The role of the Hot Springs fault in the development of the San Jacinto fault zone and uplift of the San Jacinto Mountains

Nate Onderdonk
Dept. of Geological Sciences
California State University, Long Beach
1250 Bellflower Blvd.
Long Beach, CA 90840
nonderdo@csulb.edu

Abstract

The Hot Springs fault is one of several strike-slip fault strands that make up the San Jacinto fault zone in southern California. The Hot Springs fault is located at the western edge of the San Jacinto Mountains and marks the steep, linear front of this range. Topographic contrasts along the fault, offset Pleistocene basin sediments, and elevated fluvial terraces indicate a strong component of dip-slip displacement along the fault in addition to strike-slip offset. This vertical component of motion has contributed to the uplift of the San Jacinto Mountains and controlled the deposition of sediments shed from the rising mountains during Pleistocene time. Geomorphic, geologic, and structural relationships along the Hot Springs fault indicate that the fault is an older strand of the San Jacinto fault zone that accommodated both strike-slip displacement and local topographic development during the early development of the San Jacinto fault zone.

Introduction

The San Jacinto fault zone is a major strike-slip structure in southern California and an integral part of the San Andreas fault system (Figure 1). The fault zone is oriented parallel to the southern San Andreas fault and may be accommodating the majority of the plate boundary strain in the area. It is the most seismically active fault in southern California and the kinematics, earthquake history, and slip-rate of the fault zone indicate that it is a major seismic hazard for the surrounding communities.

An equally important aspect of the San Jacinto fault zone is its influence on regional topography and drainage networks. Displacement along this fault zone has had a great impact on the physiography of the area and interactions between the multiple fault strands have created local topographic highs and basins along the fault zone. Initiation of displacement along the San Jacinto fault zone resulted in the uplift of the eastern San Gabriel Mountains and has contributed to basin inversion and uplift of the Timoteo Badlands in the San Bernardino area (Morton and Matti, 1993). The fault zone also bounds the southwestern edge of the San Jacinto and Santa Rosa Mountains, but exactly how much uplift of these ranges can be attributed to fault strands along this trend is unknown.

The San Jacinto Mountains are delineated on their southwest side by the Hot Springs strand of the San Jacinto fault zone (Figure 1). The topographic differences that occur across this range-front fault suggest that it has been the dominant structure controlling uplift of the range along the west side. However, little is known about the Hot Springs fault and its influence on topographic development along the San Jacinto fault zone. This paper describes the structural framework and kinematics of the Hot Springs fault, its relation to the rest of the San Jacinto fault zone and evaluates its role in the uplift of the San Jacinto Mountains.

The San Jacinto Fault Zone

The San Jacinto fault zone splays from the San Andreas fault in the eastern San Gabriel Mountains and strikes southeastward 200 km to the western Imperial Valley. The fault zone is currently the most active component of the San Andreas system in southern California in terms of microseismicity and frequency of larger magnitude earthquakes (Given, 1981; Sanders and Kanamori, 1984; Sharp, 1981; Thatcher et al., 1975; Wesnousky, 1986). At least nine earthquakes of M>6 have occurred on faults in this zone since 1890 (Wesnousky, 1986), and seismic recording stations detect a high level of microseismicity within the zone.

The total offset has been estimated to be between 24 km and 30 km of right-lateral displacement across the Claremont and Casa Loma faults in the central and northern part of the fault zone (Sharp, 1967; Morton and Matti, 1993) and about 21 km across the Coyote Creek and Clark faults in the southern part of the fault zone (Sharp, 1967; Dorsey, 2002). Estimates of slip rate along the San Jacinto fault zone range from 8 mm/yr to over 20 mm/yr (e.g., Sharp, 1967; Rockwell et al., 1990; Morton and Matti, 1993; Dorsey, 2002). Recent studies have revealed slip rates at the higher end of that range and suggest that Holocene slip rates on the San Jacinto fault may be faster than along the southernmost San Andreas fault (e.g., McGill et al., 2007; Fletcher et al., 2006; Kendrick et al., 2002; Morton and Matti, 1993). Geodetic studies indicate that the San Jacinto fault is accommodating a larger amount of the plate boundary displacement than the southernmost San Andreas fault (e.g., Becker et al., 2005) suggesting that the fault zone is the dominant plate boundary structure in southern California.

The San Jacinto fault zone is a series of fault segments that splay and overlap. This arrangement is most likely a reflection of the young age of the fault zone and the limited time it has had to develop into a single continuous structure. The age of the San Jacinto fault zone is inferred to be between 1 Ma and 2.4 Ma with the younger age favored in more recent studies (e.g., Sharp, 1981; Morton and Matti, 1993; Kendrick et al., 2002). The variations in age are the result of determinations of slip amounts and slip-rates on different fault segments within the zone. The splaying and overlapping fault segments make it difficult to infer total offset, age, or slip-rate for the fault zone before data is available on all the segments. The lack of studies along the Hot Springs fault are especially problematic due to the fact that this fault overlaps with two other major strands of the fault zone: the Claremont fault and the Casa Loma fault. These two faults, along with the Hot Springs fault and the Thomas Mountain fault make up the fault zone along the western edge of the San Jacinto Mountains and are the only known Quaternary structures that may have affected the uplift of the mountains.

