STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: [Signature]

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

W.R. Dickinson  Date
Department Chairman, Geosciences
ACKNOWLEDGEMENTS

I would like to thank my academic committee for their guidance throughout this thesis. Bill Dickinson, my chief advisor, has a keen interest in the Tertiary sedimentation of this part of the world. I value his insights. Also, he and his wife, Jackie, were great camping companions. Steve Reynolds contributed his time and his thoughts, and his unlimited enthusiasm for the project. Paul Damon introduced me to the geology of the state and helped me get started in graduate school.

Many residents of Aravaipa Valley deserve thanks for their hospitality, logistical support and contributions to a colorful field experience. I would especially like to thank, and to say hello, to John and Norma Lupke, and Jay and Ginny Schnell. Thanks also to the Defenders of Wildlife, represented by John, for the shelter provided during much of the field work.

I am indebted to many friends who helped during all phases of this project. Dickson Cunningham, John Field, Suzanne Fouty, Jim Lombard, Jennifer Martin, Maryanne Mckittrick, Kik Moore, and Nan Schmidt provided assistance and support throughout this project. I often did not think I would finish but for the help of Nan.

Finally, I wish to thank the folks at the Office of Arid Lands for their support during this long ordeal. Special thanks are extended to Nan Schmidt and Roger Mark, true friends, and my mother Virginia Kessler Walsh.
# TABLE OF CONTENTS

LIST OF FIGURES ........................................ v
LIST OF PHOTOGRAPHS ................................... vi
ABSTRACT .................................................. vii

1. INTRODUCTION .......................................... 1

2. HELLHOLE CONGLOMERATE SEDIMENTOLOGY ............ 8
   - Conglomerate Facies .................................. 10
   - Sandstone Facies .................................... 13
   - Intercalated Non-clastic Units ......................... 14
   - Clast Compositions .................................. 15
   - Paleocurrents ....................................... 15
   - Stratigraphic Relationships ......................... 17

3. DEPOSITIONAL ENVIRONMENT OF THE HELLHOLE CONGLOMERATE ...................................... 24

4. OTHER TERTIARY CONGLOMERATES OF ARAVAIPA VALLEY AND THE GALIURO MOUNTAINS ............... 28
   - Apsey Conglomerate Member of the Galiuro Volcanics ........................................ 28
   - Crazy Horse Conglomerate ............................ 30
   - Klondyke Conglomerate ................................ 32

5. SUMMARY OF TERTIARY CONGLOMERATE DEPOSITIONAL ENVIRONMENTS ................................ 39

6. STRUCTURAL GEOLOGY ................................... 42
   - Faults ............................................. 42
   - Folds ............................................. 43

7. DISCUSSION ............................................. 47

LIST OF REFERENCES ....................................... 54
LIST OF FIGURES

Plate 1. Compilation Geologic Map . . . Pocket

1. Location of Study Area . . . . . . . . 3

2. Compilation Map Sources . . . . . . . 4

3. Maximum Clast Diameter Isopleths . . . 9

4. Hellhole Conglomerate Clast Compositions . . 16

5. Paleocurrent Rosettes for the Hellhole Conglomerate . . . . . . . . 18

6. Paleocurrent Rosette for the Crazy Horse Conglomerate . . . . . . . . 31

7. Stowe Gulch facies of the Klondyke Conglomerate Clast Composition . . 33

8. Paleocurrent Rosettes for the Fourmile Creek facies of the Klondyke Conglomerate . . 35

9. Cross Section . . . . . . . . . . . . . 49
LIST OF PHOTOGRAPHS

1. Conglomerate facies of the Hellhole Conglomerate ........................................ 11
2. Conglomerate facies of the Hellhole Conglomerate ........................................ 12
3. Sandstone facies of the Hellhole Conglomerate ........................................ 12
4. Galiuro Volcanic - Hellhole Conglomerate Fault Contact .................................. 19
5. Galiuro Volcanic - Hellhole Conglomerate Depositional Contact ....................... 21
6. Hellhole Conglomerate – Klondyke Conglomerate Contact ................................ 21
7. Apsey Conglomerate Member of the Galiuro Volcanics .................................... 29
8. Crazy Horse Conglomerate .............................................................................. 29
9. Stowe Gulch facies of the Klondyke Conglomerate ........................................ 38
10. Fourmile Creek facies of the Klondyke Conglomerate ..................................... 38
11. Stowe Gulch Fault ......................................................................................... 44
12. Hellhole Monocline ....................................................................................... 45
ABSTRACT

The Hellhole Conglomerate is an alluvial fan deposit of Miocene age which crops out in Aravaipa Valley, southeastern Arizona. The predominantly flat-lying conglomerate fills a late Oligocene half-graben basin formed by upper crustal rotation and translation along an underlying detachment fault. Oligocene volcanic rocks constitute the predominant clast type. The formation is deformed by Miocene compression.

The Hellhole Conglomerate is one of three Tertiary clastic units exposed within Aravaipa Valley. The Crazy Horse Conglomerate predates active block rotation. The Hellhole Conglomerate postdates active block rotation yet predates the exposure of the granitic Santa Teresa Mountains along the eastern flank of Aravaipa Valley. The Klondyke Conglomerate, which unconformably overlies the Hellhole Conglomerate, records deposition in a basin not unlike the present day Aravaipa valley.
The Hellhole Conglomerate is a Miocene sedimentary formation. Exposures lie within Aravaipa Valley, east of Tucson, in southeastern Arizona. The conglomerate is of interest because of its structural setting, bounded by flat-lying Oligocene volcanic rocks to the west and tilted Oligocene volcanic rocks to the east.

An understanding of the Hellhole Conglomerate can contribute to paleogeographic reconstructions of Aravaipa Valley for Tertiary time. Davis and Hardy (1981) described the Eagle Pass detachment fault, exposed on the east flank of Aravaipa Valley, and introduced the concept of opposing extensional regimes symmetric about the Galiuro Mountains. In this model, the untilted Galiuro Volcanics of the Galiuro Mountains are viewed as a 'non-distended' footwall block. To the northeast of the volcanics, extensional basins formed by the rotation of blocks along northeast-vergent detachment surfaces, such as the Eagle Pass fault. The Hellhole Conglomerate, postdating and lying adjacent to the Galiuro Mountains, contains a sedimentological key to the post-Oligocene tectonic development of Aravaipa Valley.

