GEOLOGY OF HAWK CANYON, ANZA-BORREGO DESERT STATE PARK, CALIFORNIA

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Abstract

Hawk Canyon is located in the West Borrego Mountain area in Anza-Borrego Desert State Park. This particular area has been studied insufficiently and is therefore poorly understood. This project served to increase the overall geologic knowledge of Hawk Canyon and its adjacent western sediments. It resulted in the development of a detailed geologic map and a comprehensive geologic interpretation of the area. The surface geology map constructed during this project contained abundant structural data, particularly in the western sediments, allowing for stereonet interpretation of general bedding trends and faults. The structural data was also utilized to hypothesize the presence of a significant western listric normal fault which has led to the current orientation of this project's lithologic units. Further surface mapping is required to pinpoint the location of the listric fault. Activity along this fault and a major normal fault that bounds the east side of West Borrego Mountain may still be ongoing. My map indicates locations of various other faults throughout the study area as well. In addition, surface mapping allowed a description of the site's lithologic units and the calculation of their thicknesses. The derived thicknesses resulted in a true scale stratigraphic column and several cross sections to be developed for the area. No detailed local stratigraphic columns or cross sections had previously been published of Hawk Canyon. Constraining the thicknesses of the units is also useful for geologic history interpretation. Referencing these thicknesses supplies insight into the duration and timetable of regional tectonic events. The lithologic descriptions offer information on the nature of these tectonic events. This study has increased the understanding of the local geology and will serve as a tool for future research.

Introduction

Purpose and Objectives

The main purpose of this project is to add to the overall geologic knowledge of Hawk Canyon and its vicinity. My objectives were to create a surface geologic map of Hawk Canyon and its adjacent western sediments, and to draw cross sections to constrain unit thicknesses and the general three dimensional interpretation. Previously published maps of this area have been rather general and do not include much structural data. The map developed during this project aims to be more complete and contains ample structural data, especially in the western sediments as the data pertaining to these sediments in previous maps is particularly limited. The map spans from the eastern boundary fault of Hawk Canyon to the western edge of a narrow canyon called "The Slot."

The data compiled during the mapping process will then be utilized to investigate the structural geology of the area. This will be done by employing a combination of stereonets, cross sections, and a stratigraphic column. The stereonets will display data pertaining to sedimentary bedding and faults. The fault stereonets should prove to be notably useful as they will enable the determination of the regional stresses that have resulted in the present state of Hawk Canyon. Lastly, the findings of this project will be combined with the previous work done in this area to formulate a general description of Hawk Canyon's geology. This will include a description of the foremost lithologic units in the province. Along with this description will be the interpretation of Hawk Canyon's varying depositional environments and a discussion of its cumulative geologic history.

Figure 1. Map of Southeastern California with study area indicated. Map compliments of <http://www.parks.ca.gov>

Regional Geology

Hawk Canyon is located in Anza-Borrego Desert State Park in the western Salton trough of Southern California. The region is well known for its complexity and extensive geologic record. Late Cenozoic faulting is common throughout the zone, mainly in the form of normal faulting and right-lateral strike-slip faulting (Figure 4, Table 1). Much of the area is considered part of the San Andreas Fault system, which records the more recent fault displacements within a long-lived transtensional plate boundary. This system delineates the boundary between the Pacific plate and the North American plate and is especially seismically active as a result. The Pacific plate's northern movement over the past 25 to 30 million years has produced a complicated network of faults, mountain fronts and sedimentary basins.

Over the past 10 to 15 million years, the two plates have displayed a minor extensional component which has caused the Salton Trough and Gulf of California to open up (Dorsey, 2005). The main structure responsible for this extension in the western Salton Trough is the low-angle west Salton detachment fault. The extension has led to an influx of sediment accumulation throughout the region during the Miocene and Pleistocene. The evolution of this area during this time period can generally be divided into three stages:

1. Early (?) to late Miocene sedimentation, volcanism, and formation of non-marine rift basins
2. Pliocene to early Pleistocene extension and transtension (combined extension and strike-slip motion) on a system of regional detachment faults (Figure 2). This also included the formation of a large basin that initially filled with

marine sediments followed by terrestrial sediments. The terrestrial sediments were mostly deposited by the Colorado River.

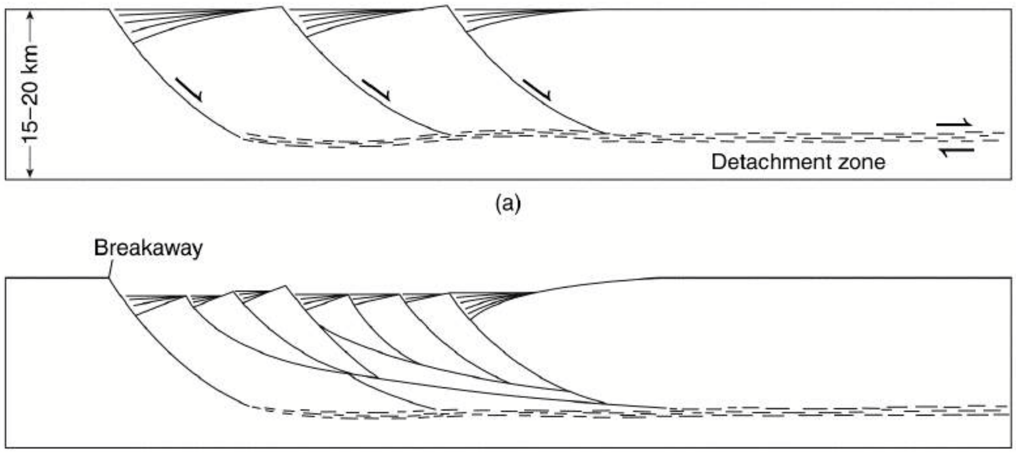


Figure 2. Model of a detachment fault system similar to the one responsible for the creation of the Salton Trough <http://ic.ucsc.edu/~casey/eart150/Lectures/3NormStrkSlpFlts/4Thrust.Normal_StrkSlp_flts.htm>

3. Pleistocene to present (Holocene) strike-slip faulting causing folding in the San Jacinto and Elsinore fault zones, resulting in uplift and erosion of the older deposits

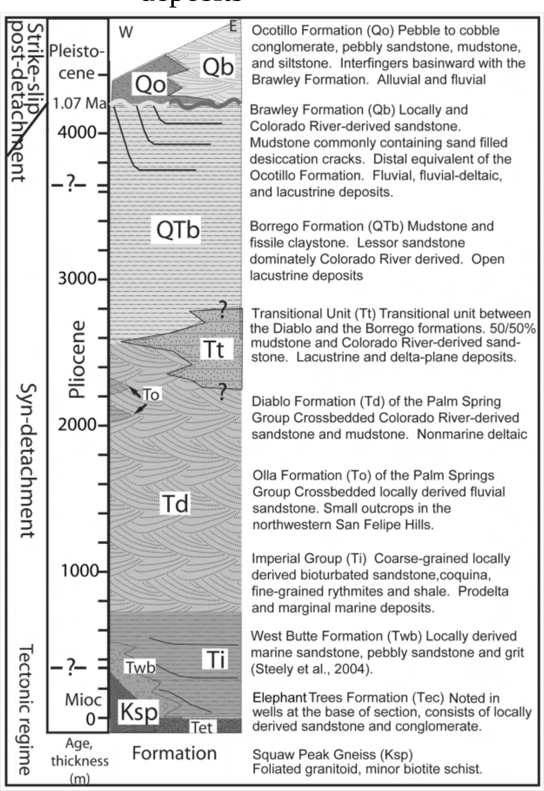


Figure 3. Typical stratigraphic column of the western Salton Trough (Kirby et. al., 2007)

Due to the influx of sediment as a result of subsidence, the region is predominately comprised of various sedimentary units (Figure 3).

The sediments indicate a fluctuating fluvial environment consistent with the three stage timeline previously discussed. “The sediments were dated using a combination of micropaleontology, vertebrate paleontology, geochronology, and paleomagnetism studies”

(Dorsey, 2005). In 1998, Axen and Fletcher determined the Imperial Group, Palm Spring Group and perhaps the upper part of the Split Mountain Group were all deposited in a vast sedimentary basin just east of the west Salton detachment fault system. This determination indicated slip along the west Salton detachment fault system probably began in the late Miocene and continued into the early Pleistocene. This resulted in subsidence accompanied by an increased accumulation of sediment, leading to the creation of the Salton Trough of Southern California. The slip on the detachment fault was mostly terminated by the initiation of strike-slip faulting. The strike-slip faulting is the main component still active today and has resulted in a complex and strongly seismically active region.

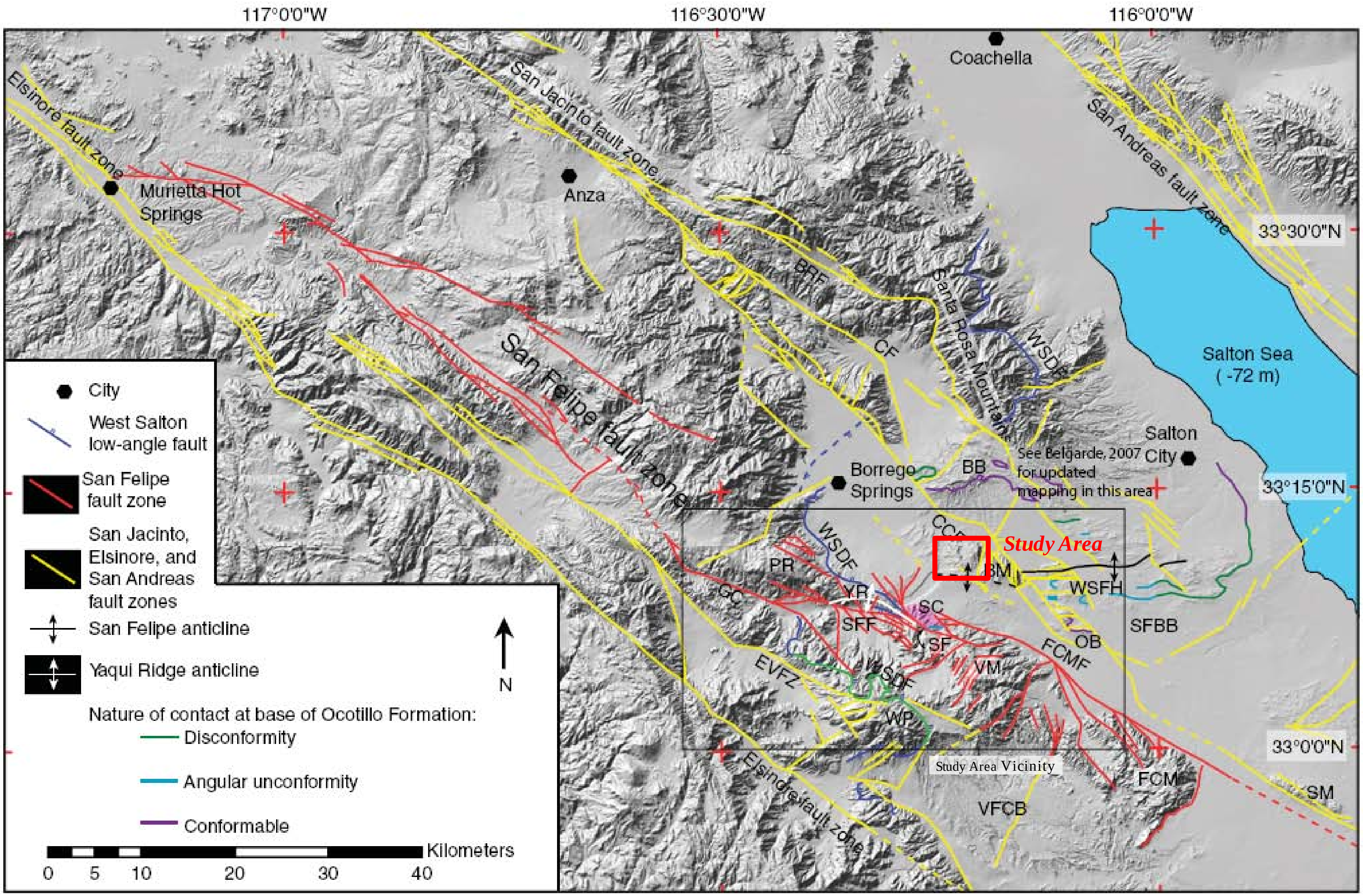


Figure 4. Regional fault map. Faults are compiled and modified from Rogers (1965); Jennings (1977); Kennedy and Morton (1993); Kirby (2005); Lutz (2005); Kennedy (2000, 2003;) and Steely (2009). Map from Steely et al GSA Bulletin 2009. Abbreviations: BB—Borrego Badlands; BM—Borrego Mountain; BRF—Buck Ridge fault; CCF—Coyote Creek fault; CF—Clark fault; EVFZ—Earthquake Valley fault zone; FCM—Fish Creek Mountains; FCMF—Fish Creek Mountains fault; GC—Grapevine Canyon; OB—Ocotillo Badlands; PR—Pinyon Ridge; SC—Sunset Conglomerate of the Ocotillo Formation (pink); SF—Sunset fault; SFF—San Felipe fault; SFBB—San Felipe-Borrego subbasin; SM—Superstition Mountain; VFCB—Vallecito–Fish Creek subbasin; VM— Vallecito Mountains; WP—Whale Peak; WSDF—West Salton detachment fault; WSFH—western San Felipe Hills; YR—Yaqui Ridge.

Abbrev.	Fault Name	Type of Movement	Length (km)	Slip Rate (mm/yr)	Probable Magnitude (M_w)	Last Major Rupture	Magnitude	Recurrence Interval
BFZ	Brawley Fault Zone	Right-lateral strike-slip	15	20	5 to 6.5	October 15, 1979	6.4	Unknown
BSZ	Brawley Seismic Zone	Right-lateral strike-slip	45	-	-	-	-	-
CCF	Coyote Creek Fault	Right-lateral strike-slip	80	2 to 6	6.5 to 7.5	April 9, 1968	6.5	100 to 300 years
EVFZ	Earthquake Valley Fault Zone	Right-lateral strike-slip	25	1.0 to 3.0	6.0 to 7.0	Holocene	-	Unknown
ERFZ	Elmore Ranch Fault Zone	Left-lateral strike-slip	10	0.5 to 1.5	5.8 to 6.5	November 23, 1987	6.2	150 to 300 years (?)
EFZ	Elsinore Fault Zone	Right-lateral strike-slip	180	4.0	6.5 to 7.5	May 15, 1910	6.0	250 years
HSF, BRF	Hot Springs and Buck Ridge Faults	Right-lateral strike-slip	75 (w/ CF)	-	-	Holocene	-	-
IF	Imperial Fault Zone	Right-lateral strike-slip	69	15 to 20	6.0 to 7.0	October 15, 1979	6.4	30-40 years of 6.4 (1979)
						May 19, 1940	6.9	700 years for 6.9 (1940)
SAF	San Andreas Fault Zone	Right-lateral strike-slip	1200	20 to 35	6.8 to 8.0	January 9, 1857	7.9 (approx.)	140 year average
SJFZ	San Jacinto Fault Zone	Right-lateral strike-slip	210 (w/ CCF)	7 to 17	6.5 to 7.5	April 9, 1968	6.5	100 to 300 years per segment
SHF	Superstition Hills Fault	Right-lateral strike-slip	30	1.7 to 5.5	6.0 to 6.8	November 24, 1987	6.6	150 to 300 years
SMF	Superstition Mountain Fault	Right-lateral strike-slip	28	5.0 to 9.0	6.0 to 6.8	Holocene	-	Unknown

Table 1. Regional and local fault data. Data compliments of Southern California Earthquake Data Center. <http://www.data.scec.org/index.html>

Field Site Description

Hawk Canyon is located in Borrego Mountain in Anza-Borrego Desert State Park. Borrego Mountain is west of CA-86, north of CA-78 and east of CA-79 (Figure 5). The area is fairly remote and only accessible by a dirt road. To get to Hawk Canyon from Borrego Springs, take Borrego Springs Road southeast. Turn left on CA-78. After approximately one mile, turn left on Buttes Pass Road. Note that this road is unpaved; however it is marked by a small sign. The road forks after about one mile. Stay right at this fork. Take the next left to gain entrance to Hawk Canyon.

