beneath the silica apron.

Most of the well-developed mud basins have silica deposits at their upper extremities. These silica deposits may have been local caps to hydrogeothermal "pressure cooker" systems which altered the andesites into easily eroded "mud basins". Smith has described the alteration as being "an intimate mixture of alunite and opal... containing a large percentage of the zeolite clinoptilolite".

The Squaw Springs Fault east of Red Mountain is thought to be among the latest structural features to impose itself upon the area. The fault is recognized as an air photo lineament and is poorly represented in outcrop by irregular quartz veins that cut late andesite dikes north of Squaw Springs Well. The fault is considered to be an extension of the Harper Fault. It is expected to exhibit right-lateral motion. The Sydney Peak Fault mentioned previously, to the west of the Randsburg Mining District, may be an extension of the parallel Lenwood Fault. The Harper, the Lenwood, and the Blackwater Faults are major faults which cross the Mojave Block and impinge on the Rand and Lava Mountains. It is important to emphasize that this suite of much discussed regional faults has not been identified within the Randsburg Mining District itself. They are identifiable on the COCORP seismic data (Plate 8) as those faults which cut both the Rand Thrust and the detachment fault (Horizons A & B respectively).

EXPLORATION SIGNIFICANCE OF SUPERPOSED STRUCTURAL EPISODES

The Randsburg Mining District has enjoyed a turbulent tectonic history. The late structural and mineralization history since the upper Oligocene has been outlined remarkably well by this thesis work. Major deficiencies exist in defining the distinctive chemistry, mineralogy, and metallogeny of alteration and mineralization associated with each major structural episode, but the macroscopic patterns are clear. Examination of the patterns reveals varied crosscutting relations that hold the potential for multiple mineralizing events in well-prepared ground at structural intersections. Extrapolations of visible patterns under the restraining influence of kinematic and geometric necessity can guide expectations in areas covered by alluvium or young volcanics. Geochemistry and geophysics should be applied to evaluate these expectations prior to more expensive physical explorations.

The episodic fault systems are superposed across faults of different trends from earlier strain episodes. The superimposition of younger faulting across older faulting increases the amount of broken ground available to provide depositional sites for ore and gangue minerals. The fault intersection is the more likely candidate for reactivation and opening to solutions whenever stress regimes favor one or the other of its component parts to accommodate strain. The passage of hydrothermal solutions offers the opportunity for new mineral deposition and old mineral re-mobilization. Re-mobilization can serve to concentrate ore minerals or to dilute a preexisting deposit. At shallow levels in the subsurface, concentration is favored over dilution.

RAND THRUST AND CROSS-FAULTS

The Rand Thrust dips to the south on the south border of the Randsburg Mining District core area. It is a major structural feature with important exploration potential. It is a unique feature in several respects. It represents a chemical, lithological, and structural contrast lying at a low angle in the shallow subsurface. It juxtaposes two differing rock types, the more mafic Rand Schist and the sialic Atolia Quartz Monzonite, across a mylonitic contact. In addition, this mylonitic contact contains a persistent but variable thickness of carbonate mylonite containing gneissic fragments. The carbonate and gneiss are presumed to be derived from the Paleozoic Johannesburg Gneiss. The mylonite serves as a clear seismic reflector that has been traced in the subsurface for 15 miles SW of the Rand Mountains by the COCORP team (Cheadle et al., 1984, Plate 8).

This mylonite reflector holds the potential for service as one or all of the three following types of depositional settings for ascending mineral solutions. 1) It might form an impervious structural cap beneath which hydrothermal solutions could be ponded or along which they could travel. 2) It might form a brecciated host for ore deposition where affected by younger high or low angle faulting. 3) It might form a zone of chemical contrast which promotes precipitation of ore materials, a particular possibility for the carbonate mylonite which would submit to massive replacement or skarnification in the process.

One particular target which combines the potential virtues of depositional settings (2) and (3) is the intersection of the Atolia Fault Zone with the Rand Thrust. A small, high grade scheelite skarn or replacement body is predicted to exist at 1,400 to 5,000 feet depth where they intersect. A north-south cross-section depicting the geometry of the intersection of the Rand Thrust with the Atolia Fault Zone and the Rand Contact Fault is included (Plate 6). The actual depth of intersection is expected to approach the shallower figure due to shallowing of the thrust fault dip and uplift of the southern end of the thrust with respect to the northern end by younger cross-faulting. The Union Mine has been worked to depths beyond 1,100 feet. Still, the projected intersection is at depths which are probably economically unattractive to explore.