Goals and Methods

The goal of this study was to describe the Hellhole Conglomerate and its geologic setting. Sedimentology, stratigraphic relations, and structure were studied in the field. Clast compositions, paleocurrent indicators, and maximum clast sizes were recorded. Sedimentological style was observed in a series of 5-10 m 'abbreviated' stratigraphic
sections. Contacts and structural features were mapped on 1:24,000-scale field sheets. The sedimentology and stratigraphic relationships of the clastic sediments overlying the Hellhole Conglomerate were also studied in order to compare and contrast them with Hellhole strata. Reconnaissance observations were made of two additional Tertiary clastic units within the area. Finally, in order to understand the various sedimentary units in a regional context, geologic maps of the Klondyke, Jackson Mountain, and Christmas 15 minute quadrangles and the Brandenburg and Holy Joe Peak 7 1/2 minute quadrangles, along with miscellaneous maps from the Santa Teresa and Mescal Mountains, were compiled on a 1:100,000-scale base map.

Location and Access

The study area lies within Aravaipa Valley, north of the town of Klondyke (figure 1). Aravaipa Valley lies to the northeast of Tucson in Graham County and the eastern part of Pinal County in southeastern Arizona. Access is possible by travelling north from Willcox along the Fort Grant road or by travelling west from state highway 70 along the Klondyke road. The Klondyke road intersects state highway 70 south of Fort Thomas and west of Safford.

Previous Work

The Hellhole Conglomerate was first described by Simons (1964) who mapped the Klondyke Quadrangle. Ross (1925), Creasey (1961), Willden (1964), Krieger (1968), and Blacet and Miller (1978) published geologic maps of nearby areas. Three University of Arizona theses, Robinson
Figure #1: Location of the study area. Regional geology within the outlined area was compiled during this study. Shaded area is underlain by Hellhole Conglomerate. (Map is from State of Arizona, 1:500,000; Allan Cartography, 1987)
4) __________ 1968.

Figure #2: Compilation map (plate 1) sources
(1975), Hauck (1985) and Burchell (in progress), looked at various geological problems that were pertinent to this study. Davis and Hardy (1981) provided a valuable tectonic synthesis of the area.

General Geology

The northern part of the Galiuro Mountains is a broad plateau, locally referred to as "the Tablelands." An extensive, thick sequence of flat-lying to gently warped Oligocene volcanic rocks defines this topographic feature. To the north and east, the landscape is broken into a series of tilted ranges which strike N30-70W. The ranges are the Mescal Mountains, which lie to the north of the volcanic plateau, and the Santa Teresa Mountains, which lie to the east and northeast. The Mescal and Santa Teresa Mountains are composed of Precambrian through Tertiary strata which dip consistently to the southwest. Aravaipa Valley, a northwest-trending basin, lies between the Galiuro and Santa Teresa Mountains. The valley drains to the northwest, through the Galiuro Mountains and into the San Pedro River. The southern end of Aravaipa Valley is a drainage divide separating the externally drained valley from the internally drained Sulphur Spring Valley to the south.

Precambrian rocks exposed within the region consist of granitic crystalline rocks, Pinal Schist, Apache Group (predominantly Dripping Spring Quartzite), and Troy Quartzite. The Precambrian units are commonly exposed along the crests of tilt-block ridges in the Mescal Mountains. Precambrian granodiorite and Pinal Schist flank the Tertiary plutonic rocks exposed in the core of the Santa Teresa
Mountains. Paleozoic strata consist primarily of Cambrian Bolsa Quartzite, Devonian Martin Formation, Mississippian Escabrosa Limestone, and Pennsylvanian-Permian Naco Group. Cretaceous rocks consist of granitic crystalline rocks, the sedimentary Pinkard Formation and an overlying volcanic unit composed of lava, tuff, breccia, and clastic sedimentary rocks.

Oligocene volcanics are the most common rock type exposed within the study area. The Galiuro Volcanics is a thick sequence of lava flows and ash-flow tuffs ranging in composition from andesite to rhyolite. The sequence can be subdivided into two parts: a basal section of lava flows intercalated with minor tuff and an overlying section in which ash-flow tuff predominates. Stratigraphic relations between individual flows are complex and suggestive of several eruptive centers (Creasey and Krieger, 1978). The volcanics are well dated and range from 28.9 Ma for a lower rhyolite tuff to 22.8 Ma for the highest unit, the upper andesite member. The strata are generally undeformed, though locally warped. Along the Aravaipa side of the Galiuro Mountains, the base of the volcanics is nowhere exposed.

The Horse Mountain Volcanics, which crop out as a tilted, nearly continuous belt of silicic volcanic rocks along the southwest flank of the Santa Teresa Mountains and as a second, less continuous, homocline to the west, were mapped by Simons (1964) as Cretaceous-Tertiary in age. Since this work, the formation has been dated at 20.0 Ma and 21.8 Ma (Reynolds and others, 1986) and correlated with the Galiuro Volcanics (Hauck, 1985). Blacet and Miller (1978) mapped tilted volcanic units along the eastern flank of the Santa Teresa Mountains in
the Jackson Mountain quadrangle as Galiuro Volcanics.

The Galiuro Volcanics and correlative units exposed farther east are here compiled together as the Tertiary volcanic unit by this author (plate 1). The Older Tertiary Volcanics of Willden (1964) is included in this map unit, based on Willden's description of the rocks.

The Santa Teresa Granite and the Goodwin Canyon Quartz Monzonite, dated at 22.85 Ma and 24.95 Ma (Shafiqullah and others, 1980) form the extensive plutonic core of the Santa Teresa Mountains. Over 110 square miles are underlain by these units. Together, they are jointly designated as Tertiary granitic rock by this author (plate 1).

The Hellhole Conglomerate is one of at least three discrete conglomerate units cropping out within Aravaipa Valley (Plate 1). A tilted conglomerate at Eagle Pass, here named the Crazy Horse Conglomerate, lies along the eastern flank of Aravaipa Valley. It predates the Hellhole Conglomerate. The Older Alluvium of Simons (1964), here renamed the Klondyke Conglomerate, lies between the Hellhole and Crazy Horse Conglomerates and postdates both units. The Klondyke Conglomerate is here subdivided into two facies based on geographic position and provenance studies. A fourth clastic unit, the Apsey Conglomerate member of the Galiuro Volcanics, crops out to the west of the Aravaipa Valley.
CHAPTER 2
HELLHOLE CONGLOMERATE SEDIMENTOLOGY

The Hellhole Conglomerate is coarse, clast-supported, stream flow and very coarse, matrix-supported debris-flow conglomerate that fines to the south and west into well-stratified sandstone with thin mudstone beds and minor gravel lenses. Oligocene volcanic rocks are the predominant clast type. First described by Simons (1964), the formation crops out in a broad belt along the east flank of the Galiuro Mountains. Approximately fifty square miles is underlain by the Hellhole Conglomerate. The rock is well indurated and consequently forms high cliffs where cut by major drainages. Aravaipa Creek bisects the exposures from east to west (plate 1).

An accurate assessment of the thickness of the Hellhole Conglomerate is not possible because an unequivocal top or bottom of the section is nowhere exposed. A minimum thickness, calculated in the field, is 488 m (1600 ft). A maximum thickness, inferred from interpretations of depth to bedrock from two-dimensional gravity profiles (Robinson, 1975), is at least 1220 m (4000 ft), and possibly as great as 2440 m (8000 ft).