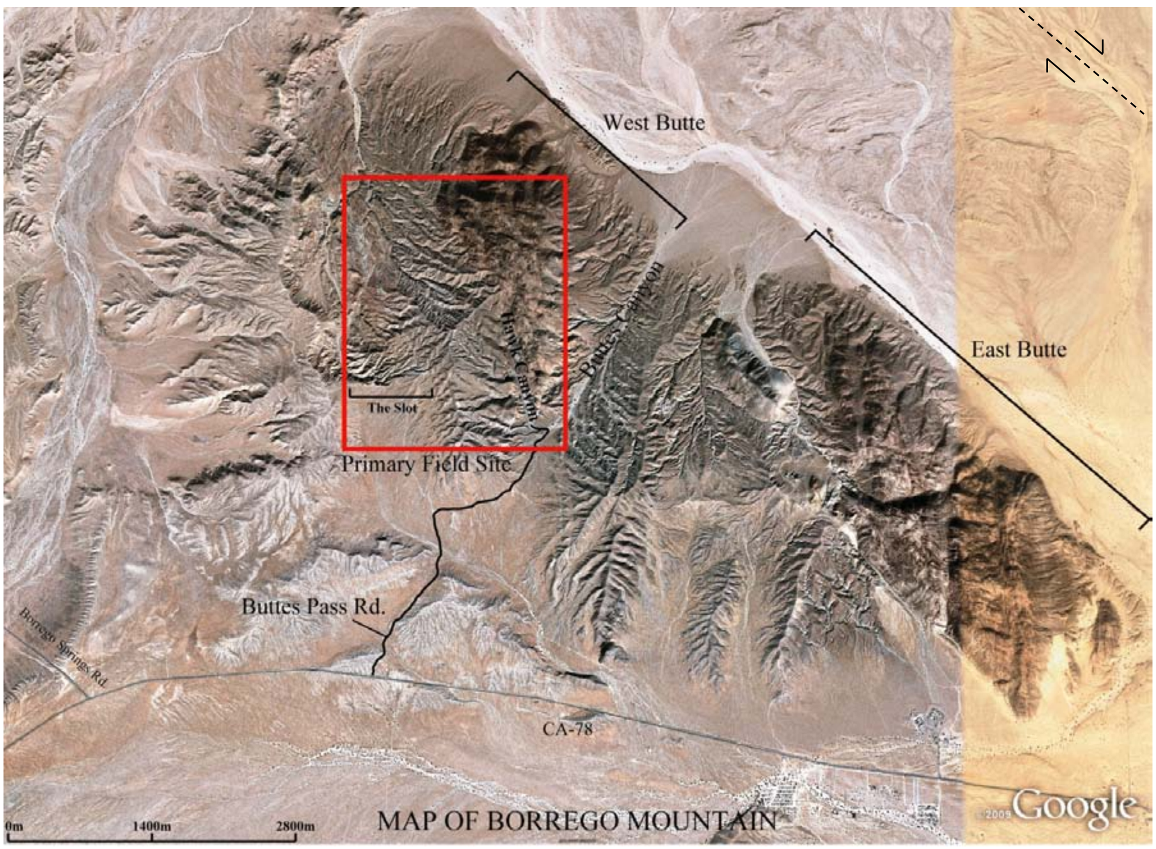


Figure 5. Overview map of Borrego Mountain with field site indicated

Hawk Canyon is located at about 700 feet of elevation in West Butte of Borrego Mountain at the mouth of Buttes Canyon. It is in desert climate and is therefore a very arid region. The land is only used for recreation and various types of research as it is a protected state park. There is minimal vegetation cover in the area and there is no known local water source. The climate has extreme fluctuations like most desert climates. The region averages 6.86 inches of rain per year but is susceptible to flash flooding. Temperatures average a low of 43°F in January and an average high of 107°F in July. However, it is not uncommon for the daily high and low to vary by upwards of 50°F. Strong winds with speeds in excess of 20 miles per hour are not uncommon in Hawk Canyon.

Discussion of Previous Work Done in Hawk Canyon

Very little previous research has been published about Hawk Canyon. The most pertinent publication was written in 1995 and is entitled "Neogene Stratigraphy of the Borrego Mountain Area, Anza-Borrego Desert State Park, California" authored by C. Herzig, A Carrasco, G. Murray, D. Rightmer, J. Lawrence, Q. Milton, and T. Wirths of San Diego State University. This study focused on creating an overview analysis of the strata exposed in Borrego Mountain. Within the analysis are a general surface map, stratigraphic column and brief descriptions of the lithologic units of Borrego Mountain. This paper will be used to assist in the geologic analysis of Hawk Canyon.

Alexander Steely's dissertation is entitled "The evolution from late miocene [sic] West Salton detachment faulting to cross-cutting Pleistocene oblique strike-slip faults in the SW Salton Trough, Southern California" and was written in 2006. The reconnaissance mapping Steely conducted for his project extended into my study area.

Multiple other sources are relevant to Hawk Canyon but focus only on areas in its vicinity or its region as an entirety. These will also be used to derive information about local geology.

Observational Data

Field Techniques

The main field objective of this project was to create a detailed surface map of Hawk Canyon and its western sediments. The map was drafted over a series of trips to the study area. A digital United States Geological Survey topographic map was obtained from their public database. My advisor and professor at the time, Dr. Jonathan Nourse, acquired and overlaid this map with a Universal Transverse Mercator (UTM) coordinate system grid. This was done using computer software called ArcGIS. The grid is displayed in the NAD 27 MEXICO datum. Mapping was then conducted at the field site using a Garmin GPSMAP 76CSx global positioning system. The unit was configured to utilize the NAD 27 MEXICO datum and the coordinates were set to be displayed in UTMs.

Elevation measurements in this project are from the USGS topographic map rather than the GPS unit. This was decided in an effort to reduce error and increase the functionality of the project's completed map (See Figure 6 for completed map). Waypoints were taken along the boundaries of the mapped rock units as well as points in which orientation data was collected. The GPS waypoints and corresponding structures were then plotted on the field map utilizing the overlaid UTM grid. This was completed in the field, allowing visual relationships to be taken into account while mapping. All orientation data was acquired using a Brunton GEO Pocket Transit compass with a 0-360° scale or a similar instrument. Rock sample collecting is strictly prohibited in Anza-Borrego State Park by California law unless permitted by the state. This resulted in no rock sample collection in the field site. However, lithologic descriptions were noted while mapping of the area was conducted.

All of this project's GPS data was recorded in a field notebook and is tabulated below in Table 2. This table indicates the coordinates of all the GPS waypoints taken along with their corresponding notes. The notes distinguish the type of structure being located or measured at the particular waypoint. All of the orientation data recorded in this project is organized by the structure it was measured on in Table 3.

Global Positioning System (GPS) Data and Notes

Table 2. Global positioning system (GPS) data and corresponding field notes

Hawk Canyon, Anza-Borrego, California
Datum: NAD 27 Mexico

		UTM Coordinates				*Rock Type*		*In Contact With*		*Fault*		
WP #	**Date**	**East**	**North**	**Rock Type**	**In Contact With**	**Strike**	**Dip**	**Strike**	**Dip**	**Strike**	**Dip**	**Other Notes**
Now entering Hawk Canyon												
001	12/16/08	0574271	3671374	Sedimentary Breccia	Tonalite							Contact where breccia fragments are cobble sized directly against tonalite
002	12/16/08	0574295	3671351	Pegmatite in Tonalite		118	65SW					
003	12/16/08	0574267	3671356	Bedded Sandstone	Tonalite							Sandstone atop and directly in contact with Tonalite. Sedimentary Breccia pinched out
004	12/16/08	0574264	3671329									
005	12/16/08	0574246	3671311	Bedded Sandstone + Tonalite	Alluvium							Contact intersects the road
006	12/16/08	0574244	3671346	Bedded Sandstone	Alluvium	165	22SW					6 meters to east this Sandstone overlies the Sedimentary Breccia
007	12/16/08	0574248	3671375	Sedimentary Breccia	Tonalite							
008	12/16/08	0574238	3671370	Sedimentary Breccia	Bedded Sandstone			146	22SW			Alluvium contact is 10 meters to east
009	12/16/08	0574193	3671284	Lower Red Sandstone	Green Siltstone	356	27SW					3 meters west of Alluvium contact, 3 meters west of green siltstone/sandstone. Following 1 meter thick red unit
010	12/16/08	0574199	3671231	Lower Red Sandstone	Green Siltstone							
011	12/16/08	0574170	3671211	Green Siltstone	Red Siltstone							Top of green Siltstone with bottom of Red Siltstone. 20 meters up west of 1m thick red Sandstone
012	12/16/08	0574132	3671230	Red Siltstone	Cliff-Forming Sandstone			353	37SW			Top of red Siltstone, bottom of cliff-forming sandstone. Sandstone/conglomerate has rounded, sub-angular pebble sized clasts
013	12/16/08	0574126	3671456	Green Siltstone	Red Siltstone							Upper green Siltstone, Lower red Siltstone
014	12/17/08	0574156	3671617	Sedimentary Breccia	Tonalite							Tonalite on east, Breccia on west
015	12/17/08	0574135	3671669	Sedimentary Breccia	Tonalite							Tonalite on east, Breccia on west
016	12/17/08	0574117	3671694	Sedimentary Breccia	Bedded Sandstone			336	24SW			Bedding was taken 5 meters north of waypoint
017	12/17/08	0574095	3671607	Green Siltstone	Alluvium							Alluvium to east
018	12/17/08	0574068	3671635	Green Siltstone	Red Siltstone							Top of green, bottom of red
019	12/17/08	0574045	3671652	Red Siltstone	Cliff-Forming Sandstone			156	14SW			Bedding was taken 5 meters west of waypoint

020	12/17/08	0574062	3671558	Green Siltstone	Red Siltstone							Top of green, bottom of red
021	12/17/08	0574076	3671568	Green Siltstone	Alluvium							
022	12/17/08	0574111	3671510	Green Siltstone	Red Siltstone							Green to east
023	12/17/08	0574104	3671495	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
024	12/17/08	0574089	3671517	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
025	12/18/08	0574054	3671558	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
026	12/18/08	0574126	3671528	Green Siltstone	Alluvium							Green to west
027	12/18/08	0574136	3671481	Green Siltstone	Alluvium							Green to west
028	12/18/08	0574134	3671468	Green Siltstone	Red Siltstone							Red to west
029	12/18/08	0574113	3671469	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
030	12/18/08	0574147	3671437	Alluvium	Green Siltstone							Green to west
031	12/18/08	0574111	3671409	Alluvium	Red Siltstone							Red to west, green unit pinched out
032	12/18/08	0574104	3671416	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
033	12/18/08	0574094	3671395	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
034	12/18/08	0574103	3671311	Red Siltstone	Cliff-Forming Sandstone			330	20SW			Sandstone to west
035	12/18/08	0574137	3671338	Red Siltstone	Green Siltstone							Red to west
036	12/18/08	0574164	3671370	1m thick Red Sandstone	Green Siltstone							Green to west
037	12/18/08	0574165	3671354	1m thick Red Sandstone	Green Siltstone			334	15SW			Green to west, bedding taken 5 meters west of waypoint
038	12/18/08	0574162	3671274	Green Siltstone	Red Siltstone							Red to west
039	12/18/08	0574135	3671269	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
040	12/18/08	0574132	3671252	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
041	12/18/08	0574172	3671252	Green Siltstone	Red Siltstone							Red to west
042	12/18/08	0574202	3671231	Lower Red Sandstone	Lower Green Sandstone							New green unit is siltstone/sandstone
043	12/18/08	0574208	3671212	Lower Green Sandstone	Alluvium							Green to west
044	12/18/08	0574211	3671188	Lower Green Sandstone	Alluvium							Green to west, Red siltstone is 10 meters north from this point
045	12/18/08	0574178	3671168	Green Siltstone	Alluvium							Green to west
046	12/18/08	0574159	3671191	Green Siltstone	Red Siltstone							Red to west
047	12/18/08	0574150	3671158	Red Siltstone	Alluvium							Red to west
048	12/18/08	0574122	3671170	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west

049	12/18/08	0574024	3671521	Cliff-Forming Sandstone		166	16SW					Camp
050	12/18/08	0574085	3671654	Green Siltstone	Alluvium							Green to west
051	12/18/08	0574053	3671708	Red Siltstone	Colluvium							Red to west
052	12/18/08	0574038	3671694	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west, red siltstone pinches out (inferred)
053	12/18/08	0574030	3671733	Cliff-Forming Sandstone	Colluvium	335	15SW					10 meters to northeast the red member reamerges
054	12/18/08	0574018	3671752	Cliff-Forming Sandstone	Red Siltstone							Sandstone to west, colluvium projects 15 meters northeast from this point + 7 meters to west
055	12/18/08	0573990	3671784	Colluvium	Cliff-Forming Sandstone							Sandstone to west
056	12/18/08	0574023	3671821	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
057	12/18/08	0574039	3671821	Green Siltstone	Red Siltstone							Red to west
058	12/18/08	0574042	3671802	Colluvium	Green Siltstone							Green to west of colluvium. Also Red Siltstone contact with Tonalite
059	12/18/08	0574057	3671824	Tonalite	Sedimentary Breccia							Breccia north of tonalite with green siltstone west and in contact with both
060	12/18/08	0574039	3671845	Green Siltstone	Bedded Sandstone							Breccia is directly under the sandstone
061	12/18/08	0574038	3671863	Fault						315	72SW	NORMAL FAULT, displacment of 2 meters, bottom of green Siltstone and Sandstone
062	12/18/08	0574035	3671894	Green Siltstone	Sedimentary Breccia							Bottom of green Siltstone with underlying Sandstone and Sedimentary Breccia, Green unit 6-8 meters thick
063	12/18/08	0574022	3671883	Red Siltstone	Bedded Sandstone							
064	12/18/08	0574011	3671907	Red Siltstone	Bedded Sandstone							
065	12/18/08	0574030	3671902	Green Siltstone	Bedded Sandstone			343	27SW			
066	12/18/08	0574008	3671928	Red Siltstone	Bedded Sandstone							
067	12/18/08	0573998	3672017	Red Siltstone	Tonalite							Green Siltstone pinched out, Tonalite to east
068	12/18/08	0573988	3672001	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
069	12/18/08	0574014	3672014	Red Siltstone	Tonalite							Tonalite to east
070	12/18/08	0573988	3672033	Red Siltstone	Tonalite							Tonalite to east
071	12/18/08	0574003	3672131	Sedimentary Breccia	Tonalite	350	06SW					Sedimentary Breccia is 7-10 meters thick and sits below the red unit
072	12/18/08	0574006	3672137	Sedimentary Breccia	Tonalite							Saddle
Now leaving Hawk Canyon and entering the slot												
073	12/19/08	0573343	3671582	Sandstone		166	19SW					Sandstone Conglomerate, light brown/brown
074	12/19/08	0573230	3671607	Sandstone + Siltstone		185	14NW					Fine sand-sized grains with siltstone beds, about 10 meters thick

075	12/19/08	0573149	3671564	Sandstone		015	22NW					Sandstone beds with conglomerate. Less than 5% conglomerate, mostly fine sandstone
076	12/19/08	0573019	3671514	Sandston + Siltstone		173	35SW					Sandstone with silt beds, mostly sandstone
077	12/19/08	0572937	3671477	Sandstone								Green and Red Siltstone exposed in a cliff about 13 meters above us in cliff
078	12/19/08	0572813	3671528	Red and Green Siltstone	Sandstone	355	17SW					Red and Green Siltstone is to the northwest of the sandstone
079	12/19/08	0572791	3671516	Red and Green Siltstone	Fine Sandstone							Fine Sandstone is overlying the red and green Siltstone
080	12/19/08	0572840	3671549	Red and Green Siltstone	Sandstone							Bottom of red and green Siltstone
081	12/19/08	0572847	3671565	Red and Green Siltstone	Fine Sandstone							Top of red and green Siltstone
082	12/19/08	0572880	3671593	Red and Green Siltstone	Sandstone							Bottom of red and green Siltstone
083	12/19/08	0572872	3671585	Red and Green Siltstone	Fine Sandstone							Top of red and green Siltstone
084	12/19/08	0572819	3671500	Red and Green Siltstone	Fine Sandstone							Top of red and green Siltstone
085	12/19/08	0572857	3671511	Red and Green Siltstone	Sandstone							Bottom of red and green Siltstone
086	12/19/08	0572871	3671508	Red and Green Siltstone	Fine Sandstone							Top of red and green Siltstone, fine sandstone and siltstones are above unit
Now leaving the slot and traversing back to Hawk Canyon through drainage												
087	12/19/08	0573496	3671620	Conglomerate		350	19SW					50-60% clasts, cobbled sized stones on some, well bedded - cobble & pebble conglomerate with coarse sandstone
088	12/19/08	0573620	3671606	Conglomerate		164	24SW					75-80% clasts but less cobble conglomerate
089	12/19/08	0573743	3671607	Conglomerate		049	08NW					40-50% clasts with sandstone
090	12/19/08	0573869	3671584	Conglomerate		068	15NW					50-80% clasts, large cobble beds
091	12/19/08	0573937	3671515	Conglomerate		156	24SW					80-90% clasts
092	12/19/08	0574005	3671512	Conglomerate	Cliff-Forming Sandstone	333	17SW					Contact above camp, bedding taken 8-10 meters west of waypoint
Now entering Hawk Canyon												
093	12/19/08	0574314	3671226	Sandstone	Tonalite							
				Fault						025	55SE	NORMAL FAULT
094	12/19/08	0574322	3671216	Sandstone		023	37NW					
095	12/19/08	0574219	3671138	Green Siltstone	Alluvium							Green to west
096	12/19/08	0574199	3671125	Green Siltstone	Red Siltstone							Red to west
097	12/19/08	0574126	3671097	Red Siltstone	Cliff-Forming Sandstone							Sandstone to west
098	12/19/08	0574096	3671084	Conglomerate	Cliff-Forming Sandstone	310	27SW					80-90% clasts