An economical and educational alternative would be to explore the Rand Contact - Rand Thrust intersection which occurs very near surface. The Rand Contact Fault is a scheelite bearing (Hulin, 1925, p. 72) member of the Atolia

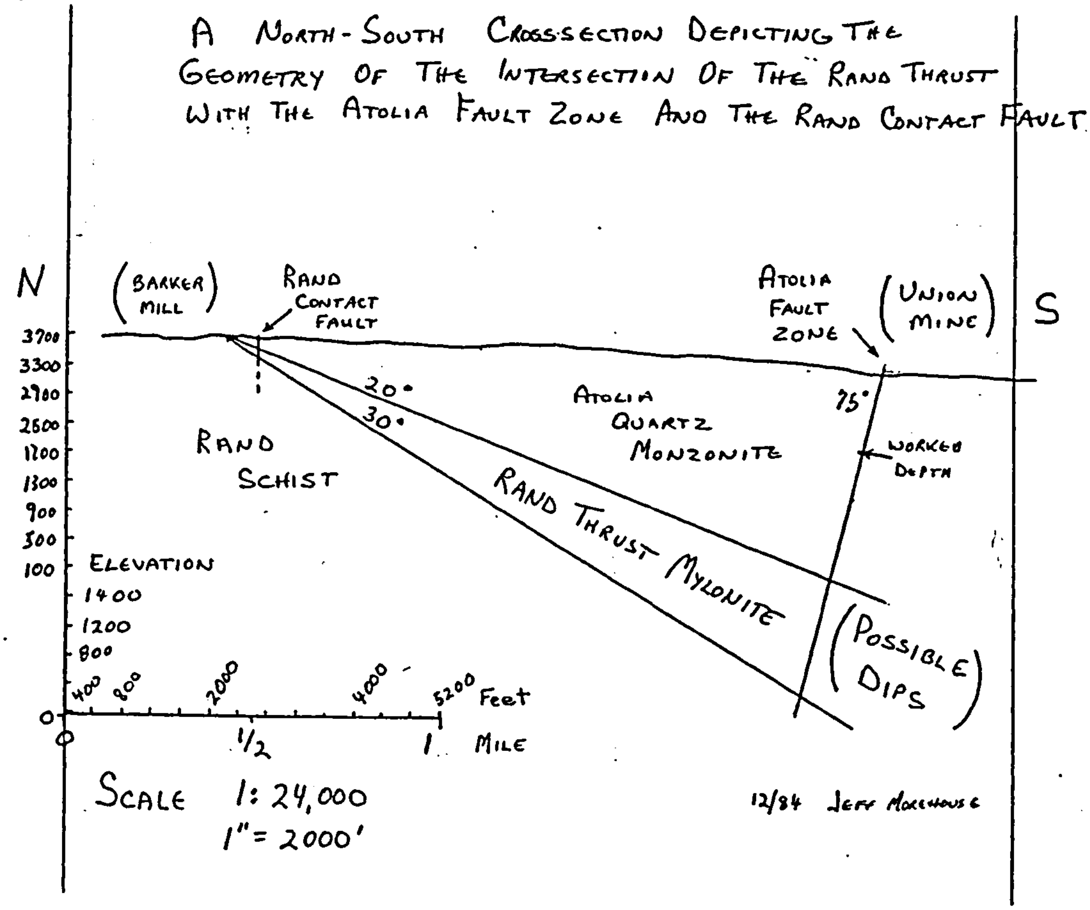


Plate 6. A north-south cross section depicting the geometry of the Rand Thrust with the Atolia Fault Zone and the Rand Contact Fault.

Fault Episode. The Rand Contact - Rand Thrust intersection is a relatively accessible laboratory for the study of cross-fault contributions to mineralization along the Rand Thrust. In addition to being an ore target itself, it could contribute much to an evaluation of the importance of this type of target in and around the Randsburg Mining District. There are several shafts along the length of the Rand Contact Fault which may, but probably do not, reach the Rand Thrust. The original Rand Contact claims probably lie to the north of the thrust outcrop where an abortive attempt was made to sink and drift to the Rand Schist - Quartz Monzonite contact. The contact was misinterpreted to be intrusive and steep (Hulin, 1925, p. 140).

Also, the Hawk Scheelite Mine northwest of the Randsburg Mining District is localized where the Rand Border Fault cuts mylonites of the Rand Thrust. Ore has been described as occurring in "tactite layers... and quartz veins in quartzite, limestone, gneiss, and schist" (Troxel and Morton, 1962). Indeed, the marbles and gneiss of the Johannesburg Gneiss above the north limb of the Rand Thrust offer further unmapped potential.

THE ATOLIA EPISODE AND CROSS-FAULTS

The Atolia Episode Faults have been interpreted to occur from the Atolia District on the south to the Rand Border

Fault on the north. They occur sporadically within the Randsburg Mining District and are especially well developed within the Stringer District. Most of the E-W- to NE-striking, N-dipping faults are considered to be a part of this episode. They almost universally carry scheelite values indicating a remarkably broad and rich mineralizing event.

Atolia Episode vs. Yellow Aster Episode

A strand of the Gorman-Big Gold-Buckboard fault zone is found to curve into and reactivate Atolia Episode faults north of the Buckboard Mine along the Holly Rand Fault. Slickensides trend 47 degrees E and plunge 28 degrees, indicating NE transport of the hanging wall. The fault plane at this point strikes 95 degrees and dips 36 degrees north. Although uncharacteristic for "tear faults", which are usually high angle faults, the reactivated Stringer District faults commonly dip moderately northward. Other Yellow Aster Episode faults like the New Deal, Yellow Aster, and Big Dike faults do not seem to cross the Stringer District so they may die out into tear faults also.

Still other Yellow Aster Episode faults such as the Buckboard, Orphan Girl, Gold Coin, and KCN distinctly cross the Stringer District. Cross-cutting relations are contradictory and mutual due to multiple reactivation of the Stringer District. Stringer District Atolia Episode faults were reactivated again during the paralleled emplacement of the Osdick Rhyolite Dikes.