The Claremont fault, which is the northernmost extent of the San Jacinto fault zone, extends southeastward from the eastern San Gabriel Mountains to the city of Hemet in the San Jacinto Valley. In the Hemet area, the Claremont fault has created a straight mountain front that bounds the northeastern edge of the San Jacinto Valley (Figure 1). The San Jacinto Valley is approximately 2 km deep and C^{14} dates from wood samples collected from drill holes indicate that the valley has been subsiding at a rate of 3 to 5 mm/yr for the last 40,000 years (Morton, 1995). The San Jacinto Valley has been identified as a strike-slip pull-apart basin resulting from a right-step between the Claremont fault and the Casa Loma fault (Sharp, 1967; Crowell, 1974). The Casa Loma fault lies at the southwestern side of the San Jacinto Valley and extends about 55 km to the southeast into the Anza plateau. Both of the faults are active with abundant microseismicity and strong geomorphic expressions.

The Hot Springs Fault Zone

The Hot Springs fault, originally named by Fraser (1931), steps eastward off the southeastern extent of the Claremont Fault 3 km north of the city of Hemet. It is expressed as a zone of faults that can be traced for about 50 km southeast along the mountain front to Garner Valley where the main trace is lost beneath alluvium. Due to the lateral discontinuity of a single fault segment, and in order to include the large number of secondary faults along the Hot Springs trend, the term "fault zone" is used herein to describe the larger structural zone. A dominant southeast-striking fault can be identified along most of the length of the zone, however, and the name "Hot Springs fault" is applied to this feature.

Geology along the fault zone

Along much of its length, the Hot Springs fault marks the contact between Pleistocene sedimentary strata and older crystalline rock of the San Jacinto Mountains. The crystalline rocks include tonalite to granodiorite plutonic rocks of the Peninsular Range batholith and older metasedimentary rocks that consist of various grades of micaceous schist, gneiss, migmatite, and arkosic quartzite. The Pleistocene sedimentary strata along the Hot Springs fault zone are known as the Bautista Beds (Frick, 1921). The Bautista Beds are a nonmarine formation with a total thickness of approximately 2,500 m. The unit is exposed along the San Jacinto fault zone from Hemet southeast to the northern Anza-Borrego valley and ranges from coarse fanglomerate to fine lacustrine shale (Figure 1). These strata were derived from the rising San Jacinto Mountains and were deposited as alluvial fans, stream deposits and lake deposits (Dibblee, 1981).

In the Soboba Hot Springs area (Figure 2) and along the sides of San Jacinto Canyon (Figure 3) the Bautista Beds consist of poorly indurated fine sand and shale with sparse lenses of pebble conglomerate. The visible thickness is about 350 m and the unit is exposed for approximately 35 km^2 in the foothills northeast of Hemet and above San Jacinto Canyon. The fine-grained nature of the Bautista Beds next to the steep mountain front indicates that they were not deposited in the rugged environment that currently exists. Stream gradients in Bautista time must have been considerably lower than the present-day streams that contain pebble and boulder sized clasts. Where not disturbed by faults, the beds have consistent attitudes with low dips of about 5°-25°. To the south and southeast of the Soboba Springs area, the Bautista Beds become coarser and grade laterally into thick conglomerate beds, that are well exposed in Bautista Creek and along Highway 74 in San Jacinto Canyon. The strata in this area have undergone a considerable amount of deformation since their deposition. Beds are shattered throughout by small faults and folded up to steep angles at the base of the larger bounding faults. Gentle anticlines and synclines exist within the beds and trend approximately east-west along the fault zone. Small remnants of Bautista strata are also found at higher elevations within the crystalline rock at two locations along the fault zone. Their current positions indicate that the strata have been vertically separated by displacement along the Hot Springs fault zone.

Structural Framework

The northwest end of the Hot Springs fault zone forms a restraining step-over with the Claremont fault (Figures 1 and 2). The main Hot Springs fault does not splay off the Claremont Fault as depicted on previous maps (Jennings, 1977; Sharp, 1967) but rather continues to the northwest and can be traced as far as the San Jacinto Potrero (Figure 2; Onderdonk, 1998). The uplifted terrain within the step-over is cut by several northwest-striking faults and is bounded on the south side by a major east-striking reverse fault herein referred to as the Soboba fault. At its west end, the Soboba fault connects to the Claremont fault and is marked by a prominent scarp approximately 9 m high. Outcrops show that the fault dips nearly vertical and striations on the fault surface indicate an approximately equal amount of north-side-up and right-lateral displacement for the last movement. The fault marks the contact between the uplifted crystalline rock on the north side and fine-grained sandstone beds of the Bautista Formation on the south side that have been drag-folded up against the fault to angles of 85°-60°. The dips of these beds abruptly shallow to angles of about 35°-20° away from the fault. The Soboba fault extends 2 km to the east and is delineated by scarps developed in both the crystalline rock and overlying Holocene colluvium. At its east end, the fault curves northward and most likely merges with one of the northwest striking faults within the step-over. There is no direct connection between the Soboba fault and the Hot Springs fault, although a set of smaller reverse faults that branch off of the Hot Springs fault are aligned with the strike of the Soboba fault.

Along most of its 50km length, the Hot Springs fault zone delineates a steep linear mountain front that forms the west side of the San Jacinto Mountains. The northwestern section of the fault zone in the Indian Canyon area (Figure 3) is composed of multiple anastomosing active fault strands with the easternmost marking the edge of the mountains. The faults are marked by deflected and beheaded streams, scarps, springs, vegetation lineaments, and outcrops showing breccia zones, gouge, and fault planes. Fault strands observed in outcrop dip 70° or steeper to the east. Several isolated pods of Bautista Beds are cut and uplifted by fault movement. In addition to being cut by numerous small faults, the beds are folded into a large anticline and syncline. The axes of these folds trend parallel to the fault zone.