099	12/19/08	0574073	3671092	Conglomerate		182	20SW					
100	12/19/08	0574071	3671084	*Incorrect suspiscion of fault (omit from map)*						*195*		
101	12/19/08	0574091	3671082	Conglomerate		312	49SW					
102	12/19/08	0574087	3671122	Conglomerate	Cliff-Forming Sandstone			350	24SW			
103	12/19/08	0574086	3671040	Conglomerate	Cliff-Forming Sandstone							
104	12/19/08	0574137	3671047	Cliff-Forming Sandstone	Alluvium							
105	12/19/08	0574294	3671052	Conglomerate		097	47SW					
106	12/19/08	0574249	3671045	*Incorrect suspiscion of fault (omit from map)*								
002	10/10/10	0574085	3671484	Cliff-Forming Sandstone		149	17SW					
003	10/10/10	0574090	3671459	Cliff-Forming Sandstone		152	18SW					
004	10/10/10	0574122	3671451	Green Siltstone		168	33SW					
005	10/10/10	0574059	3671396	Red Siltstone		336	28SW					
006	10/10/10	0574109	3671343	Red Siltstone		330	31SW					
007	10/10/10	0574201	3671206	Lower Green Sandstone		163	18SW					
008	10/10/10	0574137	3671165	Red Siltstone		158	34SW					
Now mapping east of slot and west of Hawk Canyon												
009	10/10/10	0573451	3671462	Coarse Sandstone		154	19 SW					Coarse sandstone with some pebbles 1-10mm, averaging 5mm
010	10/10/10	0573487	3671309	Coarse Sandstone		341	28SW					
011	10/10/10	0573561	3671202	Conglomerate		291	34SW					Coarse conglomerate
012	10/10/10	0573644	3671092	Conglomerate		308	28SW					
013	10/10/10	0573616	3671240	Conglomerate		354	32SW					Boulders present
014	10/10/10	0573589	3671393	Conglomerate		323	26SW					Mainly pebbles
015	10/10/10	0573564	3671523	Conglomerate		331	29SW					Bedding on a 1/2 ft thick sandstone bed within conglomerate
016	10/10/10	0573597	3671219	Conglomerate		284	09SW					Conglomerate with small cobbles (5cm)
017	10/10/10	0573657	3671194	Conglomerate		338	18SW					Large cobbles present
018	10/10/10	0573717	3671176	Conglomerate		335	14SW					Large cobbles present
019	10/10/10	0573777	3671146	Conglomerate		333	25SW					
020	10/10/10	0573873	3671126	Conglomerate		336	16SW					Large cobble beds
021	10/10/10	0574012	3671094	Conglomerate		151	18SW					Large cobbles present

022	10/10/10	0574073	3671043	Conglomerate	Cliff-Forming Sandstone	325	21SW					
081	3/19/11	0574043	3671360	Conglomerate		004	36NW					
082	3/19/11	0573964	3671344	Conglomerate		110	26SW					
083	3/19/11	0573912	3671337	Conglomerate		105	27SW					
084	3/19/11	0573805	3671273	Conglomerate		355	35SW					
085	3/19/11	0573852	3671408	Conglomerate		135	36SW					
086	3/19/11	0573760	3671588	Conglomerate		032	26NW					
087	3/19/11	0573937	3671737	Conglomerate		267	17NW					
088	3/19/11	0573876	3671863	Conglomerate		333	23SW					
089	3/19/11	0573796	3671815	Conglomerate		125	24SW					
090	3/19/11	0573767	3671784	Conglomerate		135	20SW					
091	3/19/11	0573961	3671864	Fault						045	83SE	Fault can be traced at least 30 meters, multiple faults with this trend in area, would consider it a fault zone, no displacement, clay fault gouge
				Fault						332	84SW	Intersecting faults, no displacement seen on faults, clay present

Orientation Data by Structure

Table 3. Orientation data tabulated by source structure

Tonalite	**Sedimentary Breccia**	**Bedded Sandstone**	**Lower Green Sandstone**
	350/05SW	165/22SW	167/18SW
		146/22SW	
		336/24SW	
		023/37NW	
Lower Red Sandstone	**Green Siltstone**	**Red Siltstone**	**Cliff-Forming Sandstone**
356/27SW	334/15SW	336/28SW	353/37SW
	343/27SW	330/31SW	156/14SW
	168/33SW	158/34SW	330/20SW
	163/18SW		166/16SW
			335/15SW
			350/24SW
			149/17SW
			152/18SW
Conglomerate		**Fine Sandstone #1**	**Sandstone #1**
350/19SW	354/32SW	185/14NW	166/19SW
164/24SW	323/26SW		154/19SW
049/08NW	331/29SW		341/29SW
068/15NW	284/09SW		
156/24SW	338/18SW		
333/17SW	335/14SW		
310/27SW	333/25SW		
182/20SW	336/16SW		
312/49SW	151/18SW		
097/47SW	325/21SW		
291/34SW	004/36NW		
308/28SW	110/26SW		
105/27SW	267/17NW		
355/35SW	333/23SW		
135/36SW	125/24SW		
032/26NW	135/20SW		
Fine Sandstone #2	**Sandstone #2**	**Red-Green Siltstone**	**Fine Sandstone #3**
173/35SW	015/22NW	355/17SW	

FAULTS

Normal	**Reverse**	**Strike-Slip**	**Unknown**
315/72SW			045/83SE
025/55SE			332/84SW

DIKES / SILLS

Felsic	**Mafic**
118/65SW	

Lithology

The lithologic units in Hawk Canyon and its vicinity are predominately sedimentary rocks (Figure 6). The only exceptions in this study are the tonalite basement complex and the pegmatite dikes that it has been intruded by. The various sedimentary rock units serve as a record of tectonic activity and fluvial energy in the region. Samples of the rocks were not collected due to restrictions by California state law but observations were noted throughout this project. All of the sedimentary units are said to be Late Pliocene to mid Pleistocene in age (Steely, 2004) and deposited as a result of the progradation of the Colorado River delta into this area (Herzig, 1995).

Tonalite (Ktn)

This is the only plutonic unit in Hawk Canyon. It is known to be the batholith of the Peninsular Ranges and has relatively common exposures regionally. Hand lens analysis shows a quartz content higher than twenty percent pushing this rock from a quartz diorite into a tonalite classification. It has a phaneritic texture with phenocrysts ranging from 1 to 10 millimeters and is Cretaceous in age. The tonalite has been intruded by a series of pegmatite dikes. The dikes have a composition similar to most granites and range in thickness from 1 centimeter to approximately 1 meter.

Sedimentary Breccia (Tsb)

The sedimentary breccia sits noncomformably on the Cretaceous tonalite. It is composed of pebble sized fragments of locally derived pegmatite and potassium feldspar. The clasts are angular and held together by a fine sandstone matrix resulting in its breccia classification. It appears slaty in outcrop. It has an estimated thickness of 11.9 meters.

Bedded Sandstone (Tbs)

This is a well bedded coarse grained sandstone unit. The composition of the sandstone's clasts varies throughout the canyon and it is poorly sorted. It has an estimated thickness of 3.3 meters.

Lower Green Sandstone (Tlg)

The lower green sandstone is a rare unit in Hawk Canyon as only one outcrop was discovered. It is medium grained. It is also well bedded and heavily fractured in some areas. It has an estimated thickness of 3.8 meters.

Lower Red Sandstone (Tlr)

The lower red sandstone is an oxidized well-sorted medium grained sandstone. The mineral composition is difficult to determine due to the oxidation. The thickness of the unit within the canyon is only about one meter.

Green Siltstone (Tg)

The green siltstone is an easily identifiable unit throughout Hawk Canyon. It is primarily a siltstone with interbedded shale and quartz-rich sandstone. Gypsum is present in the unit. This coupled with the very fine grain size of this unit is indicative of it being a playa lake deposit. It is possible this deposit formed in a marine delta plain as Herzig suggests this unit is part of either the Imperial Formation or Palm Springs Formation. A more regional study would need to be done to confirm this correlation. However, it can be concluded that the green siltstone records tectonic subsidence and sedimentation representing its deposition in a low energy environment. It has an estimated thickness of 9.4 meters.

Red Siltstone (Tr)

The red siltstone is another easily identifiable unit within Hawk Canyon. It is very similar to the green siltstone unit. It is a siltstone with interbedded shale and sandstone. Shale is more common in the red siltstone than in the green siltstone. Also unlike the green siltstone, no gypsum was observed. The lack of gypsum and more common occurrence of shale indicate this unit was probably deposited in a deeper, lower energy environment than the green siltstone. This records further subsidence in the area. This unit is also suspected to be part of either the Imperial Formation or the Palm Springs Formation (Herzig, 1995). It has an estimated thickness of 8.5 meters.

Cliff-Forming Sandstone (Tcf)

The cliff-forming sandstone is a well-cemented unit that readily weathers into cliffs; forming the western ridge of Hawk Canyon. The sandstone is well-sorted and composed of rounded and sub-angular pebble-sized grains. Conglomerate beds make up approximately 10% of this unit. The clasts range from pebble to cobble size. The unit indicates local uplift and a transition from low fluvial energy to moderate fluvial energy. It has an estimated thickness of 6.3 meters.

Conglomerate (Tcg)

The conglomerate unit was one of the main focuses of this study. It is the most widespread and thickest of the area's rock units as it has an estimated thickness of 275.7 meters. It is a poorly-sorted conglomerate with interbedded coarse-grained sandstone. It is typically about 75% conglomerate with 25% sandstone though the conglomerate percentage varies from 50% to 90%. Clasts in the conglomerate are both of igneous and metamorphic origin. They are typically between 1 to 30 centimeters in diameter with rare clasts of one to two meters in diameter. The conglomerate was deposited in a high energy fluvial environment and records further uplift in the region.

Fine Sandstone #1 (Tf)

This sandstone unit marks the beginning of "the slot." The slot is a narrow canyon that is comprised of various sandstones and siltstones. This unit is a fine grained sandstone with thin interbedded siltstone. It is moderately well-cemented and indicates a lessoning of fluvial energy. The sandstone has an estimated thickness of 37.8 meters.

Sandstone #1 (Ts)

This unit is composed of medium grained sandstone with interbedded pebble conglomerate. The pebble conglomerate beds typically make up less than 5% of the sandstone. The unit indicates an increase in fluvial energy and has an estimated thickness of 47.2 meters.

Fine Sandstone #2 (Tfs)

This unit is a fine grained sandstone with interbedded siltstone. The sandstone is typically made up of less than 15% siltstone. Its presence records a decrease in fluvial energy and has an estimated thickness of 56.7 meters.

Sandstone #2 (Tss)

This unit is a medium grained sandstone with interbedded pebble conglomerate and lesser interbedded siltstone. The siltstone accounts for less than 5% of the sandstone. The unit indicates an increase in fluvial energy and has an estimated thickness of 66.1 meters.

Red-Green Siltstone (Trg)

The red-green siltstone is an easily identifiable marker bed at the westernmost boundary of the slot. The unit is a siltstone with interbedded shale. The interbedded shale is not very prevalent. The unit represents a rapid decrease in fluvial energy and has an estimated thickness of 6.1 meters.

Fine Sandstone #3 (Tfss)

This is the western boundary of the project's map and its details and extent are unknown. It is a fine grained sandstone and indicates an increase in fluvial energy.

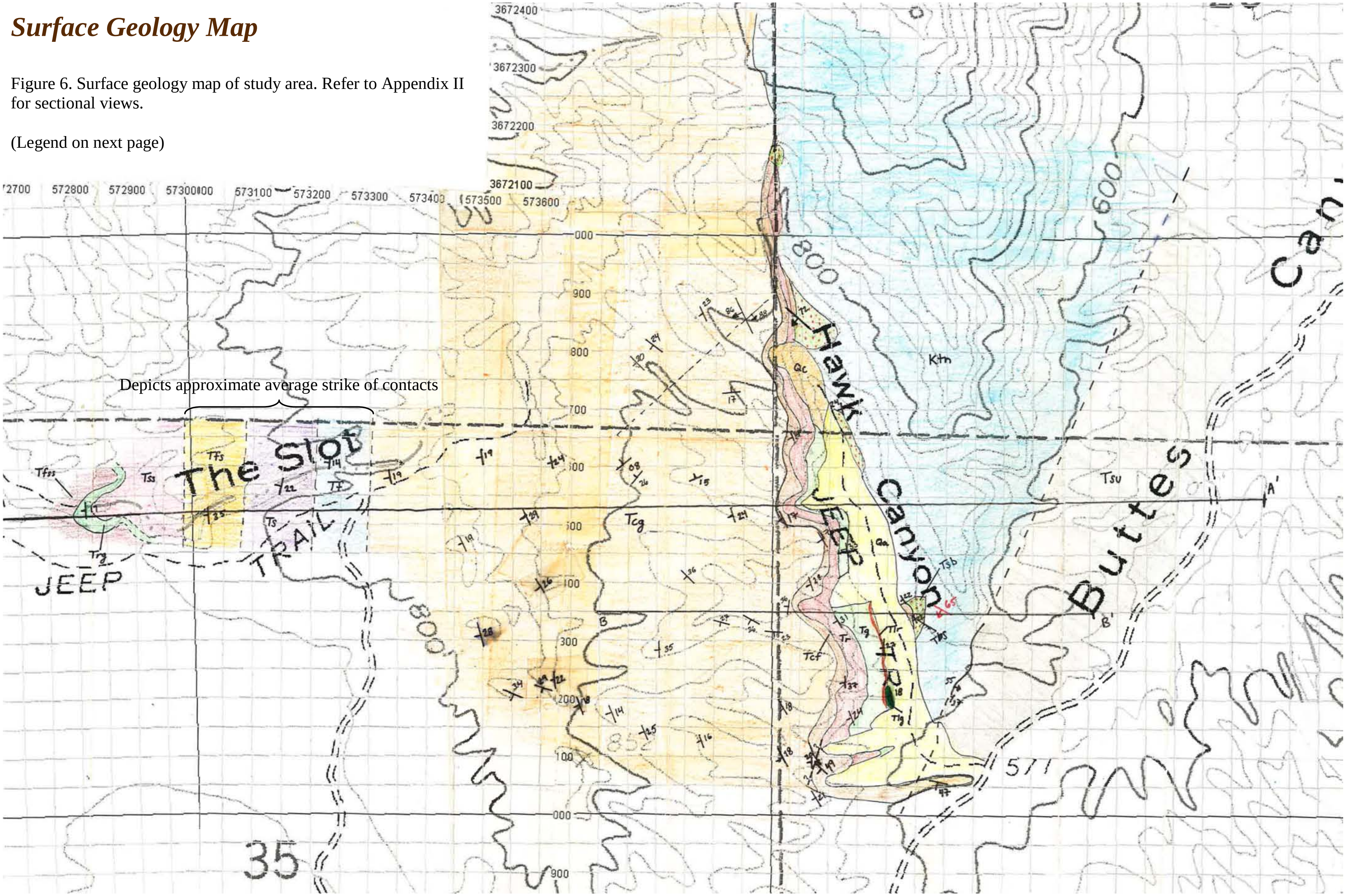
Slot Unit - Herzig et al., 1995 (Tsu)

This description is used to define a sequence of units mapped by Herzig in 1995. Herzig's map groups all of this project's slot units with adjacent sandstone units to the west. Herzig's group of units is correlated with units juxtaposed with the Cretaceous tonalite in Hawk Canyon. It is unclear which section of the units is exposed in the east. Therefore, the exposure is classified as the Slot Unit – Herzig et al., 1995. This unit is interpreted in the structural geology section of this report.

Surface Geology Map

Figure 6. Surface geology map of study area. Refer to Appendix II for sectional views.