Atolia Episode vs. Kelly Episode

Silicified faults of the Kelly Episode cut Stringer District faults at the Orphan Girl, Baltic, and the Jersey Lily Mines. The Kelly veins at these locations are very poorly explored and often specifically ignored, apparently due to the tremendous difficulty of mining by hand in the silicified veins. Frank "Pop" Royer, who owned the Kelly Mine for many years, is quoted by Richard Seaman and George Newman (personal communication, 1983, 1984) as pointing out that Kelly ore was anomalous to that of other veins in the district by being often in the hardest rock as well as in the softest. Drilling of these promising veins today should not present the same problems that confronted early prospectors.

The Hard Cash E-W striking, N-dipping fault is cut by two strands of the Big Horse Fault. The apparent lack of offset is puzzling.

Stringer District Atolia Episode and Kelly Episode faults bear a surprising geometric relationship to one another. Part of the Gunderson and the Martha fault zones of the Stringer District are nearly on strike with, but oppositely dipping to, the Big Horse and Treasure Hill fault zones of the Kelly Episode, respectively. These faults are easily but incorrectly correlated as continuous lineaments on air photos. No significant reactivation of the Atolia Episode Faults by the oppositely dipping Kelly Episode has been revealed in the field, although some might actually be expected.

Atolia Episode Extrapolations

The Atolia Fault Zone has been explored extensively on strike into alluvial covered areas by trenches and pits. The Gardner Vein was most recently discovered on the west in 1956. Further exploration could best be accomplished with geochemistry and geophysics.

The widespread and sporadic occurrence of Atolia Episode faults in the Randsburg Mining District suggests that "there may be more where these came from". In areas where these faults have not been reactivated, their visible expression by alteration, as well as their mineral potential, will be subdued.

Faults in the Stringer District may once have extended into the area of the Kelly System and been obscured by intense Kelly Episode Alteration. The Jersey Lily, for instance, produced significant scheelite (Seaman 1984, Hulin, 1925). The Kelly Mine tails contain visible scheelite (Briscoe, personal communication, 1984). Workers in the Kelly System should keep this in mind.

The Gunderson Fault on air photos has an apparent altered extension to the southwest on strike with an undocumented fault mapped by Postlethwaite (1983). During a brief visit to this intervening area, however, very few structures consistent with the geometry of the Gunderson were encountered. This is an area of abundantly disturbed metamorphic foliation containing a large percentage of serpentinites, sheared talc equivalents, and ankerite-mariposite veins reminiscent of the Mother Lode. Faulting in this area is probably old and unconstrained.

YELLOW ASTER EPISODE AND CROSS-FAULTS

Faults of the Yellow Aster episode occur back-to-back throughout the Randsburg Mining District. They are found to weakly reactivate and overprint Stringer District Atolia Episode faults with gold mineralization. In the Yellow Aster Mine, the Jupiter Fault of the Atolia Episode served as a pre-mineral hanging wall for the major mineralizing event associated with the Footwall and Yellow Aster Faults as described by Hulin (1925, p.89). The Yellow Aster Mine is cut by later faults of the Kelly Episode also as described below.

Yellow Aster Episode vs. Kelly Episode

Intersections of Yellow Aster and Kelly Episode structures are of great potential importance for undiscovered ore bodies. Both the Yellow Aster and Kelly Mines occur at intersections of these two elements in ways that have not been documented prior to this thesis work.

Yellow Aster Mine

The Yellow Aster Hanging Wall Fault appears to be intimately involved with a subtle, variably silicified cross-cutting strand of the Kelly Episode named the Hybrid Fault. The Hybrid trends irregularly northward, dipping to the east from its junction with the Big Horse Fault. On its southern end, the Hybrid is well defined as a silicified fault plane. This vein can be traced on the surface for about 1,000 feet. It is seen to cut a small fault of the Yellow Aster Episode and to offset the Triplet Dikes of Cluster D. North of the silicified portion of the vein, the fault is subtle but recognized by brecciation and drag folding of rhyolite dikes in Clusters B and C. An adit on the south-facing hillside displays the unsilicified Hybrid Fault with a complete splay of slickensides in the southern quadrant cutting the Yellow Aster Fault. Further along, on the north-facing side of the hill, a prominent silicified outcrop extends the Hybrid Fault into strongly broken ground beneath the Footwall, on strike with the Hanging Wall Fault. A subsidiary open pit beneath the Footwall Fault uses the unsilicified Hybrid as its footwall.

The Yellow Aster glory hole and underground workings were not accessible to me when this work was performed, so I have no more information on the Hybrid Fault's relationship to the Hanging Wall Fault. Hulin (1925), Robb Taylor, and Terry Brown (personal communication, 1984) say that the official Yellow Aster Hanging Wall trends at about 140 degrees and dips about 45 degrees NE, as befits a proper Yellow Aster Episode Fault. My expectation is that an investigation of the Hybrid Fault will reveal substantial post-mineralization offset of the pre-existing faulted ore bodies. Directed exploration in the Hanging Wall of the Hybrid Fault could reveal the rest of the Yellow Aster bonanza ore bodies beneath the pristine quartz monzonite hill east of the glory hole.