Through San Jacinto Canyon (Figure 3), a single Hot Springs fault can be traced along the base of the mountain. The fault is represented mainly by the straight mountain front, but is also delineated by breccia zones, springs, vegetation lineaments, and outcrops of shear zones and fault surfaces. The fault planes dip steeply to the south where exposed and striations on the fault surfaces have rakes of 40° to 55° indicating a significant amount of dip-slip displacement in addition to strike-slip. The main fault bounds the Bautista Beds along much of its length although the contact is obscured by landslides in many places. The Bautista Beds coarsen up the canyon to the southwest and dip away from the fault except where folds exist. Overlying the Bautista Beds are several terrace deposits of Quaternary age. The older terraces (grouped as "Qt_1") are composed of boulders and coarse gravel deposited on a beveled surface in the Bautista Beds and have been deformed by fault movement. These deposits are only found on the northeast side of the canyon and represent older alluvial fans that formed along the mountain front. A set of younger terraces (grouped as "Qt_2" on Figure 3) is present at lower elevations about 200 to 300 feet above the present-day canyon bottom. These terraces still retain their original surface and are used as orchard sites in the lower canyon. They are unpaired across the canyon, indicating a period of constant uplift. No attempt has been made to numerically date either the younger Qt_2 or the older Qt_1 terraces and their designation as Quaternary is based on soil development and the fact that they overlie the Bautista Beds. Other (older?) strands of the fault zone are present to the east in the uplifted terrane above San Jacinto Canyon and are manifested as prominent linear slope breaks. These structures are identified based on topographic lineaments and are difficult to see on the ground due to the homogeneity of the rocks they break. At least one of these structures extends into the Garner Valley area where a linear alignment of truncated drainage divide ridges are present along the northeast side of the valley.

Between Highway 74 and Garner Valley the main strand of the Hot Springs fault zone created a linear slope that marks the north side of Baldy Mountain (Figure 4). Along the eastern half, the fault has thrust tonalite over the fanglomerate of Garner Valley. This relationship is exposed in an outcrop along Highway 74 above the Herkey Creek Campground where the fault dips 60° to the south. Southeast of Highway 74, the fault disappears under the recent alluvium of Garner Valley and detailed mapping of the east side of Garner Valley along strike with the Hot Springs fault revealed no conclusive outcrop evidence of its continuation. A small fault is present, however, at the top of Morris Ranch Road where the fault juxtaposes fanglomerate and granitic rock against metasedimentary rocks. This fault is along strike with the Hot Springs and is exposed as a thin clay gouge zone dipping 75° to the south in a quarry cut. In addition to this fault, a linear mountain front of crystalline rock that has been overlapped by Quaternary fan deposits is on alignment with the fault, and is most likely the result of early displacement along the Hot Springs fault trend.

The southern end of the Hot Springs fault zone is linked to the rest of the San Jacinto fault zone via the Thomas Mountain fault, which is located one kilometer south of the

Hot Springs Fault Zone across Garner Valley (Figure 4). The Thomas Mountain fault truncates Pleistocene sediments in the southern part of Garner Valley and juxtaposes Quaternary alluvium against tonalite at its northern end, but appears to be overlain by older Quaternary alluvium deposited at the base of Thomas Mountain. At its southeast end, the Thomas Mountain fault merges with the Buck Ridge fault in the area of Burnt Valley. At its north end, near Lake Hemet, the fault splits into two strands that merge to the northwest with the Casa Loma fault. The steep canyon that drains Lake Hemet and Garner Valley was eroded into gouge of the northern fault splay. Excellent exposures in the spillway of the Lake Hemet dam show that the Thomas Mountain fault dips south at approximately 50° degrees. The fault most likely merges at depth with the Casa Loma fault located along the opposite side of Thomas Mountain.

Strike-slip displacement and slip-rate

Displacement along the Hot Springs fault is assumed to be dominantly strike-slip due to the fault zone structure and its relation to the rest of the San Jacinto fault zone. Hill (1981) estimated a total right-lateral displacement of about 5 km across the Hot Springs fault zone based on offset intrusive rock contacts along the eastern extent of the zone. The age of the northern San Jacinto fault zone is believed to be between 1 Ma and 1.5 Ma based on mapping and stratigraphic studies (Morton and Matti, 1993; Dorsey, 2001). If the age of the Hot Springs fault zone is assumed to be the same, the slip-rate averaged over this time period would be between 5 mm/yr and 3.3 mm/yr. However, geomorphic expression and seismic activity suggests that although the Hot Springs is still active, it is not as active as the parallel Casa Loma fault to the southwest. If the Hot Springs fault is dying out, the pre-Holocene slip-rate was most likely higher than the estimates given above. Deflected and offset streams in numerous locations should provide a means to estimate Holocene displacement and slip-rates along the fault. However, many of these offset streams are developed in the granitic bedrock and do not offset younger deposits that can be easily dated. In the few locations where deflected streams are cut into Quaternary terrace deposits, the deposits have not been numerically dated and slip rate estimates cannot be made at this time.

Dip-slip displacement and topographic development along the Hot Springs Fault Zone

In addition to strike-slip displacement along the fault zone, a considerable amount of dip-slip displacement has also occurred. Dip-slip displacement is expressed in kinematic indicators along the fault with striations on exposed fault surfaces consistently inclined to a rake angle around 45°. Steep mountain fronts, elevated plateau-like topography, deep and narrowly incised canyons, and vertically-displaced Bautista Beds and younger terrace deposits also attest to vertical movement along the Hot Springs fault zone. Accordant peaks and an elevated plateau that may represent an old fluvial beveled surface are present along the uplifted side of the Hot Spring fault. Matching this uplifted surface to the bedrock surface on the down-dropped side results in about 430 ±60 meters of vertical separation. A lower surface on which Bautista Beds have been deposited is vertically displaced approximately 140 ±20 meters across the fault in the Soboba Springs and Indian Canyon areas. The Bautista Beds in the Anza area, about 23 Km south, contain the Bishop Ash dated at 760 ka (Sharp, 1981). Using this as a maximum age of cessation of deposition, a minimum uplift rate of about .2mm/yr is obtained.