(Legend on next page)



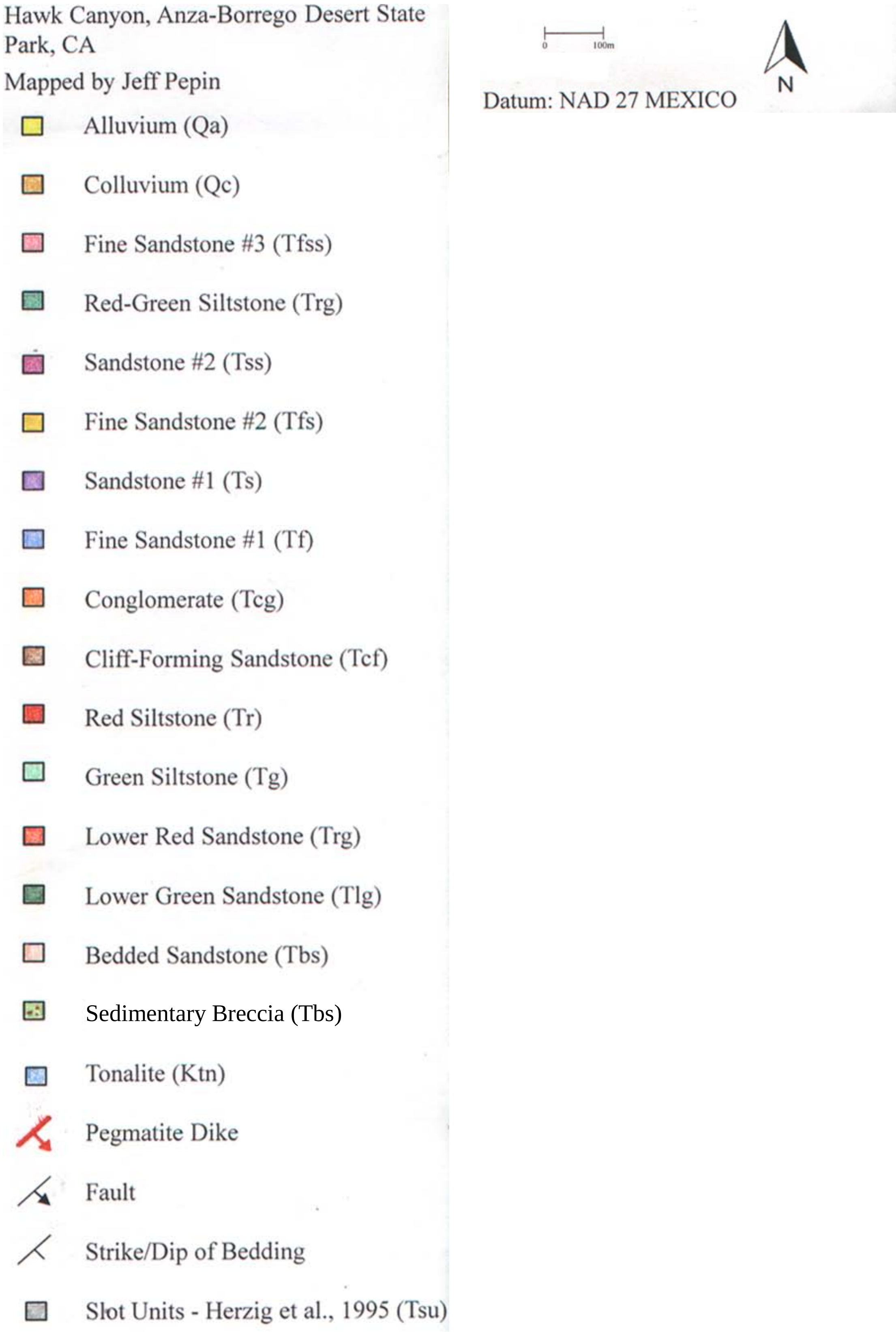


Figure 7. Legend for surface geology map (pertains to Figure 6 and Appendix II)

Analysis and Discussion

Cross Sections

Another main objective of this project was to create multiple true scale cross sections. The first cross section generated is denoted A to A’ on the surface geology map (Figure 6, Figure 8). This cross section spans from the western edge of the slot to the eastern boundary of this project. This cross section is particularly useful as it traverses the entire width of the study area and is oriented approximately perpendicular to the strike of all its lithologic units. The second cross section created is labeled B to B’ on my geologic map (Figure 6, Figure 9). It begins in the western conglomerate and ends at the eastern boundary of the study area. This cross section was constructed to portray the varying thicknesses of Hawk Canyon’s red and green siltstone beds. It also includes a mapped pegmatite intrusion into the Cretaceous tonalite.

An average dip of 22.2 degrees was derived for the study area and was implemented in both cross sections for any lithologic unit with limited structural data available. The derivation of this dip value is discussed in the structural geology section of this report.

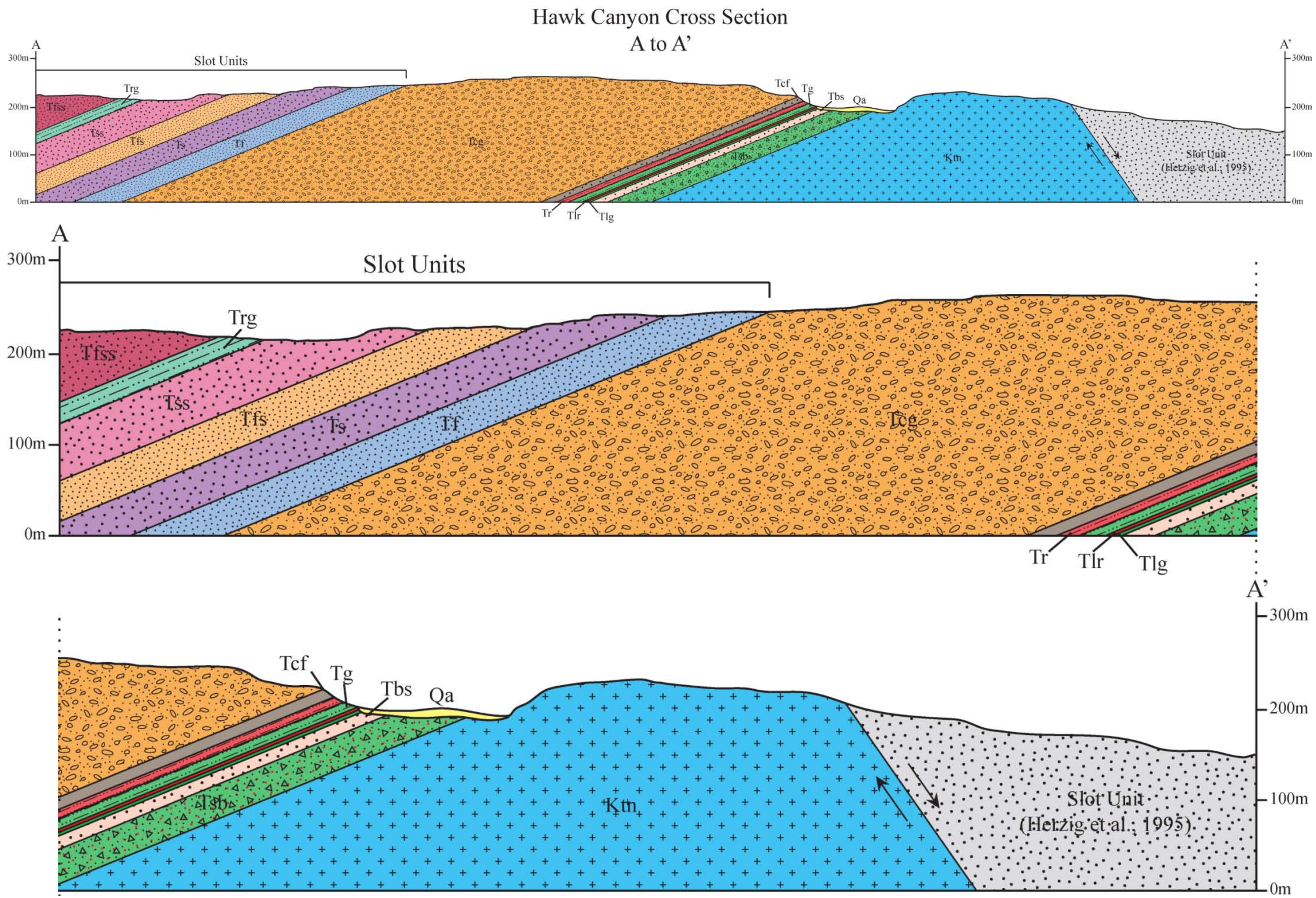


Figure 8. Cross section denoted as A to A' on surface geology map (top). This cross section depicts typical bedding relationships throughout the study area. The overall cross section has been split into two parts; the west (middle) and the east (bottom); for increased clarity

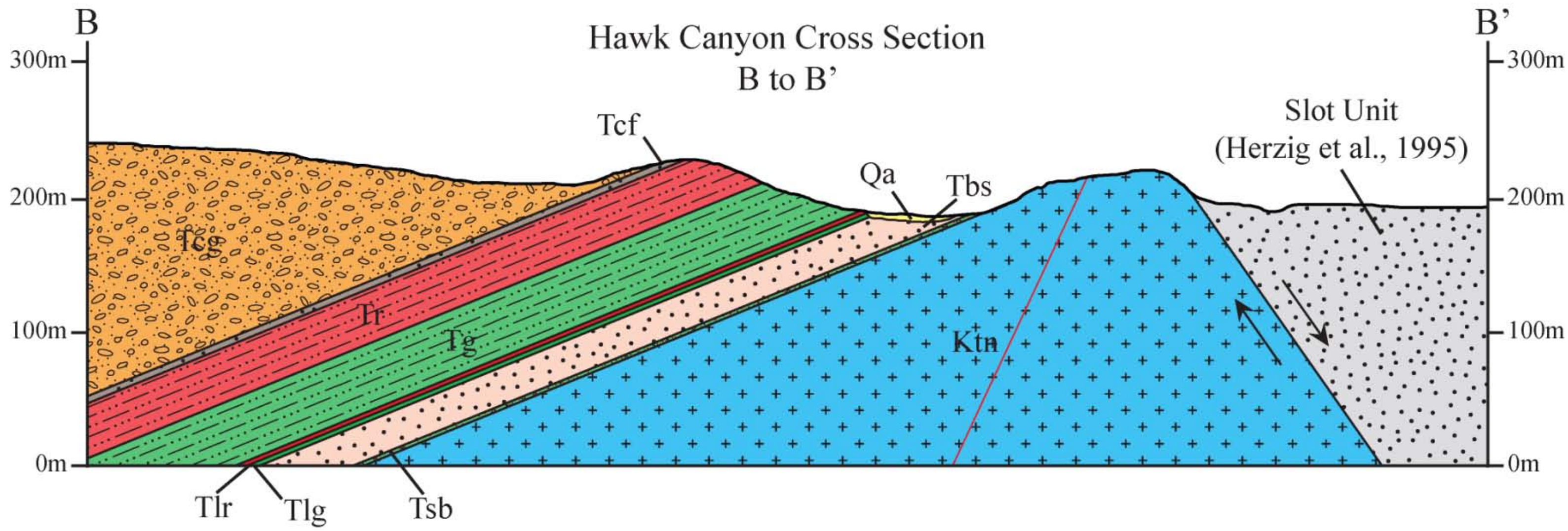
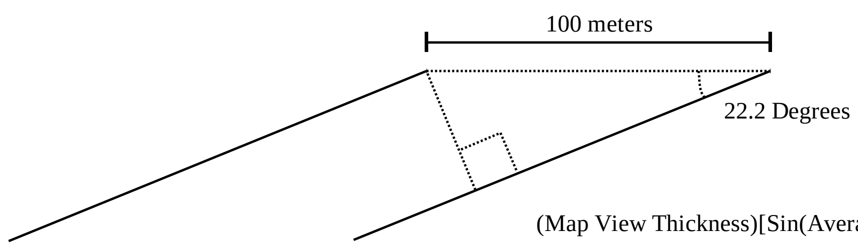


Figure 9. Cross section denoted as B to B' on surface geology map

Derivation of True Unit Thicknesses and Stratigraphic Column

The true thickness estimates for the units were determined by using a map view thickness estimation and the average dip angle of study area's bedding. The average dip value for the area was determined to be 22.2 degrees. This average value was used due to lack of sufficient structural data for some of the rock units. Dip values in the area range from about 10 to 45 degrees. Therefore, using a limited amount of data for a particular unit would increase the possible error in its true thickness estimation. Consequently, an average of all the dips taken during this project was determined and used for all of the true thickness calculations. The formula used to calculate the estimated true thicknesses and its results are shown below (Figure 10, Table 4). These thicknesses along with the surface map were utilized to create a true scale stratigraphic column (Figure 11).



(Map View Thickness)[Sin(Average Dip)] = True Thickness

(100 meters)[Sin(22.2 degrees)] = 37.38 meters

True Thickness = 37.38 meters

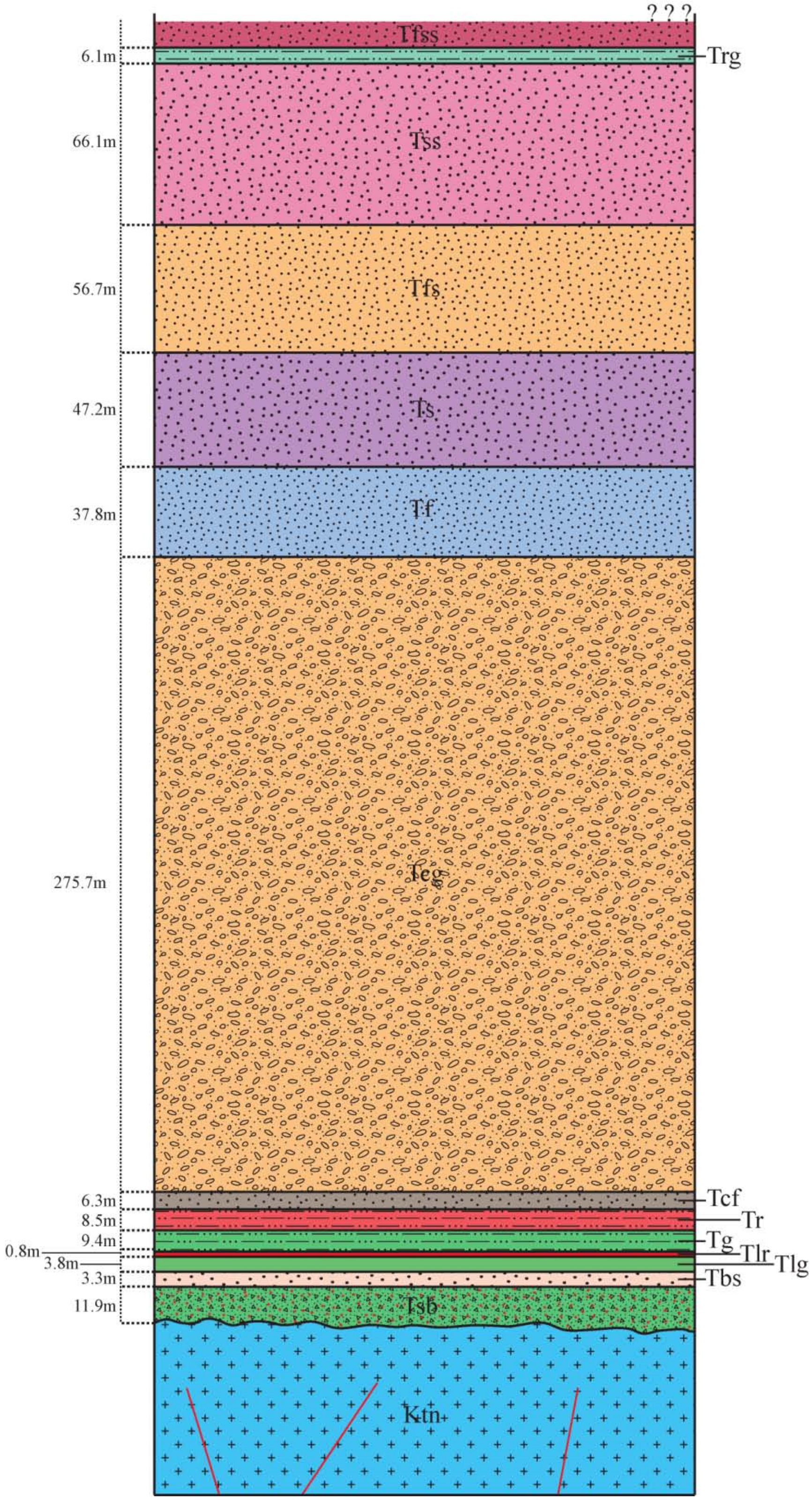
Figure 10. Depiction of true thickness calculation with sample calculation

Lithologic Unit	**Estimated True Thickness (m)**
Tonalite (Ktn)	Basement
Sedimentary Breccia (Tsb)	11.9
Bedded Sandstone (Tbs)	3.3
Lower Green Sandstone (Tlg)	3.8
Lower Red Sandstone (Tlr)	0.8
Green Siltstone (Tg)	9.4
Red Siltstone (Tr)	8.5
Cliff-Forming Sandstone (Tcf)	6.3
Conglomerate (Tcg)	275.7
Fine Sandstone #1 (Tf)	37.8
Sandstone #1 (Ts)	47.2
Fine Sandstone #2 (Tfs)	56.7
Sandstone #2 (Tss)	66.1
Red and Green Slt (Trg)	6.1
Fine Sandstone #3 (Tfss)	N/A

Total section thickness = 533.65 meters

Table 4. Tabulated estimated true thickness calculation results for each lithologic unit

Stratigraphic Column



Fine Sandstone #3 (Tfss) Western boundary of project. Detailed analysis not conducted. Extent unknown.