The Hellhole Conglomerate is Early Miocene in age. A biotite-rich ash bed, intercalated within the lowest exposed section of the Hellhole Conglomerate, yields a K-Ar date of 19.2 Ma ± 0.5 Ma (this study). Almost all of the exposed minimum thickness of 1600 ft overlies this ash bed.

The formation is subdivided into two facies based on grain size. Figure 3 is an isopleth map derived from maximum clast size data. The
Figure #3: Generalized maximum clast diameter isopleths. Data reflects intermediate diameter dimensions.
conglomerate facies is composed of fine- to very coarse-grained conglomerate. Maximum clast sizes range from centimeters to several meters throughout this facies. Typically, the formation exhibits no consistent vertical fining or coarsening. Locally, however, the formation grades south and southwest to a finer sandstone facies centered around lower Turkey Creek. Within the 20 cm isopleth of figure 3, the Hellhole Conglomerate is typically sandstone interbedded with minor gravel lenses.

**Conglomerate Facies**

The conglomerate facies of the Hellhole Conglomerate consists of coarse-grained cobble to boulder conglomerate and fine- to coarse-grained cobble conglomerate interbedded with pebbly, very coarse grained sandstone.

**Clast-supported Conglomerate**

Poorly to moderately sorted, clast-supported conglomerate beds predominate throughout the facies. The beds are as thick as one meter. Clasts are subangular to angular and exhibit well-developed imbrication. Minor amounts of interstitial sand are present. The coarsest units commonly display crude, lensoidal bed forms. Individual beds extend 1 to 5 m laterally and pinch-out or onlap adjacent beds. Individual bedding contacts are diffuse and gradational.

Finer pebble to cobble conglomerate beds are more planar in form. These units are better sorted and commonly fine upward into coarse sand. Bedding surfaces are scoured or planar; the contacts are defined by changes in grain size. Interbedded sandstones, which constitute 10-
Photo #1: Conglomerate facies of the Hellhole Conglomerate
Photo #2: Conglomerate facies of the Hellhole Conglomerate

Photo #3: Sandstone facies of the Hellhole Conglomerate
25% of the section, are coarse- to very coarse-grained, moderately sorted, and typically well graded. Sandstone beds are lenticular in shape and extend laterally over several meters before truncation by gravel units. Individual beds vary in thickness from 5 to 30 cm.

Matrix-supported Conglomerate

Matrix-supported, mass-flow units are common throughout the eastern half of the basin, and, to a lesser extent, along the western margin of the basin. These units are thick, poorly sorted, and non-imbricated. They typically lack internal stratification. Locally, a rude, coarse-tail grading is evident. Clast packing densities can be as low as 50%. Maximum clast size locally reaches several meters and commonly exceeds one meter. The matrix is composed of sand, silt, and lithic fragments; there is little clay. Upper and lower contacts are typically distinct and nongradational, and the beds are laterally extensive over several tens of meters. Truncated lenses of coarse sand are commonly associated with the units.

Sandstone Facies

The transition between the two facies of the Hellhole Conglomerate is abrupt. Within a few hundred meters, the formation changes from coarse conglomerate to laminated, slightly pebbly, medium- to very coarse-sandstone interbedded with fine-grained gravel lenses and mudstone. The facies typically exhibits thin, repetitive, fining-upward sequences of gravel, sand, and mud, interbedded with massive beds of coarse sand 15-25 cm thick. Crossbeds and ripple marks are present, but nowhere common. The mudstone units, which rarely exceed a
few centimeters in thickness, exhibit well preserved desiccation cracks. Rip-up clasts of mudstone are commonly present in overlying sandstone beds. Isolated lenses of fine- to medium-grained gravel occur throughout the section. The gravel beds are well imbricated and moderately sorted, and the clasts are subangular to rounded in shape.

In the southwest corner of section 27, T6S,R19E, within the conglomerate facies of the Hellhole Conglomerate, anomalous beds of coarse, tuffaceous sandstone are interbedded with the conglomerate. These beds exhibit massive crossbeds similar to those found within eolian deposits. Petrographic observations reveal a very porous, vitric-rich sandstone.

**Intercalated Non-clastic Units**

A limestone is exposed within Aravaipa Canyon. The bed, intercalated within sandstone, is a meter thick and continuous for less than 45 m. No fossils were found in samples taken by Simons (1964). There is no evidence throughout the sandstone for interbedded evaporite deposits.

There are rare pyroclastic deposits within the Hellhole Conglomerate. Thin, discontinuous air-fall tuff beds are found throughout the formation. Typically, the pyroclastic units are fine-grained and contain lithic fragments as well as zones of coarser, reworked sediment. Without exception, they are less than a meter thick and discontinuous. Assessment of these beds for isotopic dating potential reveals that most exhibit evidence of depositional reworking. One ash bed, however, contains a high percentage of biotite and minimal
evidence of fluvial reworking. This bed was isotopically dated at 19.2 ± 0.5 Ma (K-Ar) (this study).

**Clast Compositions**

Clasts of Oligocene volcanic rock predominate in the Hellhole Conglomerate. Over 93% of the clastic constituents are derived from volcanic sources within the Galiuro and Santa Teresa Mountains. Another 5% of the clasts are sandstone, quartzite and chert derived from Paleozoic and Cretaceous sedimentary rocks found to the north and east of the Hellhole Conglomerate. One percent of the clasts are hypabyssal rocks and could not be identified as to type or provenance. Other Intrusive compositions are completely absent.

Based on point-count analysis of the sandstone facies in Turkey Creek, the sandstone composition is feldspatholithic, according to the classification of Dickinson (1970). The sand grains are predominantly subangular to subrounded, and the cementing agent is phyllosilicate. The feldspatholithic composition is consistent with clast compositions of the conglomerate facies of Hellhole Conglomerate.

**Paleocurrents**

The conglomerate facies of the Hellhole Conglomerate consistently exhibits good clast imbrication. Over two hundred imbrication readings were taken in the field to determine paleoflow directions.

Analysis of the imbrication data reveals a crude difference in paleoflow direction between the eastern two-thirds and the western third of the Hellhole Conglomerate basin. Data compiled from outcrops
Figure #4: Hellhole Conglomerate clast compositions
within the eastern part of the basin is represented in rosette A (figure 5). The mean flow vector is S34W. Across the basin, imbrication data is less consistent (rosette B, figure 5). The mean flow vector within the western margin of the basin is S15E. Strong northeast and west components to paleodrainage within this region indicate complex coalescing drainages.

**Stratigraphic Relationships**

The Hellhole Conglomerate fills a basin which is bounded on three sides by Oligocene to early Miocene volcanic rocks. Flat-lying Galiuro Volcanics lie to the west and north. Tilted Galiuro Volcanics equivalents form the east side of the basin. In the southern end of the basin, younger clastics overlie the Hellhole Conglomerate.