Quaternary uplift of the San Jacinto Mountains has also resulted in the preservation of a sequence of uplifted fluvial terraces on the west side of the range. Most of these terraces are preserved on the western side of the Hot Springs fault and therefore represent vertical separation along fault strands farther west, such as the Claremont and Casa Loma faults. Two levels of terraces are preserved in the Soboba Reservation area and at least three levels of unpaired terraces are present along the sides of San Jacinto Canyon. None of these terraces have been dated or systematically described. These deposits should provide markers with which to estimate Quaternary uplift rates, but until numeric ages are obtained they can only serve as evidence of Quaternary (and most likely Holocene) uplift of the San Jacinto Mountains along the San Jacinto fault zone. Although the older (higher) terraces are cut by the Hot Springs fault, none of the deposits are preserved on the uplifted side of the fault to serve as a marker for vertical separation across this structure.

Uplift along the Hot Springs fault has also occurred at the northern end of the fault due to a restraining step-over arrangement with the southern end of the Claremont fault. Uplift within the step-over is recorded by elevated topography bounded by the faults, tilted Miocene-Pliocene strata on the north side of the elevated topography within the step-over, and by a sequence of terraces that have developed along the major drainage (Potrero Creek) passing though the area into the San Jacinto Valley. Tung (2008) identified four levels of terrace deposits along Potrero Creek (Simplified in Figure 2) and obtained numeric ages on two of the levels using radiocarbon dating on detrital charcoal. He calculated an uplift rate of about 1 mm/yr within the step-over area based on the relative heights of the two dated terraces. This rate most likely underestimates the uplift within the step-over because Potrero Creek is not graded to the floor of the San Jacinto Valley due to the presence of waterfalls developed in resistant crystalline rocks downstream from the terraces. However, the second highest terrace (Qt_2 of Tung, 2008) can be followed out along the drainage at a slope of about 25m/km to the point where the terrace would intersect the Claremont fault. At this point the Qt_2 terrace would be approximately 67m above the active floor of the valley. Using the radiocarbon age of 26,000 ±850 years for Qt_2 (Tung, 2008) the uplift rate across the Claremont fault in the step-over is about 2.6 mm/ yr.

Recency of faulting

Along most of its length, the main Hot Springs fault marks the contact between the Mesozoic plutonic rocks of the San Jacinto Mountains, and the Pleistocene Bautista Beds. The Bishop ash has been recognized within the Bautista Beds at two locations (Sharp, 1981; Dorsey, 2002) indicating that the upper boundary of the unit is younger than 760Ka. The Hot Springs fault and other faults in the zone bound and deform these strata so that the maximum age of the movement that offset the Bautista Beds is Late Pleistocene. Younger stream terrace deposits that lie unconformably on the Bautista Beds are also displaced by faults at many locations. These offset terraces have not been numerically dated but are presumed to be Pre-Holocene based on the degree of soil development and their heights above active stream channels. A large number of deflected and beheaded stream channels, knickpoints in stream channels, and scarps indicate Late

Quaternary offset on the Hot Springs fault although most of these features are developed in resistant tonalitic bedrock such that the offsets may be pre-Holocene. The only feature that requires Holocene surface rupture within the Hot Springs fault zone is a 2 meter scarp in colluvium along the Soboba fault that branches off the Claremont fault at the southern edge of the step-over. The fault does not link to the main Hot Springs fault and Holocene offset of the colluvium is most likely related to activity splaying off the south end of the Claremont fault. A small amount of seismicity (primarily at the southern end of the Hot Springs fault) attests to continued activity at depth along the fault zone, but further work is need to numerically document the last surface rupture.

Discussion

Age of the Hot Springs fault and relation to the rest of the San Jacinto fault zone

The Hot Springs fault is interpreted to be less active than the nearby strands of the San Jacinto fault zone based on a comparison of the number and relative age of tectono-geomorphic features, microseismicity, and locations of major historic earthquakes. Both the nearby Claremont fault and Casa Loma fault are better expressed geomorphically and exhibit younger geologic offsets than are evident along the Hot Springs fault. Dated offsets (Sharp, 1981) and trenching work near Anza (Rockwell et al., 1990) have provided evidence of Holocene surface rupture on the Casa Loma fault and abundant microseismicity reveals continued movement at depth. Several large (M>6) earthquakes between 1890 and 1923 are believed to have occurred along the Casa Loma and/or Claremont faults in the area (Thatcher et al., 1975). No paleoseismic data exists for the Claremont fault in the San Jacinto Valley area, but offset Holocene deposits and seismic activity indicate that this fault is active. Trenching studies along the fault to the north have revealed evidence of Holocene surface rupture (Wesnowsky et al, 1991; Fumal pers. comm., 2007) and the fault may exhibit slip rates as high as 20 mm/yr (Kendrick, 2002).