Red-Green Siltstone (Trg) Siltstone with interbedded shale. Shale is not very prevalent. Easily identifiable marker bed.

Sandstone #2 (Tss) Medium grained sandstone with interbedded pebble conglomerate and lesser interbedded siltstone. Siltstone accounts for less than 5% of unit.

Fine Sandstone #2 (Tfs) Fine grained sandstone with interbedded siltstone. Siltstone makes up less than 15% of unit.

Sandstone #1 (Ts) Medium grained sandstone with interbedded pebble conglomerate. Conglomerate beds comprise about 5% of unit.

Fine Sandstone #1 (Tf) Interbedded siltstone. Moderately well-cemented

Conglomerate (Tcg) Thickest unit in area. Poorly-sorted with interbedded coarse grained sandstone. Averages 75% conglomerate, 25% sandstone. Clasts from 1 to 30cm with rare clasts up to 2m.

Cliff-Forming Sandstone (Tcf) Well-cemented unit that weathers into cliffs. Well-sorted and composed of rounded and sub-angular pebble sized grains. Pebble to cobble sized conglomerate beds make up 10% of unit.

Red Siltstone (Tr) Siltstone with interbedded shale and quartz-rich sandstone. Similar to Tg but lacks gypsum and is oxidized

Green Siltstone (Tg) Primarily a siltstone with interbedded shale and quartz-rich sandstone. Gypsum present.

Lower Red Sandstone (Tlr) Oxidized. Well-sorted medium grained sandstone

Lower Green Sandstone (Tlg) Rare outcrops in Hawk Canyon. Medium grained. Well bedded and heavily fractured in some areas.

Bedded Sandstone (Tbs) Well bedded. Poorly sorted.

Sedimentary Breccia (Tsb) Nonconformably rests atop tonalitic basement. Comprised of pebble sized fragments of local pegmatite and potassium feldspar. Angular clasts in fine matrix.

Tonalite (Ktn) Peninsular Ranges batholith. Quartz content above 20%. Phaneritic with grain size range of 1 to 10mm. Intruded by 1cm to 1m thick pegmatite dikes.

Figure 11.True scale stratigraphic column with unit thicknesses indicated

Structural Analysis

Throughout this study, orientation data was gathered on bedding and faults. This data was then interpreted using several stereonet plots. Stereonets were first constructed for each individual lithologic unit (Appendix I). No stereonets were created for the tonalite (Ktn) or the fine sandstone #3 (Tfss) due to the lack of data available. The bedding plots yielded an average strike and dip direction for each of the units. These average values were then plotted on one stereonet for comparison.

The poles of all bedding were also plotted on one stereonet. The two stereonets derived an average bedding orientation in the study area to be 333/22SW (Figure 13). The dips are rather uniform throughout the study area. It is hypothesized that a significant listric fault is further west of the study area leading to its current structural position. This is consistent with the previously discussed regional detachment faulting model (Figure 2).

All fault data was then compiled into one stereonet plot. Mapping supplied fault data for four local faults. Two of the faults are normal faults while the remaining two have an unknown sense of motion. No striations or offset were visible on the two unknown faults though fault gouge was present. However, these two faults have a near vertical dip suggesting strike-slip motion. Based on the steep dip, the two faults will be assumed to be strike-slip faults. Furthermore, they will be interpreted as right-lateral faults as this is the predominate type of strike-slip faulting in the region (Table 1). Once plotted on the stereonet, the principle stress axes were interpreted and displayed on the plot as well (Figure 14). More data collection is needed to accurately constrain the stress directions of the normal faults as the current data is limited.

The throw on the eastern boundary normal fault was calculated utilizing Herzig's 1995 geology map (Figure 12) and cross section A to A' (Figure 8). The normal faulting has exposed a sandstone unit that Herzig's map correlates with the slot sediments in the west. The average map view thickness of Herzig's western sandstone unit was calculated and used to determine an average maximum projected thickness estimate for the unit. Conversely, the smallest map view thickness of the eastern sandstone unit was used to calculate a minimum projected thickness estimate for the unit. The calculated thicknesses, fault contact and lower boundary of the slot sediments were then project using cross section A to A' (Figure 15). The eastern boundary's fault throw was then derived by directly measuring the separation between the lower contacts of the units along the projected fault contact. This method determined fault throw along this normal fault to be at least 734.49 meters and at most 1,197.46 meters. Herzig claims the sandstone unit to be part of the Palm Spring Formation. Ages of the Palm Spring Formation typically range from 1.3 to 3.00 million years old (Kirby et. al, 2007). A slip rate can be estimated on this fault if we assume the faulting is slightly younger than the unit and that the faulting remains active today. The results are summarized below in Table 5.

	Thickness (mm)	**Age (yrs)**	**Slip Rate (mm/yr)**
734.39m (minimum thickness)	734390	1300000	0.565
	734390	2600000	0.282
1197.46m (maximum thickness)	1197460	1300000	0.921
	1197460	2600000	0.461

Average Slip Rate (mm/yr)	**0.557**

Table 5. Minimum long-term slip rate results

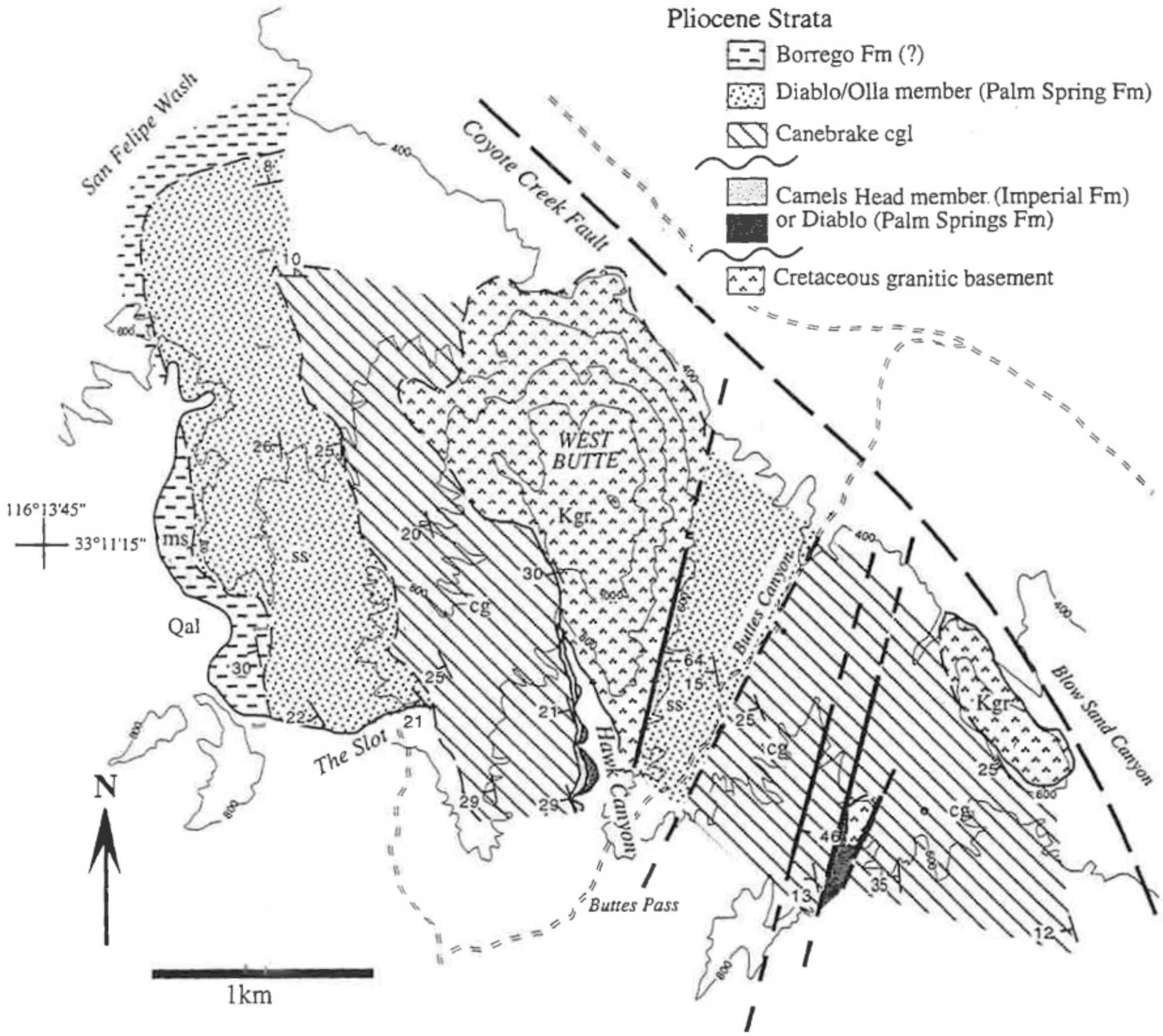


Figure 12. Herzig's 1995 geologic map of the Borrego Mountain area

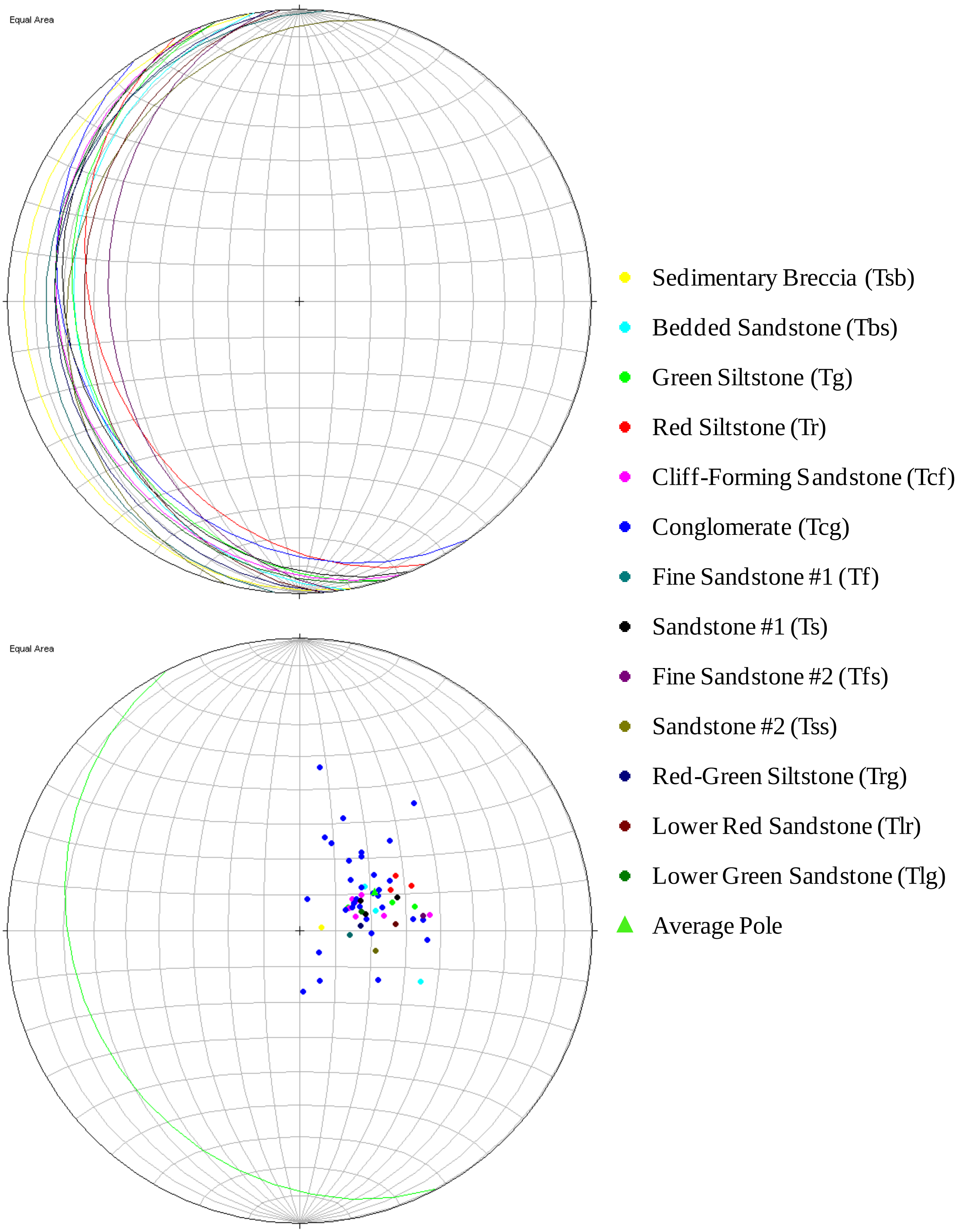


Figure 13. (Top) Stereonet showing average bedding planes for each rock unit. (Bottom) Stereonet showing all bedding poles with average bedding plane for study area