**Western Contact**

The contact between the Hellhole Conglomerate and the Galiuro Volcanics along the western margin of the Hellhole basin is best described as a buttress unconformity; the Hellhole Conglomerate abuts and overlaps a previously faulted margin of the Galiuro Volcanics. Evidence for fault movement involving the Hellhole Conglomerate is found only at the lowest topographic point along the contact (Photo #4). At the confluence of Old Deer and Aravaipa Creeks (plate 1), the contact with volcanic rocks is a 10cm wide zone of unconsolidated silt and sand fault gouge. The fault, here named the Hellhole fault, dips 80 degrees to the northeast. Elsewhere, the contact is depositional (photo #5).
Figure #5: Paleocurrent (imbrication) rosettes for the Hellhole Conglomerate
Photo #4: Galiuro Volcanic - Hellhole Conglomerate fault contact. The contact, located in Aravaipa Canyon, is subvertical.
The sedimentology of the conglomerate along the western contact is complex. Clast imbrications within the conglomerate suggest a paleoflow direction away from the high-relief Galiuro Volcanics and into the basin. Elsewhere, the formation is typically a coarse sandstone not unlike the sandstone facies exposed along Turkey Creek. Basal units are coarser and commonly lens out against the volcanic topography. Directly at the contact, the rock commonly is a very coarse, very angular, chaotic assemblage of volcanic-clast colluvium.

Northern Contact

In upper Black Canyon, at the northernmost exposure of the Hellhole Conglomerate, the contact between the conglomerate and the upper andesite member of the Galiuro Volcanics is not exposed. Sedimentological evidence throughout the conglomerate suggests that the contact is unconformable. Throughout upper Black Canyon, the Hellhole Conglomerate contains numerous beds that have essentially monolithic clast compositions of dark, amygdaloidal lava derived from the upper andesite member of the Galiuro Volcanics. Near the contact, the unit noticeably coarsens. This relationship is significant because the upper andesite member of the Galiuro Volcanics is the uppermost member of that volcanic sequence. The temporal relationship between the Galiuro Volcanics and the Hellhole Conglomerate is therefore clear: the Hellhole Conglomerate postdates Galiuro volcanism.
Photo #5: Galiuro Volcanic - Hellhole Conglomerate depositional contact. The contact, located in upper Turkey Creek, dips 40° E.

Photo #6: Hellhole Conglomerate - Klondyke Conglomerate contact exposed within Fourmile Creek.
Eastern Contact

The contact between the Hellhole Conglomerate and the tilted Tertiary volcanics at the eastern margin of the basin is an angular unconformity. The conglomerate dips slightly to the southwest and overlies the moderately to steeply tilted volcanics. The conglomerate coarsens noticeably towards the contact. Imbrications consistently indicate paleoflow to the southwest, or away from the ridge of volcanic rocks.

In sections 19, 20, 27, 28, and 29 of T5S, R19E, the contacts between Simons' Hellhole Conglomerate (Th), Horse Mountain Volcanics (TKh) and Older Alluvium (QTal) were remapped. Two previously unmapped outcrops of TKh were found and mapped in section 28. Depositionally overlying these volcanic outcrops is a small outcrop of conglomerate which resembles Hellhole Conglomerate in appearance, fabric, clast composition, and imbrication direction. Southwest of these outcrops, along the northern side of Deer Creek, in section 32, additional outcrops of conglomerate that resemble Hellhole Conglomerate in all aspects were observed. On the basis of these field criteria, the area which lies to the west of the newly discovered outcrops of volcanics and which had been mapped as QTal was remapped as Hellhole Conglomerate. Farther to the north, the paucity of outcrops made it difficult to interpret the relationships between the various units.

Southern Contact

The relationship between the Hellhole Conglomerate and the clastics lying to the south is unconformable. The contact is best
exposed within the bluffs along Fourmile Creek. Here, the contact surface is distinguished by a noticeable change in color and, to a lesser extent, by finer gravel textures in the overlying Fourmile Creek facies of the Klondyke Conglomerate. The surface exhibits up to 8 m of buried relief. The underlying Hellhole Conglomerate has a tan to green hue while the overlying Fourmile Creek facies is red and buff colored. A low percentage of granitic clasts found in the younger unit further distinguishes the two conglomerates.

Clast imbrications reveal a contrasting paleoflow direction across the contact. Paleoflow directions within Hellhole Conglomerate outcrops of Fourmile Creek are consistent with the formation as a whole. Paleoflow directions for the Fourmile Creek facies of the Klondyke Alluvium are to the northeast, or almost 180 degrees opposite that of the Hellhole Conglomerate.

Outcrops of the Klondyke Conglomerate are mapped north of Fourmile Creek, in sections 1, 12 and 14, T7S, R19E. Though a contact is not exposed, the relationship between these beds and the lower lying Hellhole Conglomerate suggests stratigraphic overlap.
CHAPTER 3
DEPOSITIONAL ENVIRONMENT OF HELLHOLE CONGLOMERATE

The Hellhole Conglomerate is an alluvial fan deposit of Miocene age. The conglomerate was deposited by surface flows reflecting a wide range of sediment to water ratios, including fully turbulent, dilute stream flow and viscous debris flow.

Coarse gravel lenses, exhibiting poor to moderate sorting, were deposited in channels entrenched into the fan surface. Such entrenched trunk drainages continuously migrate across the depositional surfaces of alluvial fans (Bull, 1972). The competency of the channelized flows accounts for the coarse nature of these deposits. Finer grained pebble to cobble conglomerate interbedded with lenses of coarse sandstone represents the more distal, middle fan sheet-flood environment. At the alluvial fan intersection point, entrenched channels give way to less restricted systems of distributary channels. The well-sorted, well-graded sheets of sandstone and gravel found within the sandstone facies of the Hellhole Conglomerate are characteristic of the distal fan environment.

Debris flows deposited the thick, poorly sorted, coarse beds of matrix-supported gravel common throughout the eastern part of the basin and found, to a lesser extent, along the western margin of the basin. Debris flows are water-saturated flows that deposit sediment 'en masse' when shear stress decreases below the yield strength of the debris. Matrix support of the clasts is possible through a combination of cohesive matrix strength, buoyancy, and dispersive pressure (Smith,
1987). Typically, debris flows contain a minor percentage of clay, which provides the cohesive strength of the matrix. When a source area is deficient in the clay-size fraction, the debris flows are non-cohesive, and the clasts are supported by dispersive pressure and buoyancy (Lowe, 1979). The Hellhole Conglomerate debris-flow units are extremely clay-poor and, therefore, are non-cohesive, viscous-flow deposits. The minor interbedded lenses of sandstone represent deposits formed during the waning stages of the debris flood (Miall, 1970).