Although Holocene displacement along the Hot Springs fault is not precluded by the relationships along the fault, it is deemed unlikely and most of the movement along the fault appears to have occurred during Pleistocene time. The age of inception for the Hot Springs fault zone cannot be conclusively determined, however, geologic relationships suggest that some faults within the zone may have been active during early deposition of the Bautista Beds. Along most of the length of the Hot Springs fault zone, the faults bound the eastern edge of the Bautista Beds. The absence of these sedimentary rocks along the eastern side of the fault zone is either the result of erosion off the uplifted side, or early movement along faults in the zone that created the topographic gradients and led to the deposition of the Bautista Beds. The lack of other structures between the eastern edge of the Bautista Beds and the higher areas of the San Jacinto Mountains supports the idea that early movement along faults in the zone elevated the mountains and resulted in the deposition of the Bautista Beds. Continued oblique displacement resulted in further uplift of the San Jacinto Mountains on the east side and offset of the Bautista Beds such that the much of the eastern edge of the basins have been lifted and eroded. Geologic relationships in Garner Valley support this hypothesis. A linear mountain front developed in the crystalline rocks of the southern San Jacinto Mountains is aligned with the Hot Springs fault to the northwest. This mountain front has been covered with Pleistocene gravels deposited as fans at the mouths of the canyons that have been identified as Bautista Beds (Axelrod, 1966; Dibblee, 1981; Dorsey, 2005). These deposits appear to thicken as they cross the linear escarpment. This partially buried mountain front may be interpreted as a degraded scarp from earlier motion along an older segment of the Hot Springs fault zone that ceased during Late Pleistocene time during the deposition of the Bautista Fans. Dorsey and Roering (2005) presented paleocurrent data from Bautista Beds in the Anza area that show a dominantly westward transport direction. The morphology of the Bautista-age fans in Garner valley and along the Hot Spring fault also indicate a westward transport direction and show that these sediments were shed from the rising mountains across the Hot Springs fault zone. Dorsey and Roering (2005) also noted that the transport directions do not reflect the current topography along the Casa Loma and Thomas Mountain faults and indicates that the uplift of Thomas Mountain along these faults occurred after deposition of the Bautista Beds. These relationships in turn support the hypothesis that the Hot Springs fault is older than these other structures and the corresponding topography.

Movement along the Hot Springs fault zone is interpreted here to have occurred mainly during the earlier history of the San Jacinto fault zone and decreased through Late Pleistocene time as the parallel Casa Loma fault began to accommodate most of the displacement. Slip along the San Jacinto fault zone was transferred to the northern Hot Springs fault across the restraining step-over with the Claremont fault that resulted in uplift within this step-over. At the southern end of the Hot Springs fault, slip most likely was transferred across Garner Valley to the Thomas Mountain and Buck Ridge faults.

Uplift of the San Jacinto Mountains along the Hot Springs fault

Uplift of the San Jacinto Mountains by displacement on the Hot Springs fault occurred during Pleistocene time. Oblique slip along faults in the zone created the steep mountain fronts and elevated plateaus that are present along the eastern side of the fault zone and account for the topographic differences that define the western edge of the mountains. The onset of deposition of the Bautista Beds probably marks the beginning of movement along the Hot Springs fault zone. The Bautista Beds are present in a linear alignment along the western side of the San Jacinto and Santa Rosa Mountains and were probably deposited in strike-slip basins associated with the early development of the San Jacinto fault zone (e.g., Sharp, 1967). In addition to any strike-slip motion on the early fault zone, the data presented here suggest that there was a significant component of west-side-down displacement on early faults in the zone that elevated the mountains and triggered deposition of the Bautista Beds along the mountain front.

The Hot Springs fault zone was one of several fault segments that lifted the San Jacinto and Santa Rosa Mountains. To the southeast, the western edge of the Santa Rosa Mountains is marked by the southern half of the Buck Ridge fault and the Santa Rosa fault. Like the Hot Springs fault, both of these faults exhibit large topographic contrasts, relatively low amounts of seismicity, and less geomorphic evidence of Holocene activity than other faults within the San Jacinto fault zone. Vertical displacement along the Santa Rosa fault is about 400 meters at its south end based on offset of mylonite in the Santa Rosa Mountains and this correlates with a 400- 500m high escarpment of the mountains

(Dorsey, 2002). Exactly how much uplift occurred along the Hot Springs fault zone is not known because no markers have been identified on the uplifted side. Geomorphic evidence points to at least 430m of uplift and differences in Helium cooling ages across the Hot Spring fault suggest 800m of vertical offset on the fault (Wolf et al., 1997).

The Bautista Beds along the northern half of the Hot Springs fault zone are composed mainly of fine-grained sandstones and lacustrine shales. The current location of these fine-grained deposits next to steep topography along the fault and the absence of coarser deposits indicate that displacement along the Hot Springs fault continued until at least 760ka (age of the Bishop Ash) and has juxtaposed low-energy environment deposits against high-relief mountain fronts. The offset terraces that overlie the Bautista Beds show continued uplift. However, the locus of uplift has since migrated westward to the Claremont and Casa Loma faults as displacement along the Hot Springs fault zone decreased. This westward migration of uplift is reflected in the topography along the Casa Loma fault and recorded by the terraces in San Jacinto Canyon that lie between Casa Loma fault and the Hot Springs fault.

The complete history of uplift of the San Jacinto Mountains remains to be resolved. Geologic and geomorphic relationships along the Hot Springs fault indicate that motion along this structure has contributed to the uplift, possibly more than 800 meters, but cannot account for most of the topographic development of the range. Despite the fact the eastern side of the range is extremely steep, the morphology of the east side is not indicative of active faulting and no active structures have been mapped along the mountain front. This suggests that most of the uplift of the San Jacinto Range must have occurred prior to Pleistocene time. George and Dokka (1994) suggested that the San Jacinto block experienced rapid exhumation and cooling during the Late Cretaceous based on apatite fission-track ages. However, Wolf and others (1997) have argued against this interpretation based on Helium cooling ages and prefer a younger Middle Tertiary age of uplift. Much of the topography of southern California is related to the opening of Gulf of California around 5ma (Atwater, 1970) and local extension within the Salton Trough occurred from Late Miocene to Pleistocene time (Axen and Fletcher, 1998). Uplift of the Santa Rosa mountains may have occurred along the West Salton Detachment Fault that is exposed along the southern east side of the range and was most active between 5 Ma and 2 Ma (Axen and Fletcher, 1998). This extensional episode may have also lifted the San Jacinto Mountains in the footwall of the extensional structure, although the location and amount of required uplift is problematic and the northward continuation of the detachment has not been identified along the east side of the San Jacinto Mountains.