The Hybrid Fault exhibits apparent left-lateral offset and drag folds of several dike clusters in the Central Swarm of the Osdick Rhyolites. Separation on these dikes is between 500 and 1,000 feet. Slickensides on the Hybrid Fault, however, plunge to the southeast, indicating either right lateral slip or reverse motion, neither of which appears tenable. The Triplet diabase is laterally separated 1,000 feet, but this figure may be enlarged due to dip on the dike. The character of the Triplet diabase changes dramatically across the Hybrid Fault. It is wider and contains larger phenocrysts on the west than on the east. A deeper level of the dike is exposed to the west, suggesting that substantial vertical movement has occurred on the Hybrid Fault as well.

Clearly, the Hybrid Fault requires more study. At this time, my subjective estimate for maximum slip on the Hybrid is 1,000 to 1,500 feet of left-lateral normal motion. Motion on this fault is probably unevenly distributed. I envision enhanced slip near the center dying out towards the ends, with the proviso that the northern end is undefined. Plate 7 illustrates this concept of motion in the plane of the fault with respect to the Triplet Diabase.

Several small silica-deficient Kelly Episode fissure veins with open space filling quartz needles, southwest of the Yellow Aster glory hole, trend directly toward the glory hole. They are not traced into the area of the pit, but they raise the possibility that mineralization in the Yellow Aster Mine was enhanced and concentrated by Kelly Episode activity.

Kelly Mine

At the Kelly Mine, the Yellow Aster Episode Juanita Fault is found to trend directly toward the glory hole from the NW. It strikes at 135 degrees and dips 40 degrees NE. Its

HYPOTHETICAL INCLINED CROSS-SECTION OF THE HYBRID FAULT, DRAWN IN THE PLANE OF THE FAULT, ILLUSTRATING THE VARIABLE MAGNITUDE OF SLIP ALONG THE FAULT.

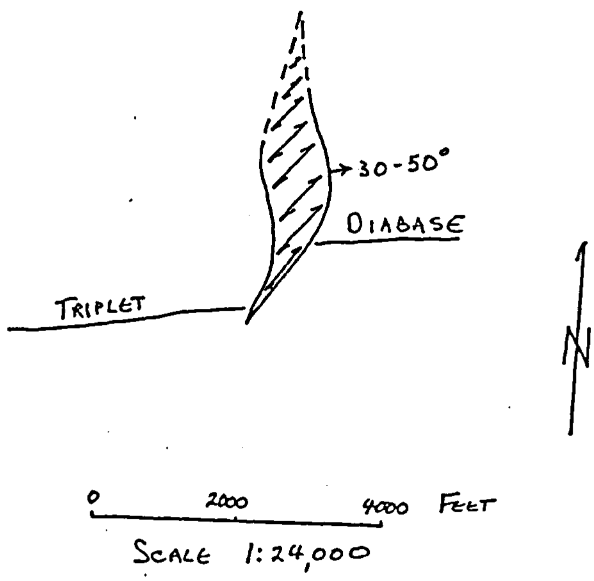


Plate 7. Hypothetical inclined cross section of the Hybrid Fault, drawn in the plane of the fault, illustrating the variable magnitude of slip along the fault.

location may be fortuitous due to slip on the Kelly Footwall, but significant slip on individual strands of the Kelly System has not been demonstrated. Gold recovered from the Kelly Mine has increased in relation to silver with depth, an apparent inversion of normal zoning patterns. The gold may well be due to earlier Yellow Aster Episode mineralization on the Juanita (and other?) faults.

Previous reports (Hulin, 1925, etc.) have emphasized that Kelly ore is localized at intersections of NE with N-S elements of Kelly Episode faults. With the Juanita Fault in the picture, the Kelly glory hole is found to lie at the intersection of a NW element with an earlier structural history as well.

Seaman Property

The Seaman property on the SW end of the Kelly Footwall, the area of the Vienna and Jersey Lily claims, boasts of all of these elements and more. Two or three NE trending veins cross the property. At least two N-S veins have been exposed or explored. The Dogpatch and Blackhawk Yellow Aster Episode faults trend into the property from the NW and SE respectively. Additionally, the Jersey Lily Fault of the Atolia Episode crosses the property in an E-W direction dipping steeply to moderately north. The only occurrence of a true gossan that I have discovered in the Randsburg Mining

District occurs near the intersection of a NE with a N-S vein. It is an oxidized leached breccia that would have contained 10-20 percent sulfides. Several shafts, now variably accessible, have been sunk on the property, but no systematic sampling or mapping of these revealing shafts has been conducted. I consider the potential for ore at this four-way intersection of structural elements to be very high.

The Dogpatch

Many other intersections of Yellow Aster and Kelly Episode faults exist or can be predicted. The Dogpatch Fault just mentioned is cut by five strands of the Kelly Episode, apparently without significant offset. These strands are not as well defined in the Dogpatch areas as they are to the east because the already shattered rocks of the Dogpatch area fractured in a less discrete and brittle fashion than the less-disturbed rocks to the east. The Dogpatch Fault must also intersect Atolia Episode Stringer District faults such as the Baltic Fault. The area is also broadly affected by N-S third order elements of the Kelly Episode as discussed in a later section on the Silicap. Other Yellow Aster Episode faults are cut by veins of the Kelly Episode in the Dogpatch area. They include the Orphan Girl, the poorly expressed Gold Coin, and the KCN.