Indicators of intermittent deposition are common throughout the sandstone facies. Thin mudstone units exhibiting well developed desiccation structures typically complete fining-upward sequences within the sandstone. Rip-up clasts of mud are often found within overlying, coarser sandstone beds. Evidence for bioturbation also exists. Zones of poorly sorted, massive sandstone suggest pervasive animal burrowing. Such features are consistent with a distal alluvial fan environment, where periodic stream avulsion results in the temporary abandonment of areas of the fan surface (Bull, 1972). The cross-bedded eolian deposits of the Hellhole Conglomerate indicate that the basin fans may have experienced sustained periods without runoff.

There is a general lack of pluvial or playa sediments within the exposed section of Hellhole Conglomerate. Only a single, discontinuous bed of limestone was observed. During the period of time represented by the exposed section of the formation, the Hellhole basin was externally drained.

Pyroclastic units are also rare within the Hellhole Conglomerate. A thin ash bed, a few poorly preserved tuffs, and more common
tuffaceous sands are dispersed throughout the formation. Though the Hellhole Conglomerate overlies the thick sequence of pyroclastic ash-flow tuffs in the Galiuro Mountains, evidence of syn-depositional volcanism is essentially absent. The coarse nature of the volcanic clasts in the Hellhole Conglomerate also supports this conclusion. In contrast, studies in depositional basins adjacent to other Tertiary pyroclastic sequences of the Southwest describe a lack of coarse volcanic fragments in fanglomerate beds derived from active pyroclastic sources (Walton, 1979).

Sediment provenance and paleocurrent indicators are compatible with deposition of the Hellhole alluvial fans within a basin defined by the Galiuro Volcanics along the northern and western margins and the tilted Horse Mountain Volcanics, equivalent to the Galiuro Volcanics, along the eastern margin. The distribution and predominance of southwestward and westward paleocurrent directions and the concentration of proximal facies within the eastern part of the formation both suggest that the most important sediment source was a tilted volcanic highland to the east and northeast. Alluvial fan systems derived from these highlands prograded westward, filling the paleobasin.

Evidence along the western contact indicates that paleo-relief of the Galiuro Mountains was substantial. The Hellhole Conglomerate abuts a nearly vertical paleocliff. Despite this relief, fans derived from the Galiuro Mountains are subordinate in the exposed section. Evidence for such fans does exist in lower Hellhole Canyon and along lower Parsons Canyon. Here, directional sedimentary structures and coarse
debris flow deposits suggest that fans were derived from the west and prograded eastward.
CHAPTER 4
OTHER TERTIARY CONGLOMERATES OF ARAVAIPA VALLEY
AND THE GALIURO MOUNTAINS

Three Tertiary clastic units crop out within the vicinity of the Hellhole Conglomerate (Plate 1). They are the Apsey Conglomerate Member of the Galiuro Volcanics, the Crazy Horse Conglomerate, and the Klondyke Conglomerate. These units are discussed below.

Apsey Conglomerate member of the Galiuro Volcanics

The Apsey Conglomerate member of the Galiuro Volcanics was described by Krieger (1968) as well indurated conglomerate composed of volcanic rock fragments. The formation is very similar in appearance to the coarse facies of Hellhole Conglomerate. The coarse conglomerate is typically poorly sorted and poorly graded. Conglomerate fabric is clast supported to matrix supported. Maximum clast sizes exceed 1 m. The conglomerate is moderately to well imbricated. Clast imbrications document a consistent west direction of paleoflow. The mean paleoflow vector for the unit is S37W (data from this study and Burchell (1988)).

The Apsey Conglomerate member conformably overlies the Hells Half Acre Tuff, rhyolite-obsidian, and Depression Canyon members of the Galiuro Volcanics. The conglomerate is itself overlain by the Table Mountain Andesite member. The unit can therefore be constrained to an age of 22.8-25.3 Ma, apparently somewhat older than Hellhole Conglomerate.
Photo #7: Apsey Conglomerate Member of the Galiuro Volcanics (beds are nearly flat-lying)

Photo #8: Crazy Horse Conglomerate (beds dip to the southwest)
Crazy Horse Conglomerate

Seven miles southeast of the town of Klondyke, in the southwest corner of Jackson Mountain quadrangle, a homoclinc of Tertiary volcanic and clastic rocks lies in low-angle fault contact with Precambrian crystalline rocks. The clastic unit is here named Crazy Horse Conglomerate, after the stream that flows across strike and exposes much of the section. The Crazy Horse Conglomerate is composed of over 1000 m of coarse-grained gravel. Sedimentary texture indicates deposition occurred under a full range of sediment-to-water ratios. Very coarse, matrix-supported debris flows are common throughout the section. Bedding strike ranges between N30W and N70W. The beds dip uniformly to the southwest at 45-55 degrees. There is a slight lessening in dip angle up-section. Beds near the upper contact dip 35-40 degrees. Clasts are predominantly subangular and are composed primarily of Oligocene volcanics. Clasts of coarse-grained, greenish intrusive rock with a mylonitic texture are present throughout the middle of the section. The clasts are similar in appearance to Precambrian mylonite exposed within the Pinaleno Mountains today. The mylonite is absent in the lower third of the section, but becomes the predominant clast throughout much of the upper section only to disappear within a few hundred feet of the upper contact. Clasts of phyllite and quartzite are present as a low percentage constituent throughout the section.

A study of paleoflow direction, made by W.R. Dickinson (unpublished field report, 1981), yields a paleoflow mean vector of N64E. An apparent change in mean flow between the lower and the upper parts of
Figure #6: Paleocurrent Rosette for the Crazy Horse Conglomerate
(data from unpublished W.R. Dickinson field report, 1982)
the section is apparent. Mean paleoflow direction in the lower section is N44E, whereas in the upper section, mean paleoflow direction is S85E (figure 6).

No absolute age for the Crazy Horse Conglomerate is available. The unit conformably overlies southwest tilted Galiuro Volcanics of Oligocene age and rests in low-angle fault contact with Precambrian granitic basement. The upper contact with flat-lying, 'basin fill' clastic sediments is an angular unconformity.

**Klondyke Conglomerate**

The Klondyke Conglomerate is an informal name given by this author to the Older Alluvium Formation of Simons (1964). The Klondyke Conglomerate represents a post-Hellhole Conglomerate period of basin clastic deposition within Aravaipa Valley. The alluvium is subdivided, for ease of discussion, into two "facies". The basis for this subdivision is differences in clast lithology and geographic location. The Stowe Gulch facies of the Klondyke Conglomerate lies to the east of the Hellhole Conglomerate and is separated from the Hellhole Conglomerate by a tilted strike ridge of Tertiary volcanics. The Fourmile Creek facies of the Klondyke Conglomerate lies to the south of Hellhole Conglomerate and unconformably overlies the conglomerate in the Fourmile Creek area. Both facies grade upward into poorly indurated basin-fill conglomerate.