Conclusion

The Hot Springs fault zone marks the western edge of the San Jacinto Mountains and was involved in the Pleistocene initiation and development of the San Jacinto fault zone. The zone exhibits right-lateral oblique slip kinematics that partially lifted the San Jacinto Mountains and controlled the deposition of the Bautista Beds during Pleistocene time. Continued movement on faults within the zone have truncated the Bautista Beds and vertically displaced them in some locations. The Hot Springs fault shows little evidence of Holocene displacement and much of the strain accommodated by the fault during Pleistocene time has probably jumped westward to the Casa Loma fault.

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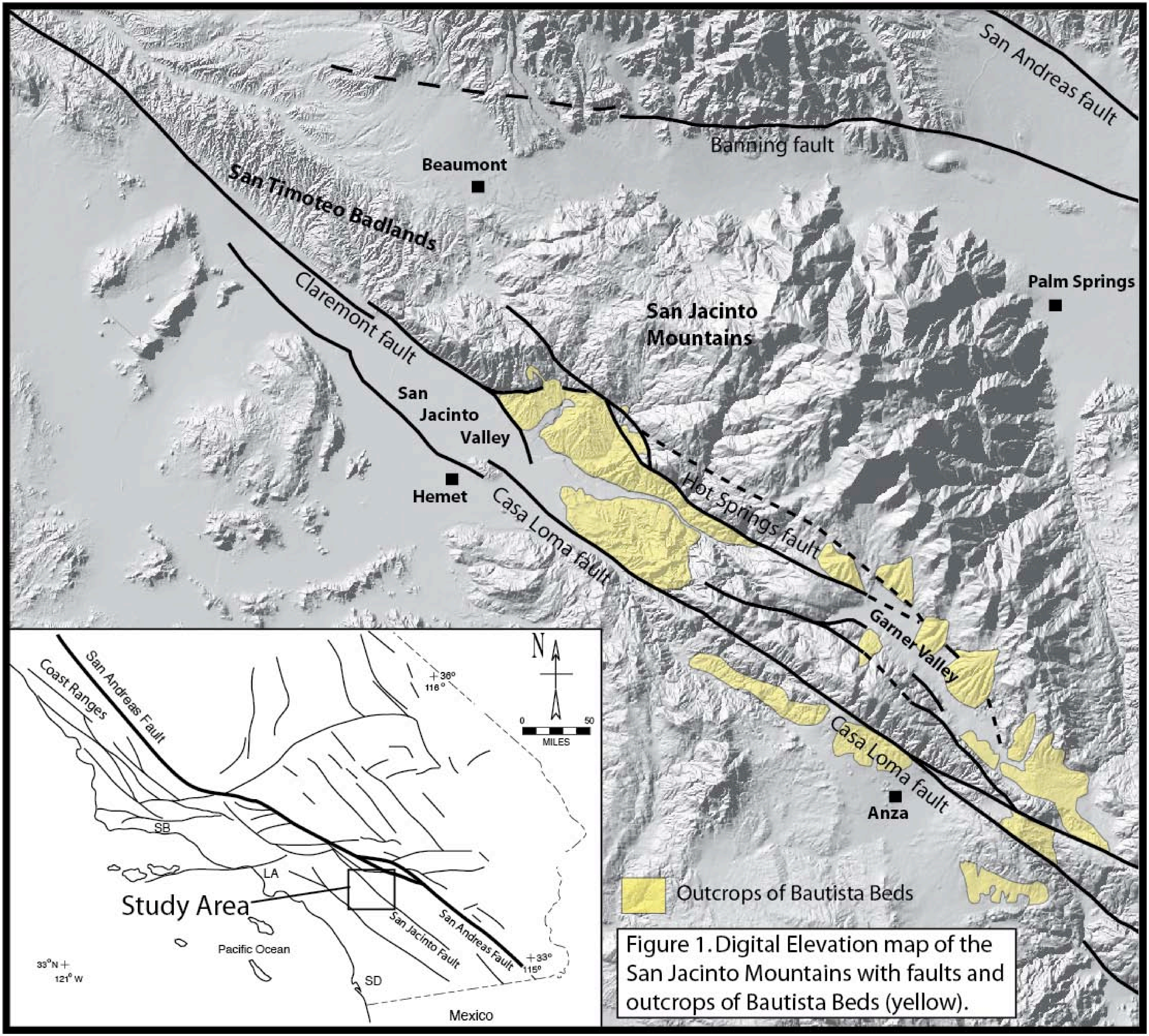
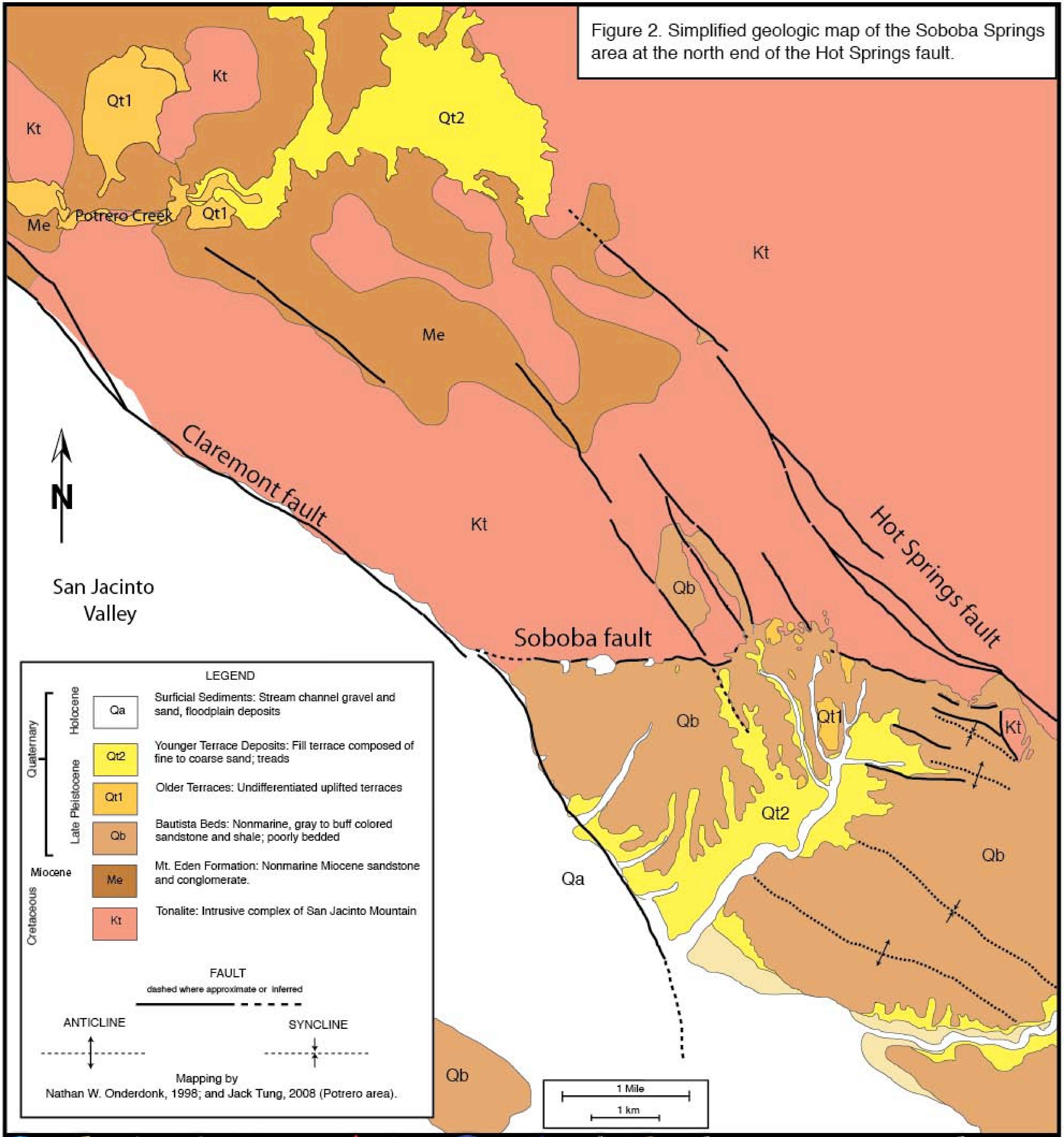