The Dogpatch area, as it is locally known, is named for the numerous prospect pits dug into the pervasively tectonized area, as if a dog were digging for bones. The area is a topographic low and oxidized to a rich red color by hematite and limonite after pyrite, plus arsenopyrite and stibnite. Apparently, gold and scheelite values are ubiquitous, but not rich enough to mine as high grade along veins. The lack of high-grade mineralization is probably due to the thorough shattering of the area, which allowed mineralizing fluids to disseminate out and saturate the whole area. The Dogpatch area is the best candidate in the Randsburg Mining District for a bulk tonnage disseminated mining operation.

Other Faults

To the north, the Big Dike Faults and the Butte-King Solomon-Ajax faults trend southward toward the Big Horse Fault, but are not known to be intersected by it.

YELLOW ASTER EXTRAPOLATIONS

The faults crossing the Stringer District may have buried extensions beneath alluvial cover to the southeast. The Buckboard, Bully Boy, Orphan Girl, and Gold Coin are all candidates for extrapolation. Interest in several of these is enhanced by diabase dikes in the faults or along their projections.

The profitable Blackhawk Faults probably have parallel faults buried beneath the alluvium to the NE and SW. The KCN and Juanita Faults exposed within the Kelly System may have extensions and parallel structures obscured by Kelly Episode Alteration.

To the south in the Atolia District, Lemmon and Dorr (1940) have mapped a NW-striking, NE-dipping fault which appears to displace the Atolia Fault Zone. This structure may be a Yellow Aster Episode Fault.

To the west, the Gorman-Buckboard Fault may be the basal back-to-back fault of the Yellow Aster Episode. However, Cheadle et al. (1984, Plate 8), interpret discontinuities in the subsurface reflector of the Rand Thrust to represent east-dipping high-angle faults to which I assign a potential Yellow Aster Episode affinity. Also, Postlethwaite (1983) has mapped NW-trending faults as far west as the Sydney Peak Fault.

To the northwest, the Yellow Aster Fault extends beyond the distinct alteration boundary into unaltered rocks. It still has four to six feet of gouge, but almost no rusty stain.

OSDICK RHYOLITE EPISODE AND CROSS-FAULTS

Osdick Rhyolite Dikes cut Yellow Aster Episode Faults at the Big Dyke and New Deal Faults. The Long Dike, Cluster C, is left-laterally separated about 20 feet by the New Deal Fault during post-mineralization activity (coeval with the Hybrid?). The Yellow Aster Episode introduced pyrite-gold alteration along faults which has weathered to form their common "rusty fault gouge". The Osdick Rhyolites introduced a second episode of pyritization superposed upon the Yellow Aster Episode.

A widespread rusty-weathering alteration centered around the Yellow Aster gold mine is mysteriously truncated on the NW beyond the Big Gold and Yellow Aster Faults. Limited field evidence suggests that these faults extend into the unaltered area. The NW truncation of alteration is perfectly coincident with a halo around pyrite-bearing rhyolite dikes of the Central Swarm of the Osdick Episode. Limonite cubes after pyrite are particularly abundant in rhyolites on the western end of the swarm. They indicate responsibility for the sharply defined rusty halo which surrounds them.

Truncation is not sharp to the south because north-dipping reactivated faults of the Stringer District have dispersed rusty weathering alteration on the surface to the south. In fact, the continuity of the Gunderson-Baltic Fault is established on color air photos by the sharp juxtaposition of rust-colored rocks in the footwall with less altered rocks of the hanging wall.

The Yellow Aster Faults were only obliquely reactivated during the Osdick Rhyolite Episode, but they appear to have been enriched in pyrite and probably gold. The probable extension of the Yellow Aster Fault beyond the rusty halo is only weakly rusty.

The solutions powered by the rhyolite diking event disseminated pyrite throughout what is now the rusty halo, but the pyrite and gold were often trapped and concentrated beneath the impermeable hanging wall shears of the Yellow Aster and Atolia Episode Faults nearby. The distinctly rusty Gorman and Snowbird faults outside of the rhyolite dike effects are found to dip toward the dike swarms. By contrast, the Alphonse Fault which dips away from rhyolites on the surface is only weakly rusty.

KELLY EPISODE CROSS-FAULTS

The Kelly Episode faults formed an evolving lateral shear couple with second and third order elements forming internal cross-cutting relations. These internal fault and fissure vein intersections provide the setting for major ore deposition at the Kelly glory hole and in the underground workings of the Kelly Mine. Substantial silver mineralization is also found along the third order elements of the system. Important production did come from the second order elements as well.

Silver anomalies are known from other portions of the Kelly Episode faults such as the Seaman property, the St. Lawrence Rand Mine, and the Silicap. Most production from Kelly Episode veins elsewhere, however, has been of gold, as at the Baltic, Monarch Rand, and Treasure Hill Mines, for instance. (Troxel and Morton, 1969, Hulin, 1925, and Newman and Seaman, personal communication, 1984).