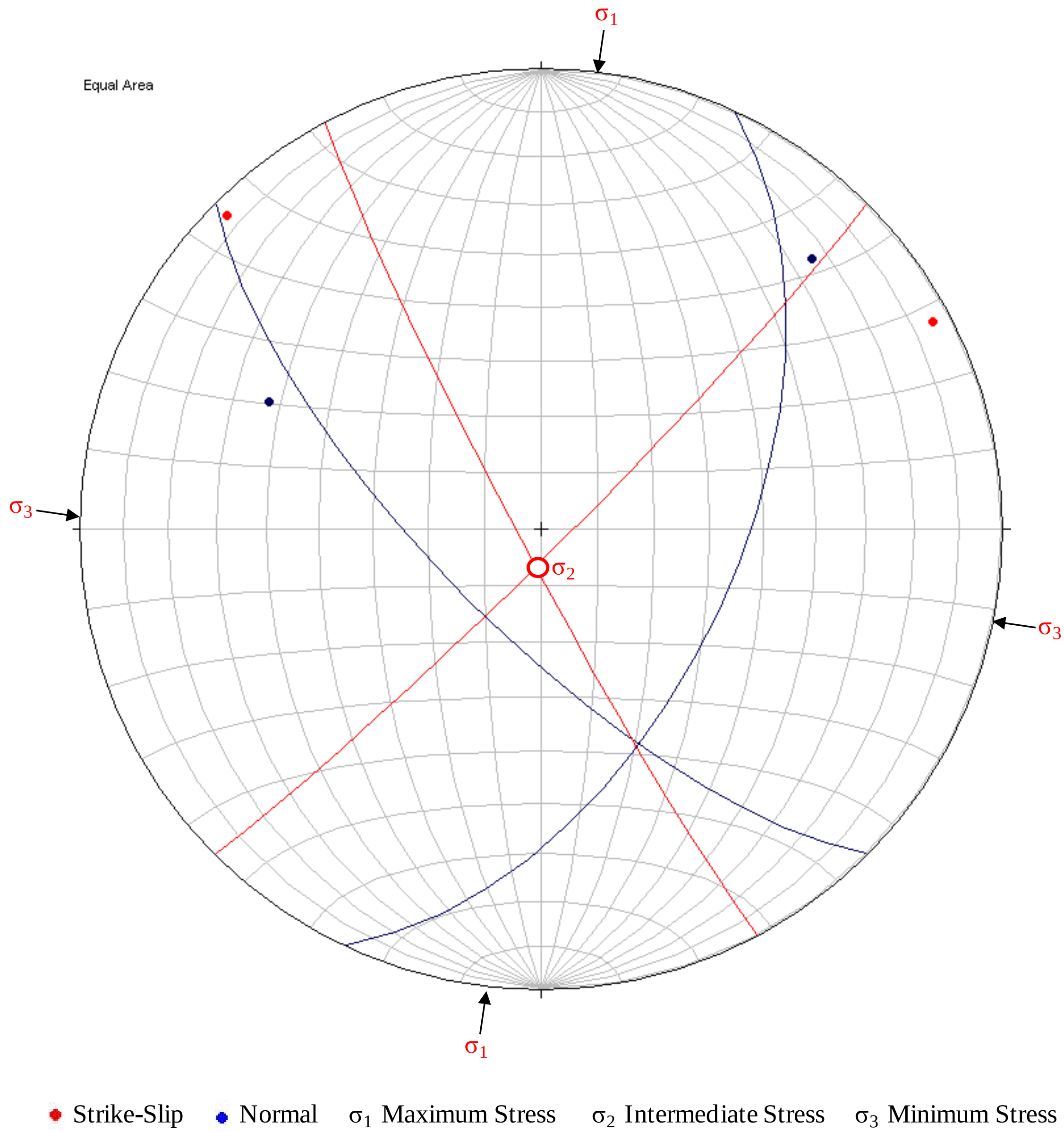


Figure 14. Stereonet showing fault planes and their principle stress axes

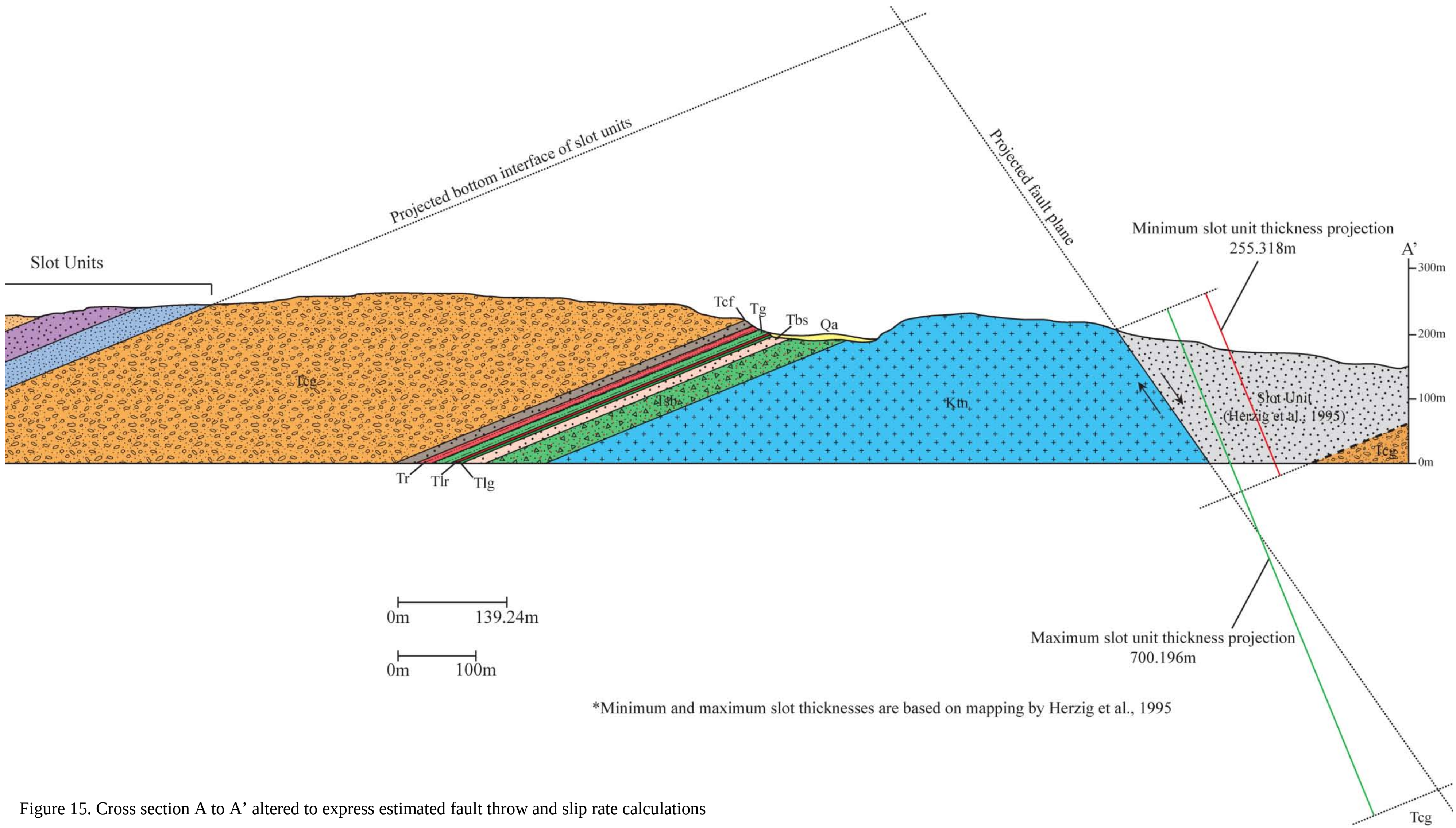


Figure 15. Cross section A to A' altered to express estimated fault throw and slip rate calculations

Geologic History

The rock units in the area record numerous depositional environment transitions as well as significant faulting events. The bedding in the mapped area averages 333/22SW. All rocks in the study area are sedimentary except for the tonalite basement and the pegmatite dikes. If we assume that the beds were deposited in correspondence with the law of original horizontality, the western sediments are the youngest in the area while the eastern sediments are the oldest. Some of the older sediments may be Pliocene in age (Herzig et. al, 1995; Dorsey et. al, 2007).

The oldest unit in the area is the tonalitic basement. This unit intruded during an episode of magmatic activity during the Cretaceous. The tonalite was then intruded by a series of pegmatite dikes and was eventually exposed to the surface. The sedimentary breccia noncomformably rests upon the tonalite. This unit contains angular pebble sized fragments of locally derived pegmatite and potassium feldspar. The clasts are cemented in a fine sandstone matrix. The grain size of this unit is indicative of an intermediately energized depositional environment. The bedded sandstone unit is the next rock unit encountered. This is a well bedded unit and is also indicative of an intermediately energized depositional environment. However, this unit is poorly sorted, which suggests a short travel distance for the gravels before they were cemented.

The lower green and red sandstone units continue to record an intermediate depositional environment. The green and red siltstone units are the next units in the section and record regional subsidence resulting in a low energy depositional environment. These units are suggested to be part of either the Palm Springs Formation or the Imperial Formation. They are said to be part of the Colorado River delta and to have been relocated due to right-lateral strike-slip faulting by the San Andreas Fault system (Herzig et. al, 1995, Kirby et. al, 2007).

Regional uplift then resulted in a depositional environment transition to an intermediately energized environment evidenced by the deposition of the cliff forming sandstone. Regional uplift continued, transitioning the area to a high energy alluvial fan environment. The conglomerate unit records this high energy transition. This unit has been linked with both the regionally exposed Canebrake Conglomerate and the West Butte conglomerate (Herzig et. al, 1995, Steely, et. al, 2009). The area then underwent two shifts from intermediate/low energy to intermediate energy leading to the deposition of the western fine sandstone and sandstone units in the slot. The red-green siltstone unit was then deposited. The shift from the high energy conglomerate to the low energy red-green siltstone records regional subsidence. The youngest mapped rock unit is the fine sandstone. This unit suggests a change to an intermediate/low energy environment.

Listric faulting is the final component of the geologic history. Listric faults can be defined as curved normal faults in which the fault surface in concave upwards with a dip that decreases with depth (Figure 2). It is hypothesized that this project’s rock units have been tilted about 22 degrees primarily due to a significant western listric fault. However, this fault is yet to be located. Brent Ritizinger has discovered an outcrop of the tonalitic basement several hundred meters to the west of the slot. This outcrop has the potential to be the location of the western listric fault but further investigation is needed. The age of this faulting has yet to be determined but must be younger than the area’s sediments. The sediments are estimated to be late Pliocene to mid Pleistocene, suggesting the faulting is somewhat young and possibly still active.

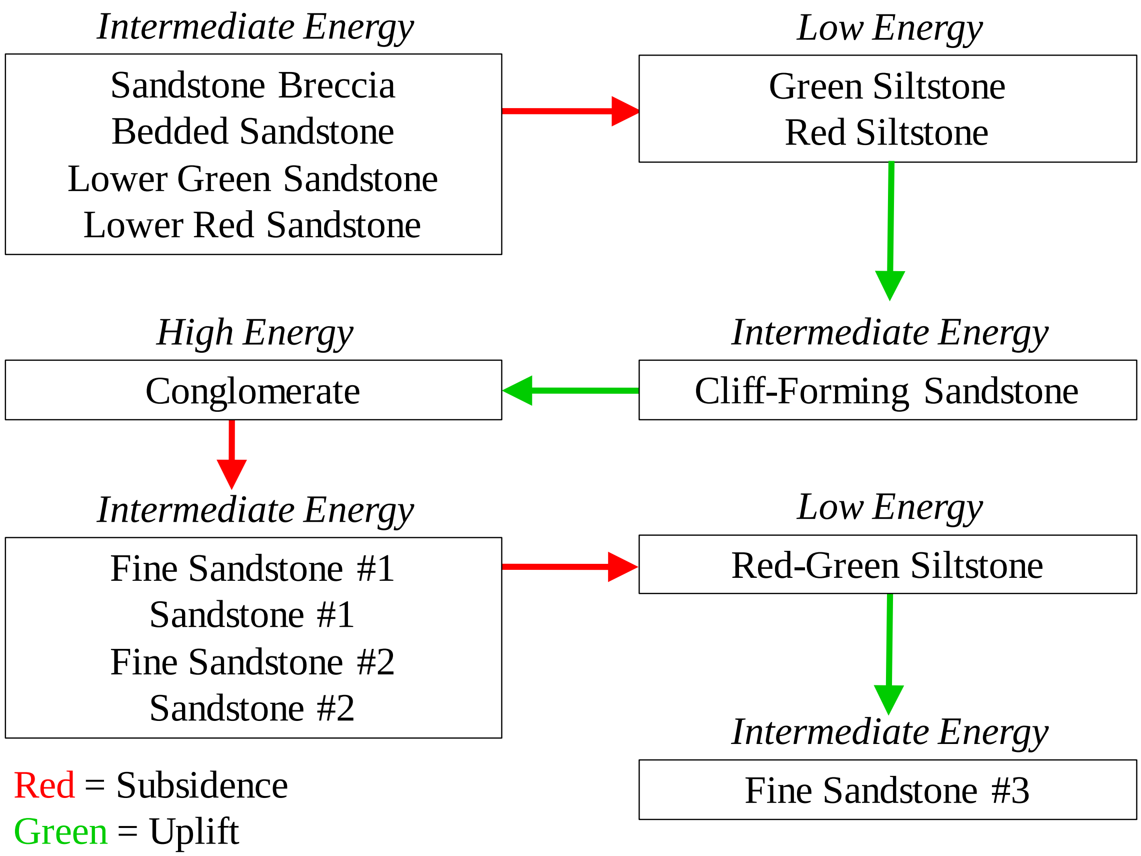


Figure 16. Flowchart portrayal of tectonic activity based on lithology

Conclusions

This study achieved its main purpose of adding to the overall geologic knowledge of Hawk Canyon and its vicinity. Surface mapping yielded ample structural data. The structural data was utilized to hypothesize the presence of a significant western listric fault which has tilted the area's beds approximately 22 degrees to the southwest. It can be concluded that this tilting has occurred between the present time and the mid Pleistocene as it must be younger than the area's youngest unit. Further surface mapping is required to pinpoint the location of the listric fault. The map indicates the location of various other faults throughout the area.

Surface mapping also provided a much greater understanding of the area's individual lithologic unit thicknesses. This allowed for a true scale stratigraphic column and several cross sections to be developed during this study. No detailed local stratigraphic columns or cross sections had previously been published of Hawk Canyon. Constraining the thicknesses of the units can also be utilized for geologic history interpretation. Referencing these unit thicknesses supplies insight into the duration and timetable of regional tectonic events. The lithologic descriptions offer information on the nature of these tectonic events. The section's total thickness measures 533.64 meters.

This project's structural analysis derived a fault throw range and a minimum long-term slip rate for the eastern boundary normal fault. The throw of this fault has a minimum value of 734.49 meters and a maximum value of 1,119.46 meters. Assuming the fault initiated shortly after the deposition of the rock units and is still active yields an average slip rate of 0.557 mm/yr.

Overall, this project has resulted in the development of a detailed geologic map along with a comprehensive geologic analysis of Hawk Canyon and its adjacent western sediments. It serves as an important step in understanding an area of very minimal previously completed research. This study has increased the understanding of the local geology and will serve as a tool for future studies.

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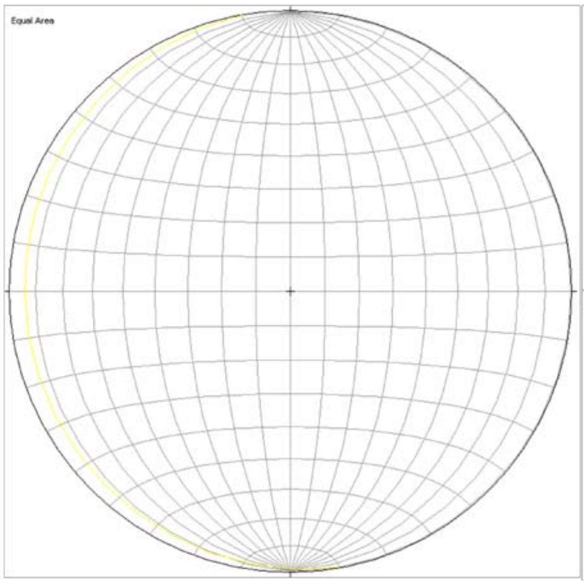
Appendices

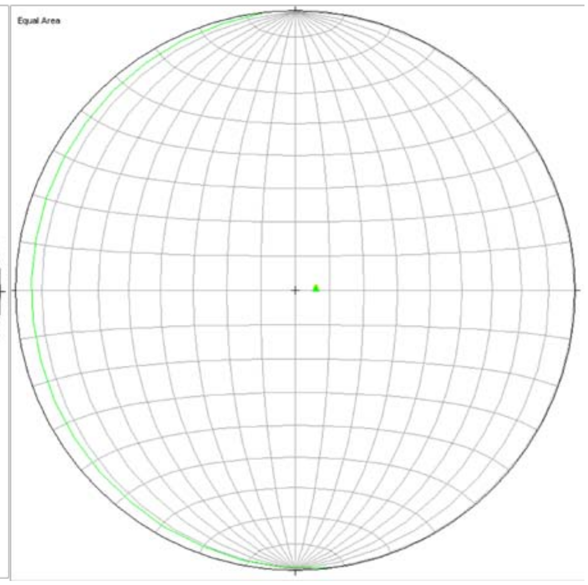
Appendix I: Stereonet Plots of Bedding

Sedimentary Breccia (Tsb)

Planes

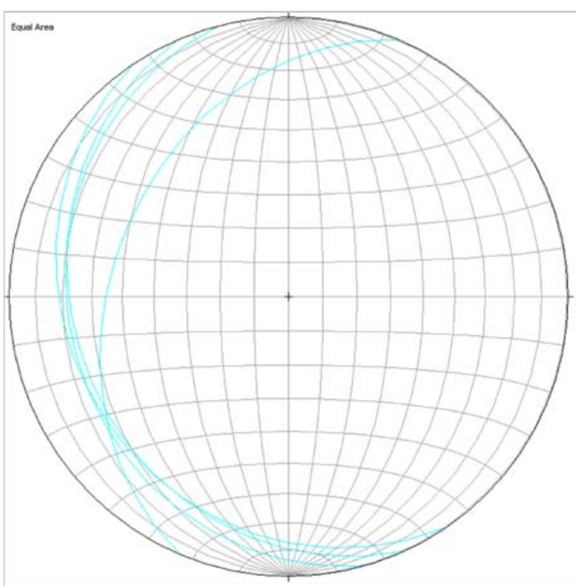


Poles with Average Plane



Bedded Sandstone (Tbs)