**Stowe Gulch facies of the Klondyke Conglomerate**

The Stowe Gulch facies of the Klondyke Conglomerate crops out as
Figure #7: Clast composition pie-diagram, Stowe Gulch facies of Klondyke Conglomerate
cliffs within the major creeks draining the northern end of Aravaipa Valley. Outcrops are sparse elsewhere. The unit is moderately indurated, clast-supported conglomerate. Typically, lenses of poorly sorted, coarse gravels are interbedded with more laterally continuous beds of sorted, normally graded, medium- to fine-grained gravel and sand. Maximum clast sizes range from 20 to 50 cm. A minimum thickness for the flat-lying unit is 300 m.

Clast compositions reflect the varied lithologies cropping out to the east in the Santa Teresa Mountains (figure 7). The clasts of volcanic rock are derived from southwest-tilted Tertiary volcanics which crop out to the east and west of the Stowe Gulch facies. The sedimentary and intrusive compositions are found only to the east. The Stowe Gulch facies is moderately imbricated. Mean paleoflow direction is to the southwest.

Fourmile Creek facies of the Klondyke Conglomerate

The Fourmile Creek facies of the Klondyke Conglomerate forms the high, vertical cliffs (photo 10) of Fourmile Creek, Long Hollow and nearby drainages lying to the southwest of the town of Klondyke. Minimum thickness in Fourmile Creek is slightly greater than 300 m. A maximum thickness inferred from the gravity profiles of Robinson (1975) may exceed 2600 m. Typically, the unit is fine-to coarse-grained, moderately sorted gravel. Maximum clast sizes do not exceed 25 cm. Well developed, fining upward sequences of medium-grained gravel are commonly exposed. Clasts are primarily andesites and rhyolites derived from the Galiuro Volcanics now exposed to the west and south. A minor
Figure #8: Paleocurrent rosette for the Fourmile Creek facies of the Klondyke Conglomerate (n=27)
percentage of the clasts are granite and schist, compositions found within the Santa Teresa and Pinaleno Mountains to the east. Clast imbrications reveal a paleoflow direction that is opposite of that within the underlying Hellhole Conglomerate. The mean paleoflow vector direction is N38E (fig 8).

**Stratigraphic Relationships**

The Klondyke Conglomerate unconformably overlies the tilted strata that define the eastern margin of Aravaipa Valley along the flank of the Santa Teresa Mountains. Inselbergs of Tertiary and Paleozoic strata are found within the basin. The western contact of the conglomerate is defined by a northeast-dipping, high-angle normal fault, the Stowe Gulch fault, which trends from the northern end of Aravaipa Valley south to where the fault intersects Aravaipa Creek 4 km from the town of Klondyke (Plate 1). South of this point, the fault is buried by Recent alluvium. This fault places the Stowe Gulch facies of Klondyke Conglomerate against an outlying ridge of tilted Tertiary volcanics and the Hellhole Conglomerate. A southern continuation of the Hellhole fault exposed within Fourmile Creek places the Fourmile Creek facies of Klondyke Conglomerate against flat-lying Galiuro Volcanics. Movement along a spur of this fault has downdropped Klondyke Conglomerate against Hellhole Conglomerate. As discussed in Chapter 2, Klondyke Conglomerate unconformably overlies Hellhole Conglomerate elsewhere within Fourmile Creek. To the south and east, Klondyke Conglomerate grades upward into coarse, unconsolidated 'basin fill'. The exposures observed on either side of the valley between Long Hollow and Crazy Horse Wash exhibit clast compositions and
imbrication directions that are consistent with deposition within the present Aravaipa Valley geography.
Photo #9: Stowe Gulch facies of the Klondyke Conglomerate
(field notebook is 19 cm long)

Photo #10: Fourmile Creek facies of the Klondyke Conglomerate
CHAPTER 5
SUMMARY OF TERTIARY CONGLOMERATE DEPOSITIONAL ENVIRONMENTS

Table 1 allows a quick comparison of the four clastic bodies discussed in this study. Few interbedded datums are available. A reasonable relative chronology can be reconstructed however, based on stratigraphic and sedimentological relationships.

The age of the Apsey Conglomerate Member of the Galiuro Volcanics is well constrained. The formation is a proximal to medial alluvial fan deposit conformably interbedded within the upper part of the well dated Galiuro Volcanics. Paleoflow data suggests that the unit was derived from a volcanic highland lying to the east.

The Crazy Horse Conglomerate is a proximal to medial alluvial fan assemblage of channel gravels and mass flow deposits. The unit was shed from a predominantly volcanic highland to the west, although, Precambrian basement was exposed within the drainage basin at some time during deposition. The Crazy Horse Conglomerate, and the volcanics that conformably underlie it, have been rotated to the southwest. This suggests that the Crazy Horse Conglomerate predates deposition of the Hellhole Conglomerate.

The Klondyke Conglomerate postdates the Hellhole Conglomerate, overlying the older unit within Fourmile Creek. The Fourmile Creek facies of the Klondyke Conglomerate is an alluvial fan deposit which has prograded northeastward off the Galiuro Mountains. The facies represents an indeterminate period of deposition within a basin not unlike the present day Aravaipa Valley. Santa Teresa Mountain rock types are found as minor constituents within the Fourmile Creek facies
of the Klondyke Conglomerate and must represent a complicated coalescence of range-bounding fans from both sides of the valley. There is no sedimentological distinction between the conglomerate and 'basin fill' exposures that crop out farther upstream in Aravaipa Valley.

The depositional environment of the Stowe Gulch facies of Klondyke Conglomerate is markedly different from that of the Hellhole Conglomerate. Paleoflow directional indicators and clast compositions are consistent with derivation from a Santa Teresa Mountain source area.
### Table 1: Summary of Tertiary Clastic Units