Kelly Second Order vs. Third Order Elements

Intersections of second and third order elements are found throughout the Kelly Episode silicified veins. Major intersections with the greatest potential for exploration include the mysterious Big Horse-Hybrid intersection, the Silicap stockwork quartz veins, the Orphan Girl hill area, the Kelly System center, and the Seaman property. Each will be discussed in turn with the exception of the Seaman property, which was discussed under the Yellow Aster Episode vs. Kelly Episode.

Big Horse vs. Hybrid

The Big Horse-Hybrid intersection is mysterious because these two veins with apparent major oblique motion appear to end abruptly at their junction. Hints of silicification can be traced a few hundred feet to the SSE in float but no further evidence of these faults has been recognized. With these faults hinged at their junction, they form a fan accommodating counterclockwise physical rotation of their footwall blocks with respect to the Big Horse hanging wall.

Expected motion of the Hybrid Fault has been discussed in the section on the Yellow Aster Mine (Plate 7). Motion on the Big Horse Fault was described with Kelly Episode Mineralization, and is indicated by normal left-lateral slickensides. One local exception may indicate scissoring along the fault. The Big Horse fault zone becomes braided near its intersection with the Hybrid. The hill at their junction is intensely silicified, sericitized, and bleached over an area in excess of 500 feet on a side. A well planned core drilling program could quickly sort out these interwoven faults and dikes while assessing mineralization.

Silicap Stockwork

The Silicap stockwork quartz veins occur at the NE end of the Big Horse Fault. They are situated at the center of a broad area of pervasive argillic alteration which differs from anything else in the Randsburg Mining District. The argillic alteration is truncated to the northwest by the Big Horse Fault which is itself intensely argillized. Argillic alteration extends south to the Triplet Diabase at the Randsburg Intrusive Complex/Rand Schist contact and east to include the Breccia Cap.

Above the stockwork quartz veins and capping, the Silicap is a thoroughly silicified manto of argillic-altered grusy sediments and broken rock fragments interpreted as a hydrothermal breccia. They are not tectonic breccias, but they may be pyroclastic.

The quartz veins occur in quartz monzonite, grusy sediments, porphyries, and felsites of the Osdick Rhyollitic Complex on the west side of the Silicap. Fourteen discontinuous high angle veins have been mapped. They trend either subparallel to the Big Horse Fault or N to NNW. Slickensides on the Big Horse sympathetic faults are consistent with those on the Big Horse. Slickensides on the steep north-trending fault veins are nearly horizontal, plunging less than 15 degrees northward.

South of the argillized segment of the Big Horse Fault and the Silicap, a number of isolated silica veins occur. One vein in an intensely argillized area contains stibnite and pyrite. Another cuts the Triplet Dikes of Cluster D. It exhibits a normal, left-lateral motion of several feet.

From the Silicap south, these generally north trending veins are taken to indicate a zone of distributed shear.

This zone is a third order element of the Kelly Episode and extends through the crushed Dogpatch area to the Orphan Girl and Jasper properties specifically.

The stockwork quartz veins beneath the silicified hydrothermal(?) breccia in the Silicap are anomalous in Ag, Sb, and As (Newman, personal communication, 1983, 1984). They lie in the center of a broad argillic alteration zone which bears witness to an extensive hydrothermal circulation system. This area is preeminent among targets in the Randsburg Mining District that are deserving of further exploration.

Orphan Girl Hill

The Orphan Girl hill is a positive topographic feature like the Big Horse or Kelly Footwall areas. It has major silica veins striking NE and N with slickensides plunging NE. These veins are surrounded by silicified, sericitized, and bleached rocks that are resistant to erosion. The silicified veins have been only weakly explored on the surface and avoided at depth in mines in the Orphan Girl Fault, presumably due to low values and the physical difficulty of exploring the silica veins by hand-mining methods.

Kelly System Center

The center of the Kelly System NW of the Kelly Footwall is complexly crosscut by NE- and N-trending veins. These have been explored by several vertical shafts and level drifts but few records are available to document these efforts. The geometric similarity and proximity to the Kelly glory hole make this area deserving of documented exploration.

KELLY EPISODE EXTRAPOLATIONS

North-south trending third order faults southeast of the Williams vein at the Bray-Bisbee and Silver King shafts suggest that another second order element may exist to the SE. Such an element is predicted to exist beneath andesite regolith to the east of the hill with the Big Four shaft.

The mysterious termination of the kinematically active Big Horse and Hybrid fault planes at their junction deserves a more careful examination than this work was able to provide. Extensions and sisters to these faults could profoundly modify the interpretation given here.

Because the Kelly Episode faults are confined to an envelope defined by an overall shear couple, distinct extensions of the faults on strike to the NE and SW are not expected to exist. An overall tectonic connection to the Red Neck-Steamwell fault zone and the Lava Mountains Faults is probable, however, and a broad extension of this sweep of faults synthetic to the Garlock to the SW is very possible.

NOTE: A diagram that summarized Jeff's ideas concerning the origin of the Rand Schist and metamorphic core complexes in a plate tectonic context is not referred to in text but constitutes a valuable conclusion and compilation. It appears as Plate 8 (in pocket).