Figure 1. Digital Elevation map of the San Jacinto Mountains with faults and outcrops of Bautista Beds (yellow).

Figure 2. Simplified geologic map of the Soboba Springs area at the north end of the Hot Springs fault.



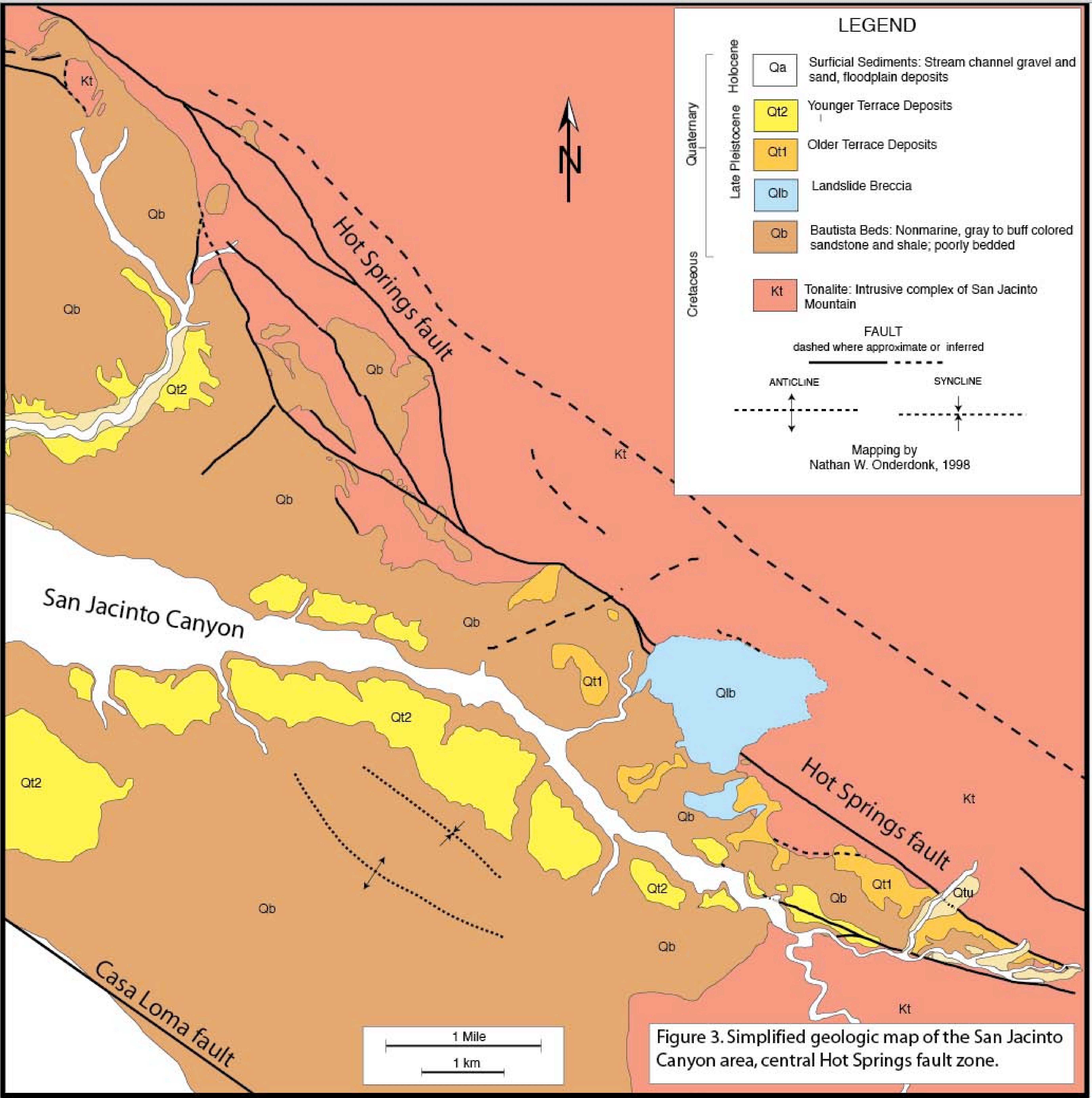


Figure 3. Simplified geologic map of the San Jacinto Canyon area, central Hot Springs fault zone.

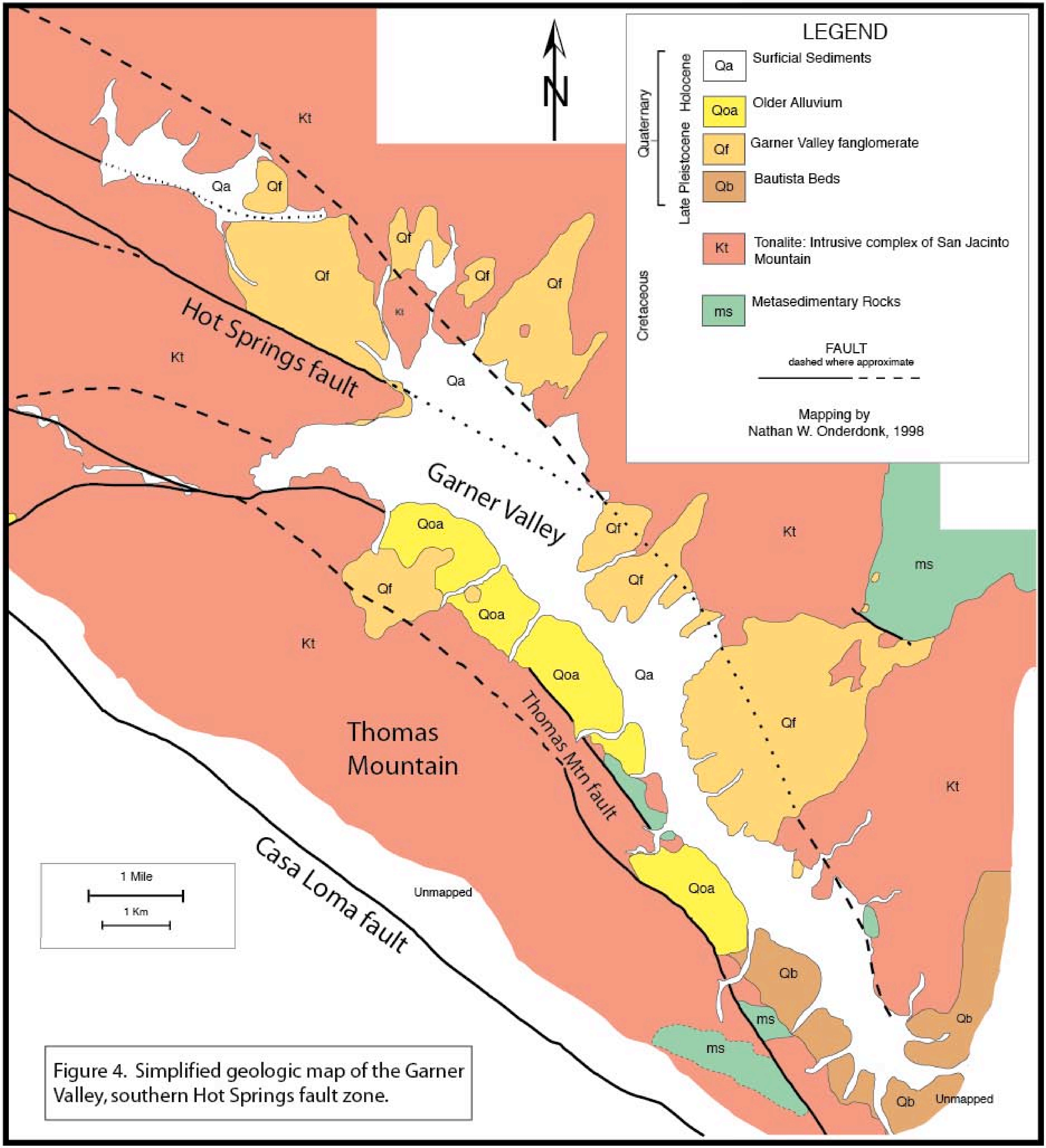


Figure 4. Simplified geologic map of the Garner Valley, southern Hot Springs fault zone.