Planes



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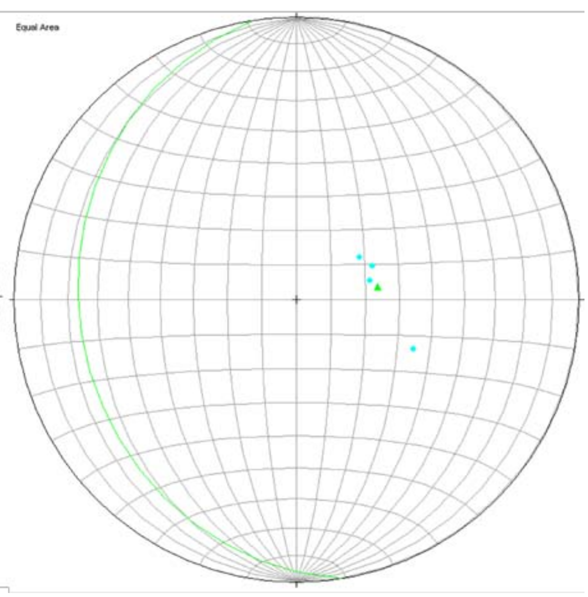
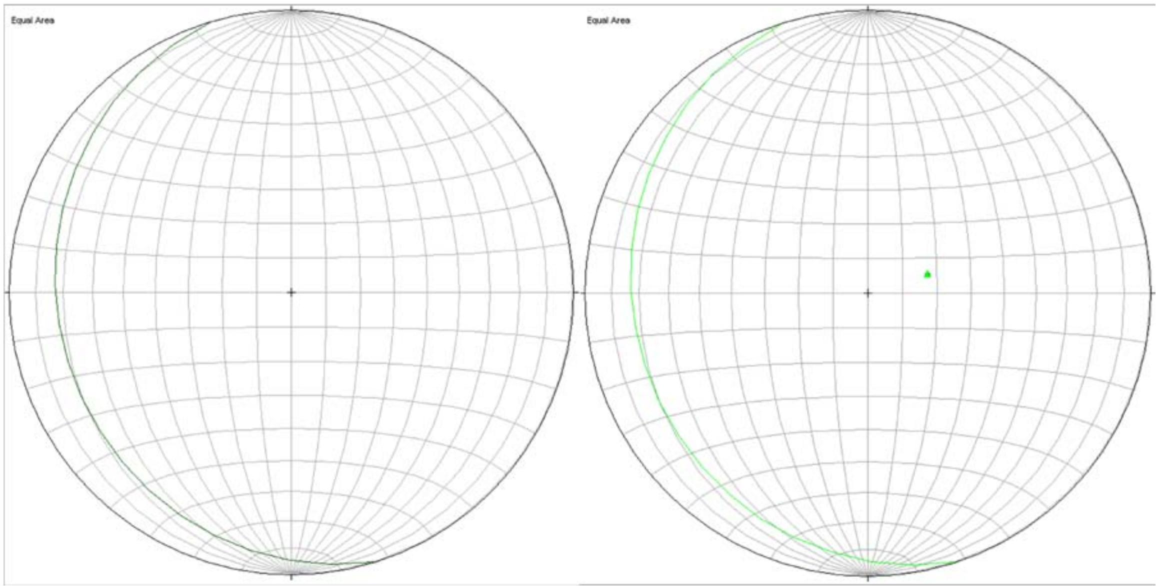


Lower Green Sandstone (Tlg)

Planes

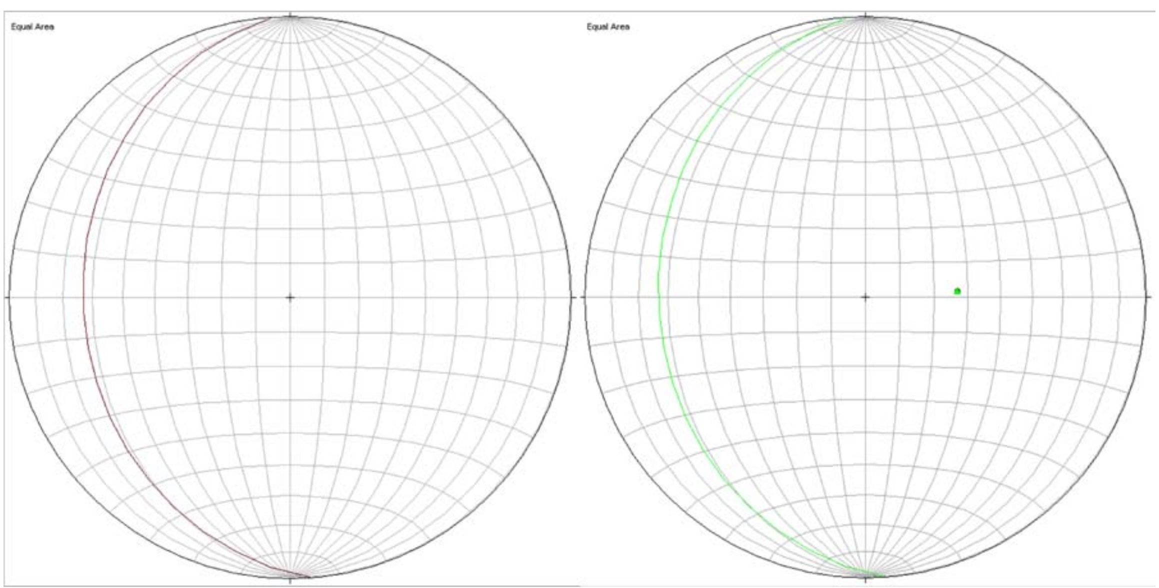
Poles with Average Plane



Lower Red Sandstone (Tlr)

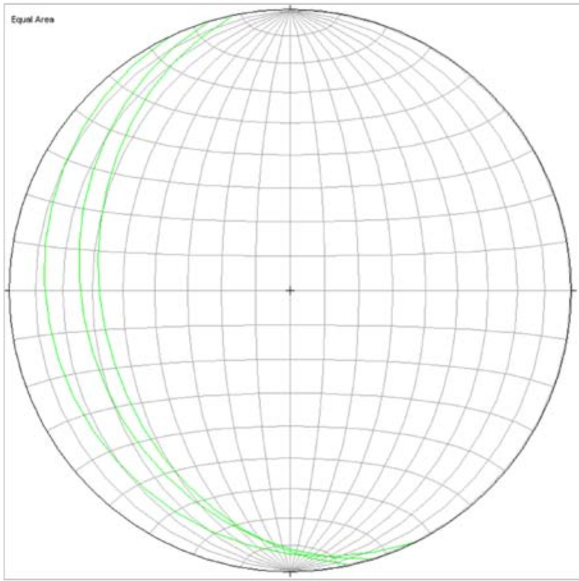
Planes

Poles with Average Plane



Green Siltstone (Tg)

Planes



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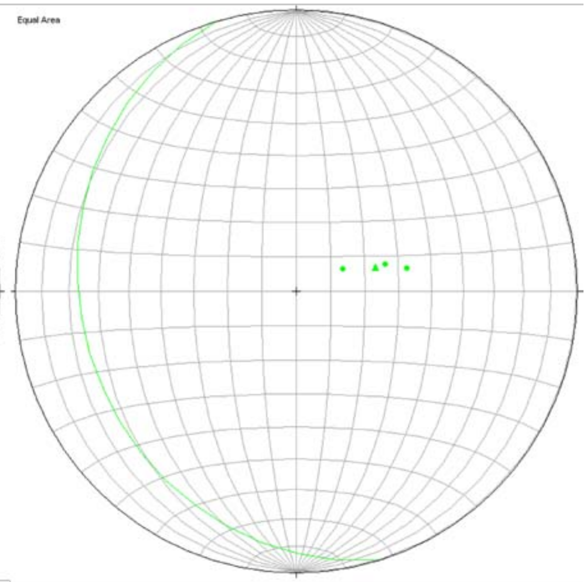
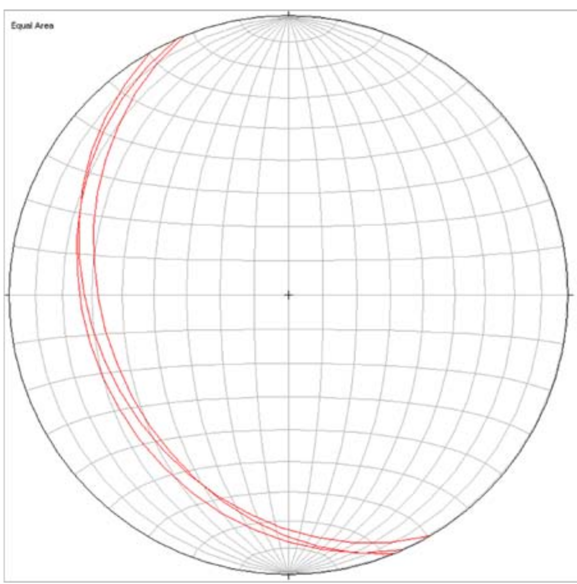
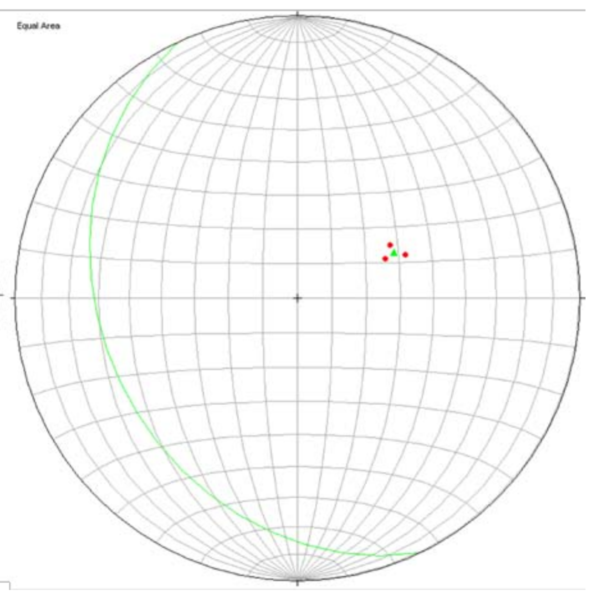


Red Siltstone (Tr)

Planes

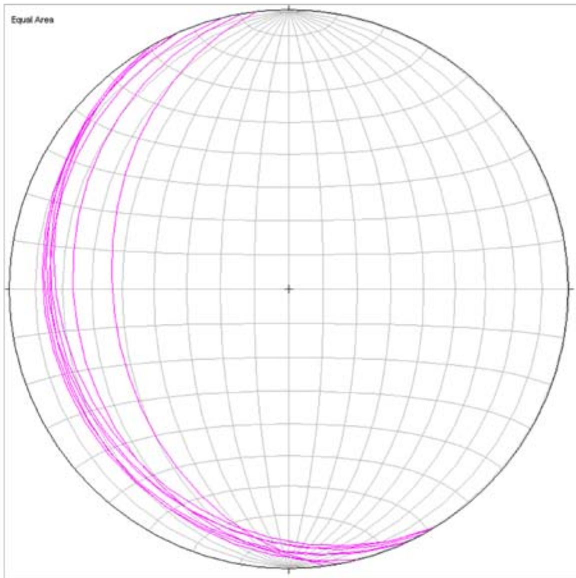


Poles with Average Plane



Cliff-Forming Sandstone (Tcf)

Planes



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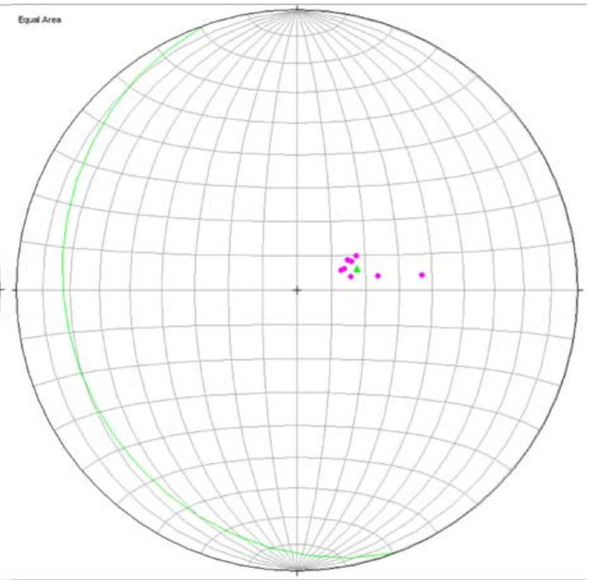
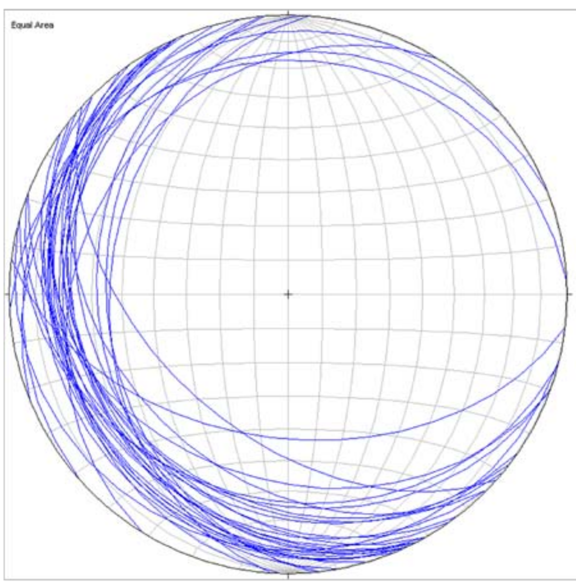


Conglomerate (Tcg)

Planes



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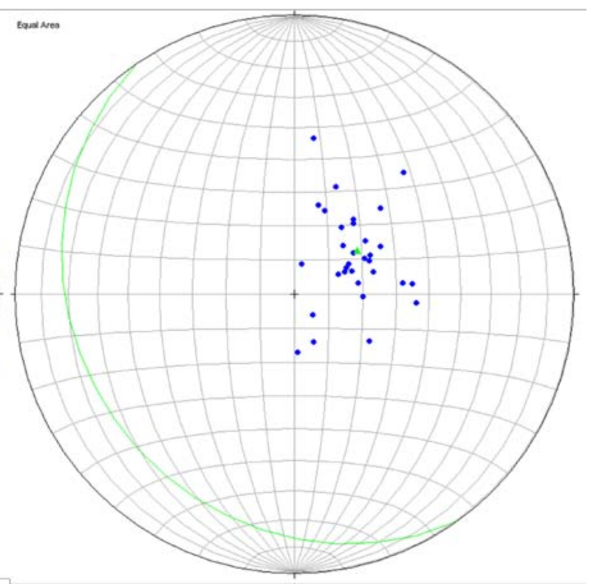
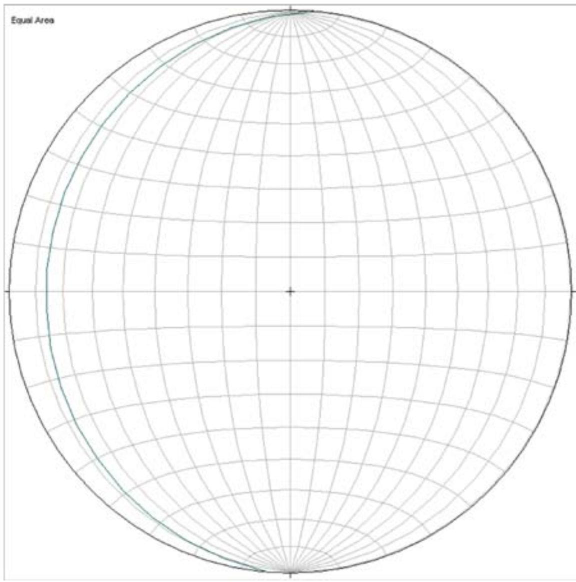


Fine Sandstone #1 (Tf)

<u>Planes</u>



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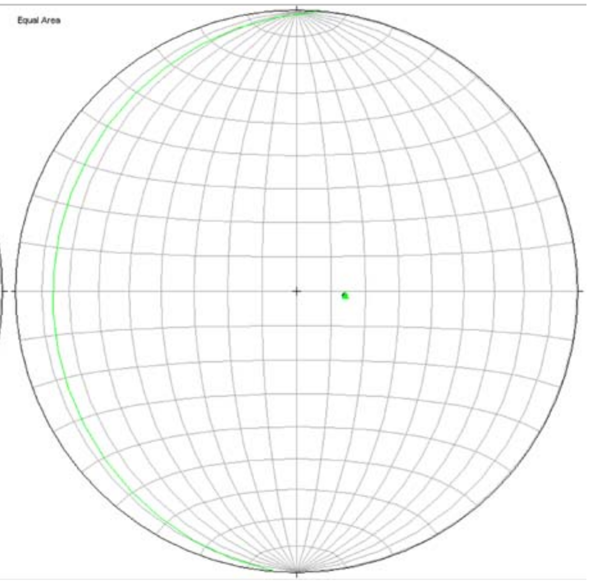

Sandstone #1 (Ts)