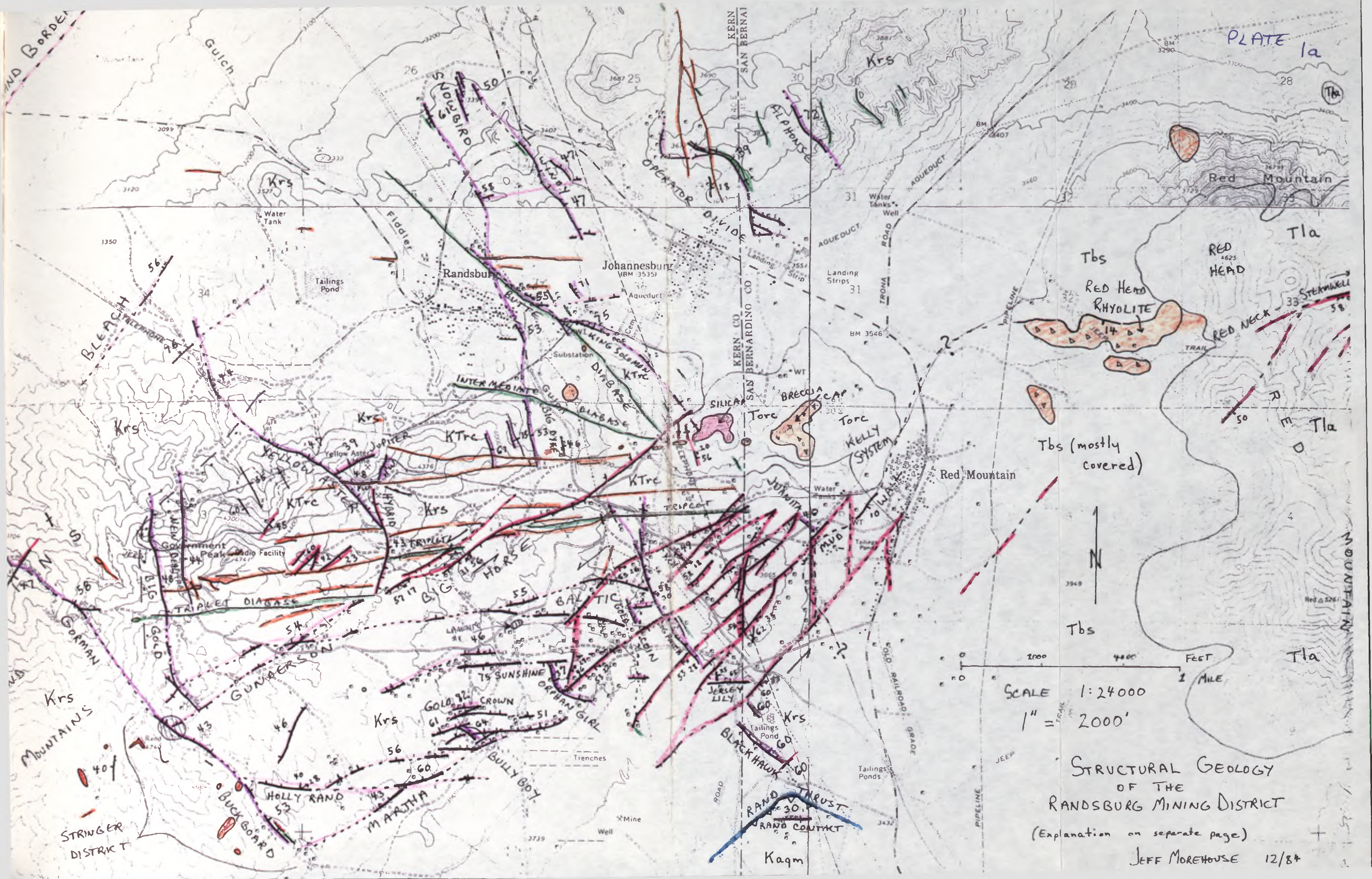


PLATE 1a
Structural Geology of the Randsburg Mining District
(Explanation on separate page)
Jeff Morehouse 12/84
Scale 1:24000
1" = 2000'
0
2000
4000
Feet
1 Mile
N
Red Mountain
Red Head
Red Head Rhyolite
Red Neck
Tbs
Tbs (mostly covered)
Tla
Krs
KTrc
Torc
Kaqm
Randsburg
Johannesburg
Red Mountain
Kern Co
San Bernardino Co
Silica
Breccia Cap
Kelly System
Rand Thrust
Rand Contact
Blackhawk
Jersey Lily
Orphan Girl
Sunshine
Crown
Gold
Bully Boy
Martha
Holly Rand
Buckboard
Gunderson
Triplet Diabase
Big Gold
Big Horse
Baltic
Tripplett
Yellow Aster
Jupiter
Hydrid
Intermediate
Diabase
King Solomon
Butte
Windy
Snowbird
Operator
Divide
Alphonse
Fiddler
Bleach
Gorman
Rand Mountains
Stringer District
Government Peak
Radio Facility
Tailings Pond
Water Tank
Trenches
Aqueduct
Landing Strips
Trona Road
Pipeline
Old Railroad Grade
Steamwell
Red Mountain
Fremont
Water Tanks
Mud
Mine
Well
Jeep Trail

EXPLANATION FOR STRUCTURAL GEOLOGY map
OF THE RANDSBURG MINING DISTRICT

Structures

Normal or oblique fault, dashed where inferred or covered; hacures point in dip direction on down-drop block and represent actual locations of attitude measurements; fault dips and slickenside plunges are statistical averages.