<table>
<thead>
<tr>
<th>Datum</th>
<th>Claystone Type</th>
<th>Paleoflow vector</th>
<th>Predominant clast lithology</th>
<th>Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klondyke Conglomerate</td>
<td></td>
<td>NE</td>
<td>Volcanics</td>
<td>Flat-lying</td>
</tr>
<tr>
<td>Fourmile Creek Facies</td>
<td></td>
<td>SW</td>
<td>Volcanics, Crystalline, Sediments</td>
<td>Flat-lying</td>
</tr>
<tr>
<td>Stowe Gulch Facies</td>
<td></td>
<td></td>
<td></td>
<td>Flat-lying</td>
</tr>
<tr>
<td>Hellhole Conglomerate</td>
<td></td>
<td>SW</td>
<td>Volcanics</td>
<td>Flat-lying</td>
</tr>
<tr>
<td>Ash intercalated within</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hellhole Conglomerate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crazy Horse Conglomerate</td>
<td></td>
<td>E</td>
<td>Volcanics, Crystalline</td>
<td>Tilted SW</td>
</tr>
<tr>
<td>Upper Andesite Member of the</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galileo Volcanics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crazy Horse Conglomerate</td>
<td></td>
<td>SW</td>
<td>Volcanics</td>
<td>Flat-lying</td>
</tr>
<tr>
<td>Apsey Conglomerate Member</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Of the Galileo Volcanics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hell's Half Acre Tuff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Klondyke Conglomerate:
  - Fourmile Creek Facies: NE, Volcanics
  - Stowe Gulch Facies: SW, Volcanics, Crystalline, Sediments
- Hellhole Conglomerate: SW, Volcanics
- Ash intercalated within Hellhole Conglomerate: 19.2 Ma
- Crazy Horse Conglomerate: E, Volcanics, Crystalline
- Upper Andesite Member of the Galileo Volcanics: 22.8 Ma
- Crazy Horse Conglomerate: SW, Volcanics
- Apsey Conglomerate Member: SW, Volcanics
- Hell's Half Acre Tuff: 23.1-25.3 Ma
CHAPTER 6
STRUCTURAL GEOLOGY

Faults
As is evident from the compilation map (plate 1), northeast-vergent normal faults striking between N30W and N70W are a pervasive feature of the study region. The northern Galiuro Mountains and the Mescal Mountains are cut by several high-angle normal faults. The low-angle Hawk Canyon fault may have approximately 10,000 ft of displacement to the northeast (S. Reynolds, pers. comm.). These faults displace Galiuro Volcanics and are therefore post-Oligocene in age.

In Aravaipa Valley, two northeast-vergent normal faults have been mapped. These faults, the Hellhole fault and the Stowe Gulch fault, are discussed below. The eastern margin of Aravaipa Valley is defined by the Grand Reef fault, a southwest-vergent high-angle normal fault. Displacement along this fault is inferred to have accompanied uplift of the Santa Teresa Mountains.

Hellhole Fault
The high-angle fault contact of the Hellhole Conglomerate and the Galiuro Volcanics is exposed in Aravaipa Canyon (plate 1). Elsewhere, the exposed contact between the two formations is depositional, although a fault contact is inferred at depth. Geophysical data compiled by Robinson (1975) indicate the existence of a steep fault dipping to the northeast. Based on the geophysical data, the hanging-wall has been offset between 1200 m and 2500 m. The fault, here named the Hellhole fault, strikes N-S to N8W.

A more recently active extension of this fault crosses Fournmile
Creek and forms the contact between the Galiuro Volcanics and the Klondyke Conglomerate (plate 1). The fault trace is marked by a zone of unconsolidated volcanic fragments and gypsum 5-10 m thick. Here, the fault strikes N38W and latest movements on it postdate deposition of the Hellhole Conglomerate. This is inferred from the apparent offset of the Hellhole and Klondyke Conglomerates within Fourmile Creek.

Stowe Gulch Fault

The Stowe Gulch facies of the Klondyke Conglomerate is in fault contact with the Hellhole Conglomerate and the tilted Tertiary volcanics exposed to the west (plate 1). The fault strikes N15W and dips 60 degrees to the northeast (photo 11). Exposure is poor. A fault along the eastern edge of the discontinuous belt of Tertiary volcanics within Aravaipa Valley was surmised by Ross (1925) and Simons (1964) in their respective maps. Topographic evidence for such a fault is strong. Minimum displacement along the fault is over 300 m based on the inference that movement along this fault opened the basin in which the Klondyke Conglomerate was deposited. Maximum displacement could be considerably greater.

Folds

The Hellhole Conglomerate is primarily a flat-lying formation. Throughout much of the area, bedding dips rarely exceed 10 degrees. However, in two northwest-trending zones that roughly parallel the strike of the basin, the Hellhole Conglomerate has been deformed into
Photo #11: Stowe Gulch fault - The footwall contains Tertiary volcanics; the hanging wall contains Klondyke Conglomerate.
Photo 12: Hellhole Conglomerate monocline; Photo view is approximately parallel to the strike of the fold.
an abrupt monocline and a gentle syncline (Plate 1).

**Hellhole Monocline**

The Hellhole monocline bisects the north-south length of the basin. The arcuate trace of the fold hinge trends N10W-N48W. Deformed beds dip gently to very strongly to the northeast. The length of the fold axis is roughly 10 km and stretches from Arizona Gulch in the northern part of Hellhole basin to Fourmile Creek. In a zone of maximum deformation, dips approach 80-90 degrees and, in one section, are slightly overturned. Along strike to the northwest and southeast of this zone, dips quickly flatten to 20 degrees and less. Beds of the Klondyke Conglomerate dip up to 15 degrees to the northeast near the southern terminus of the fold.

At a maximum, the structure is about 1.5 km in width. Detailed dip measurements, recorded along a transect perpendicular to the well defined segment of the fold, allow an estimate of shortening due to folding. Shortening of the Hellhole unit across the monocline is roughly 315 m.

**Turkey Creek Syncline**

A broad syncline, centered along Turkey Creek, parallels the trend of the monocline. Dips within the northeast limb of the syncline are very shallow, well within the range of depositional dips. However, the southwest limb dips up to 20 degrees to the northeast and away from the western margin of the basin.
CHAPTER 7
DISCUSSION

Tectonic Overview

The extensional tectonic environment of the Basin and Range province during late Oligocene and early Miocene time is well documented (Anderson, 1971; Davis and Coney, 1979; Davis and others, 1980; Shafiqullah and other, 1980; Rehrig and Reynolds, 1980; Davis and Hardy, 1981). Upper crustal distension was achieved by brittle distension and rotation above a zone of ductile shear. Characteristic products of extension are "allochthons of moderately to steeply dipping hanging-wall rocks in very low angle fault contact on structurally deeper, generally older footwall rocks" (Davis and Hardy, 1981). The Basin and Range province is subdivided into 'tilt-block' domains, regions in which there is a uniform dip direction of hanging-wall strata and uniform vergence indicated by the underlying detachment faults (Spencer and Reynolds, 1986).

The Santa Teresa Mountains-Mescal Mountains-Aravaipa Valley region to the north and east of the Galiuro Mountains is part of a tilt-block domain. Allochthonous detachments of Precambrian, Paleozoic, Cretaceous and Tertiary strata comprise the Mescal Mountains and the western flank of the Santa Teresa Mountains. The strata dip uniformly to the southwest and were faulted into position by northeast-directed translation along underlying, low-angle, detachment faults. The Eagle Pass detachment fault, described by Davis and Hardy (1981), is a well exposed segment of these underlying faults.
Basin Geometry of the Hellhole Conglomerate

Several lines of evidence suggest that the Hellhole Conglomerate filled a half-graben basin. Gravity profiles (Robinson, 1975) exhibit the asymmetric shape of the Hellhole basin. The keel of the basin is offset to the west from the center line. The differential tilt of the volcanic rocks on either side of the basin indicates a listric geometry for the basin-soling fault at depth (Wernicke and Burchfiel, 1981). The rotation of the volcanic rocks on the east side of the basin to their current southwest dip was accomplished by listric normal displacement along the Hellhole fault and by coordinated tear faulting within the 'detached' volcanic strata. The Hellhole half-graben basin opened with rotation of the volcanic rocks.