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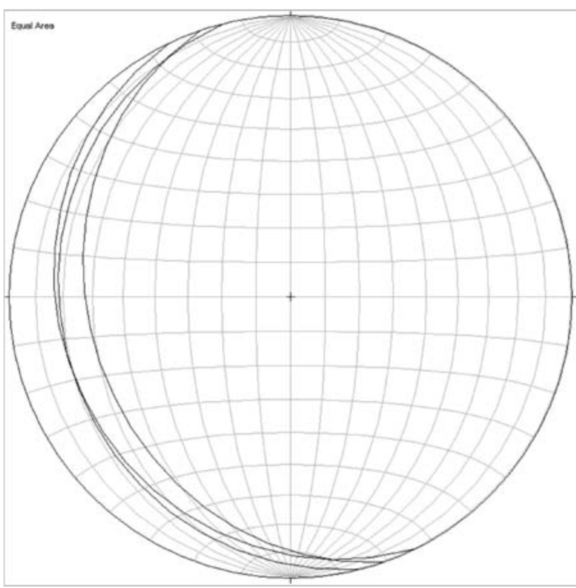
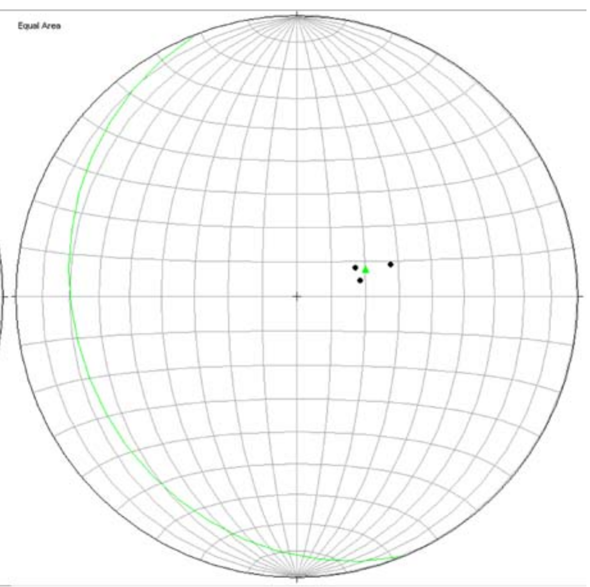
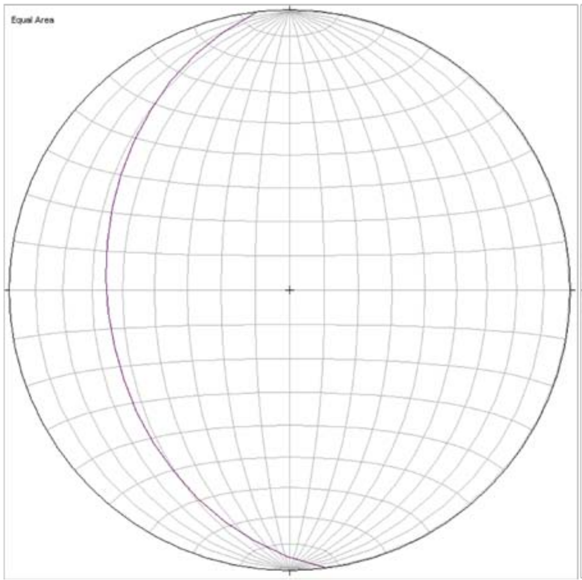


<u>Poles with Average Plane</u>

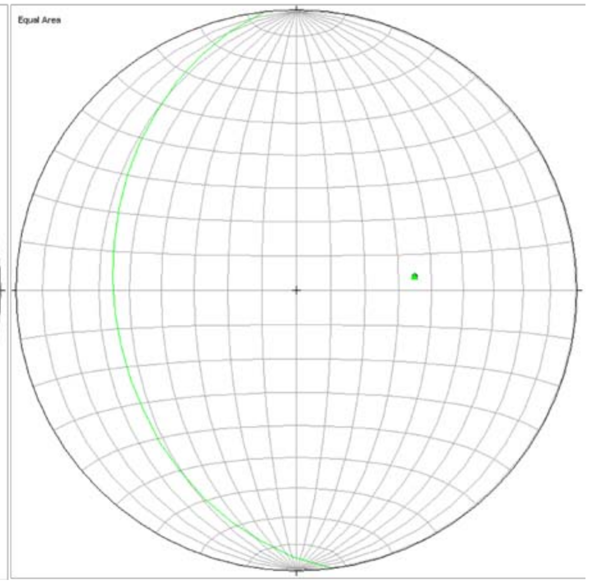


Fine Sandstone #2 (Tfs)

Planes

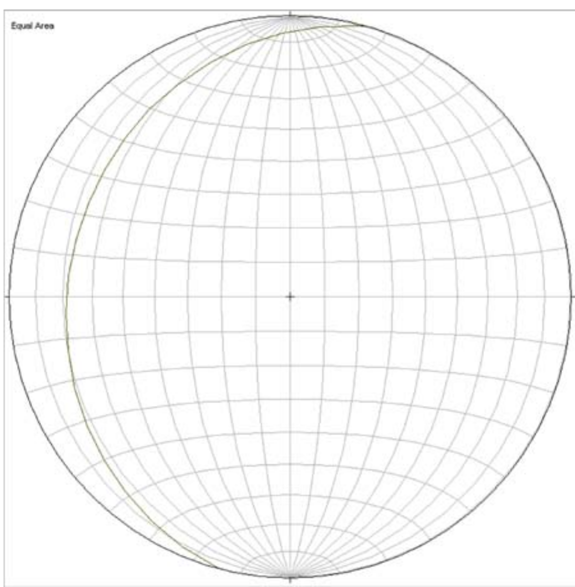


Poles with Average Plane

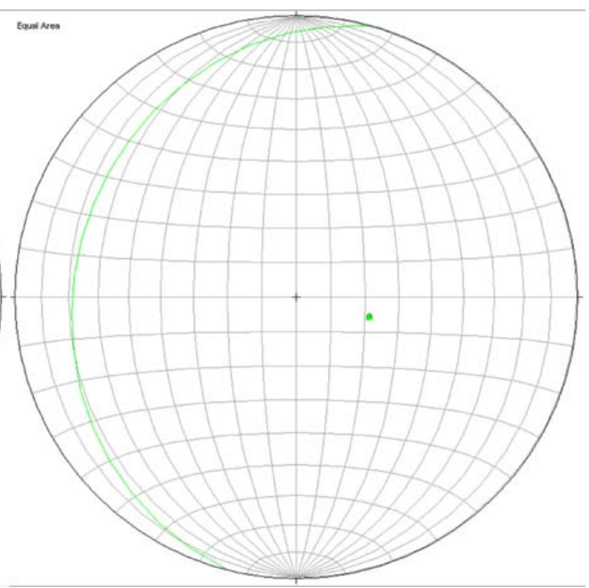


Sandstone #2 (Tss)

Planes

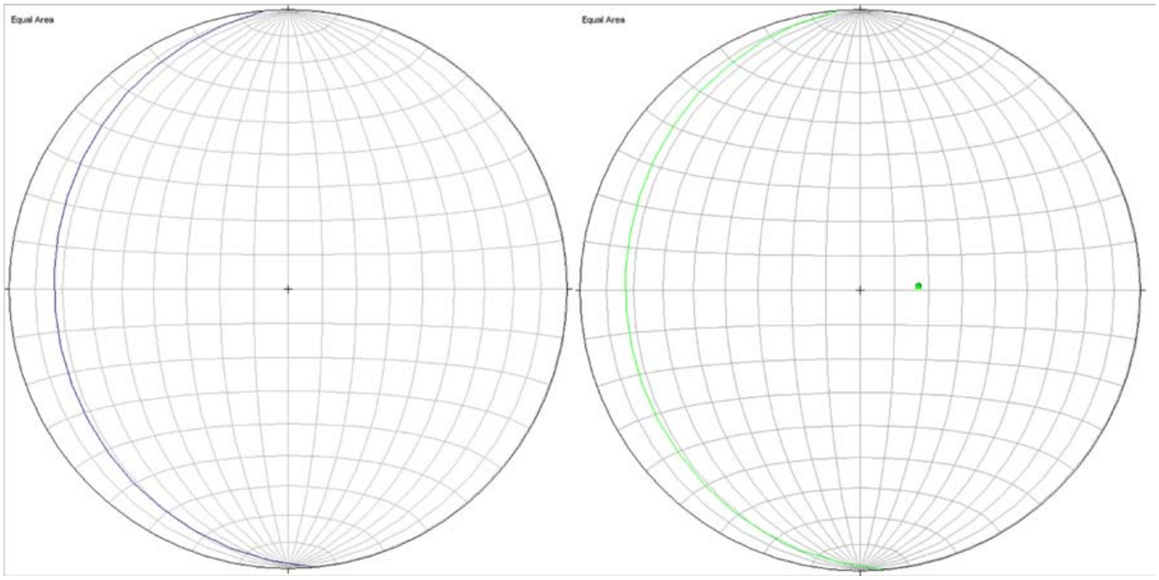


Poles with Average Plane



Red-Green Siltstone (Trg)

Planes   Poles with Average Plane

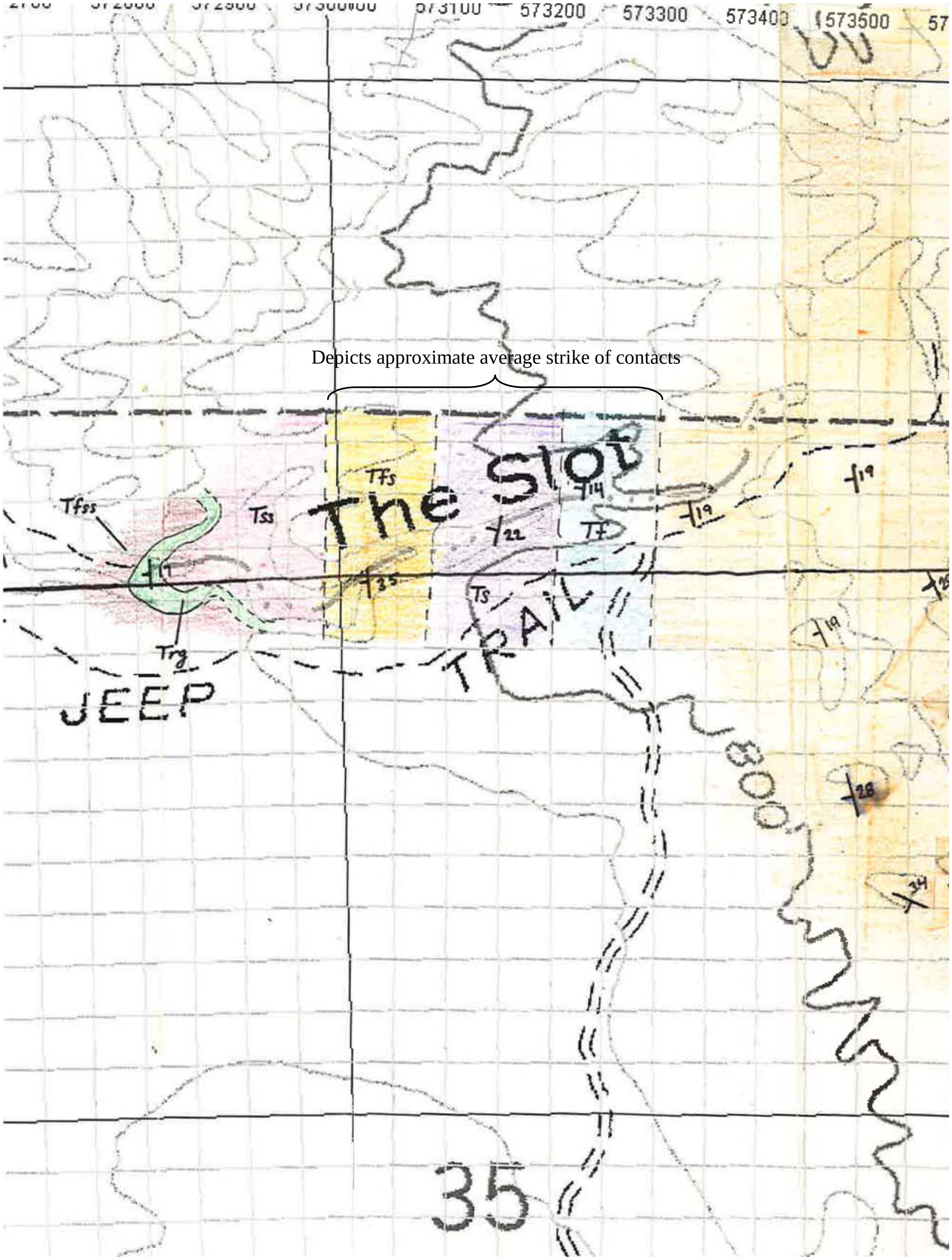


Stereonet legend

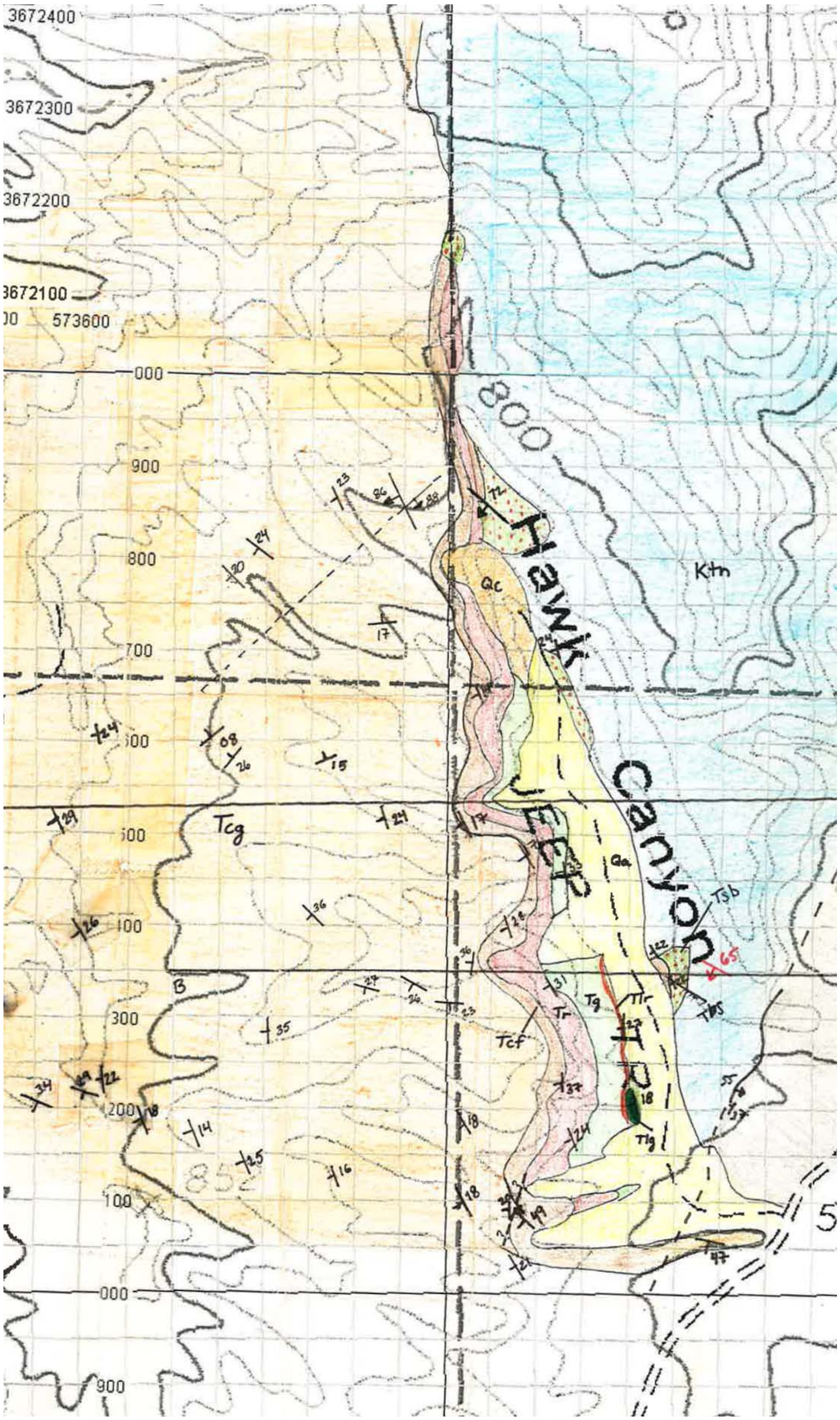
- Sedimentary Breccia (Tsb)
- Bedded Sandstone (Tbs)
- Green Siltstone (Tg)
- Red Siltstone (Tr)
- Cliff-Forming Sandstone (Tcf)
- Conglomerate (Tcg)
- Fine Sandstone #1 (Tf)
- Sandstone #1 (Ts)
- Fine Sandstone #2 (Tfs)
- Sandstone #2 (Tss)
- Red-Green Siltstone (Trg)
- Lower Red Sandstone (Tlr)
- Lower Green Sandstone (Tlg)
- ▲ Average Pole

Appendix II: Sectional Views of Surface Map

Western Section



Central Section



Eastern Section