Sense of lateral displacement indicated on oblique fault systems with predominant lateral components.

Northwest limit to broad area of rusty weathering disseminated alteration.

Approximate lithologic contact.

Structural Episodes

Kelly Episode silicified fault and fissure veins.

Osdick Rhyolite Episode felsites, and other felsites.

Yellow Aster Episode rusty gouge fault veins.

Atolia Episode gouge fault veins.

Rand Thrust Fault, teeth on upper plate point in direction of measured dip.

Lithologic Units

Tla — Lava Mountain Andesites

Tbs — Bedrock Springs Formation

Triplet Diabase

Torc — Osdick Rhyolitic Complex and other felsites, triangles indicate breccias

Butte Diabase and other basalt or diabase dikes

KTrc — Randsburg Intrusive Complex

Kaqm — Atolia Quartz Monzonite

Krs — Rand Schist

Plate 1b. Explanation for structural geology of the Randsburg Mining District.

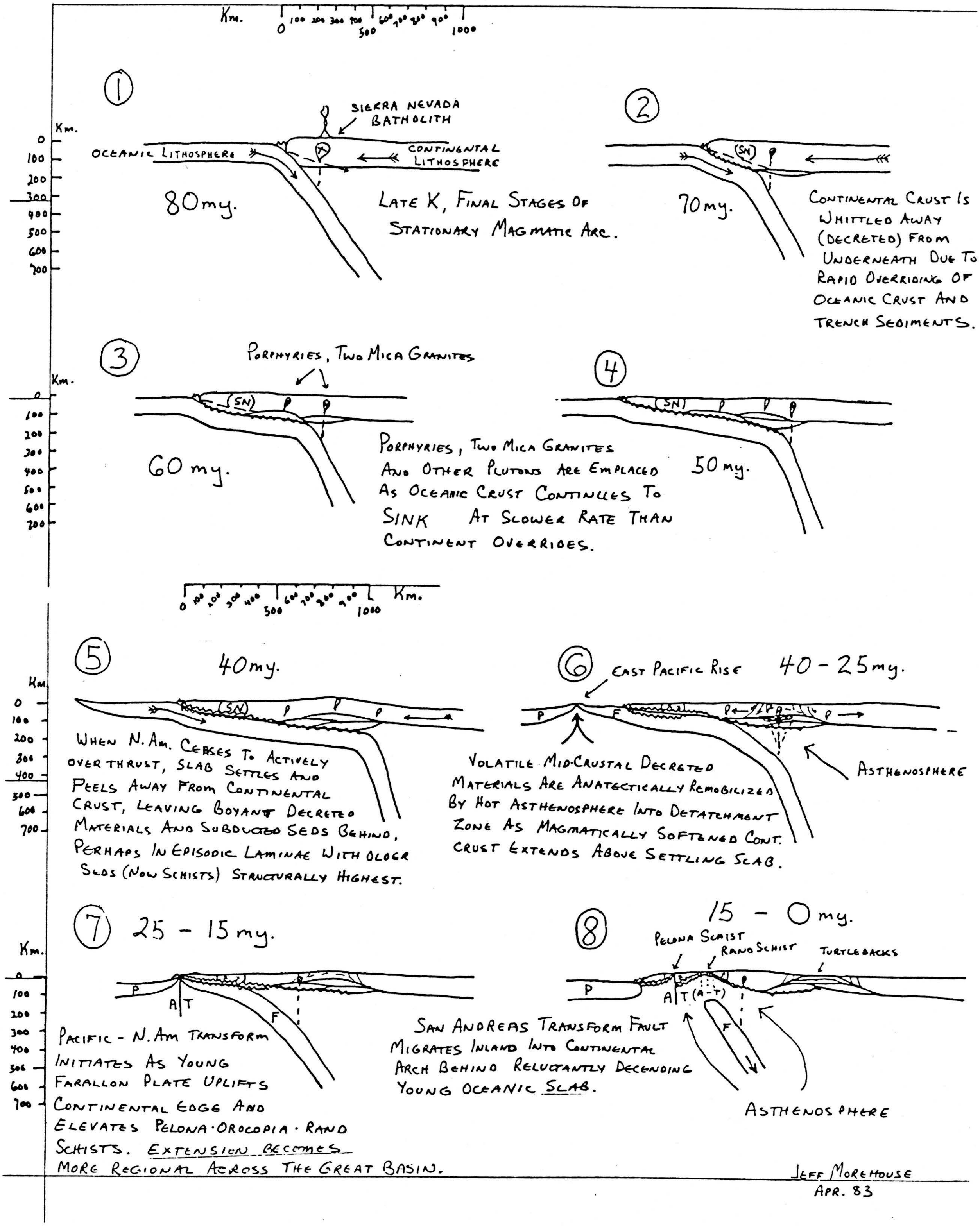


Plate 8. A schematic diagram for emplacement of metamorphic core complexes and the Pelona-Orocopia-Rand Schist as a function of continental decretion due to the overriding of the Farallon Plate by the North American Plate.

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