The shape of a half-graben basin holds implications for sedimentation patterns within the Hellhole Conglomerate. Because the surface area of the hanging-wall is broad relative to the surface area of the steeper foot-wall, streams draining the tilted hanging-wall block may have larger watersheds than corresponding streams draining the foot-wall block (Leeder and Gawthorpe, 1987). Consequently, within the Hellhole Conglomerate, sediment derived from the hanging-wall is spatially more extensive.

Mid Tertiary Geologic History of Aravaipa Valley

The sedimentology and structure of the conglomerate units
1. Hellhole fault: the Hellhole fault cuts lowermost Hellhole Conglomerate and is overlain by subsequent beds of the conglomerate. The fault is inferred to be listric at depth, because of the southwest tilt of the Tertiary Volcanics (2.)


4. Grand Reef fault: SW-side-down high-angle normal fault

5. Black Rock detachment fault: NE-vergent low-angle normal fault
discussed in the preceding chapters can be used to reconstruct a
geologic history for Aravaipa Valley during mid-Tertiary time.

Widespread Oligocene volcanic eruptions predated the surface
expression of regional extension. Synvolcanic deposition of the Apsey
Conglomerate member of the Galiuro Volcanics filled a basin within the
volcanics of the northern Galiuro Mountains. Rotation and translation
of the tilted volcanics and underlying strata occurred as the extended
terrane began to deform in a brittle fashion, breaking up into tilt-
block ranges and half-graben basins.

Fanning dips within the upper section of the Crazy Horse
Conglomerate suggest that deposition, at least of the upper section of
this unit, was synchronous with regional tilting. The chronological
relationship between the Crazy Horse Conglomerate and the Apsey
Conglomerate Member of the Galiuro Volcanics is unclear. The mere
presence of these coarse, clastic units indicates that detachment
faulting was active in this area at this time.

In contrast, the exposed section of the Hellhole Conglomerate
postdates active rotation of the volcanic rocks. With the exception of
the folded beds, the Hellhole Conglomerate is a flat-lying unit.
Gentle dips (<10 degrees) throughout the conglomerate are interpreted
as depositional dips. Due to the nature of its basin however, the
Hellhole Conglomerate is inferred to be syntectonic at depth (Cross
Section, Figure #9). The primarily depositional contact along the
Hellhole fault supports post-tectonic deposition. Evidence for
movement along the Hellhole fault is exposed at the lowest point on the
western contact of the basin. Activity along this fault soon after
ceased and the Hellhole Conglomerate abutted and overlapped the steep western margin of its basin. The lower Hellhole Conglomerate is radiometrically dated at 19.2 Ma. Movement on the Hellhole fault, and consequent tilting of the Oligocene volcanics within Aravaipa Valley, is therefore constrained to a period before 19.2 Ma.

The primary source area for the Hellhole Conglomerate is inferred to be a volcanic highland to the northeast of the formation. Northeast-side-down movement on the Stowe Gulch fault downdropped the volcanic source area and contributed to the cessation of deposition within the Hellhole basin. A resultant basin to the northeast is filled with the Stowe Gulch facies of the Klondyke Conglomerate. Clast compositions within this unit imply uplift and exposure of the Santa Teresa Mountains. It is important to note that Santa Teresa Mountain rock types were not exposed during the deposition of the Hellhole Conglomerate.

Speculations: Compression (?) of the Hellhole Conglomerate

The Hellhole Conglomerate was deformed by NE-SW directed compressional strain, resulting in the two folds within the conglomerate. Compressional structures associated with an extensional tectonic regime are observed in other areas. Spencer (1985) records Tertiary thrust faults in the Homer Mountains of the Colorado River basin. Wernicke and Axen (1988) describe basement-cored anticlines and near vertical faulting in the foot-wall of the Virgin - Beaver Dam breakaway fault of northwestern Arizona. Spencer (1985) attributes
middle Tertiary compression to the evolution of an extensional regime. Crustal extension is achieved along low-angle detachment faults. Continued extension along the detachment faults can result in isostatic uplift as a response to thinning of the crust. An effect of this uplift is concave-upward flexure of the flanks of the uplifted block (Spencer, 1984). Concave-upward flexure of the western flank of the Santa Teresa Mountains could have resulted in the compressional structures observed in the Hellhole Conglomerate.

The mechanics of compressional deformation due to the upward flexure of the Santa Teresa Mountains can be modeled mathematically. The degree of flexure of the Santa Teresa Mountains (x), total shortening (s), and crustal depth to the neutral surface (n) are related in the following formula:

\[ \tan (x) = \frac{s}{n} \]

Total shortening across the Hellhole monocline is estimated to be 0.3 km. This represents a minimum value for (s). The depth to the neutral surface for the Santa Teresa Mountains is estimated at 6 km to 12 km, based on the work of Brace and Kohlstedt (1980) on lithologic stress envelopes. The calculated values for (x) are then:

\[ x = 3.16 \text{ degrees}; \, n = 6 \text{ km} \]
\[ x = 1.33 \text{ degrees}; \, n = 12 \text{ km} \]

This result (1-3 degrees) is well within the range of possible
flexure values for the Santa Teresa Mountains. The Eagle Pass detachment surface, inferred to be a northeast-vergent, low-angle fault, is tilted to the southwest (plate 1). This represents up to 20 degrees of rotation to the southwest which may be the result of isostatic doming and flexure of the Santa Teresa Mountains.

A second explanation for local compression within the Hellhole Conglomerate is uplift of the Stowe Gulch fault footwall. Footwall uplift associated with normal faults can result from elastic rebound due to release of stress across the fault or from isostatic response of the foot-wall to the unloading of the hanging-wall (Jackson and Mckensie, 1983). The Hellhole Conglomerate, exposed within the footwall of the Stowe Gulch fault, may have been deformed in this fashion during the opening of the Klondyke Conglomerate basin to the east.

A final option to consider is that the Hellhole monocline is associated with the Basin and Range Disturbance. Perhaps displacement along high-angle normal faults such as the Grand Reef fault and the Hellhole fault south of Fourmile Creek, coincident with isostatic rise within the Santa Teresa Mountains, created the compressive vectors needed to account for the Hellhole monocline.
LIST OF REFERENCES


and western Arizona. in Crittenden, M.D., Jr., Coney, P.J. and Davis, G.H., eds., Cordilleran metamorphic core complexes. Geological Society of America Memoir 153: 79-130


