ASSOCIATION OF
ENGINEERING
GEOLOGISTS

NORTH VALLEY CHAPTER 2005 Field Event

Sacramento River Fluvial Geomorphology – Balls Ferry to Bend Ferry Bridge

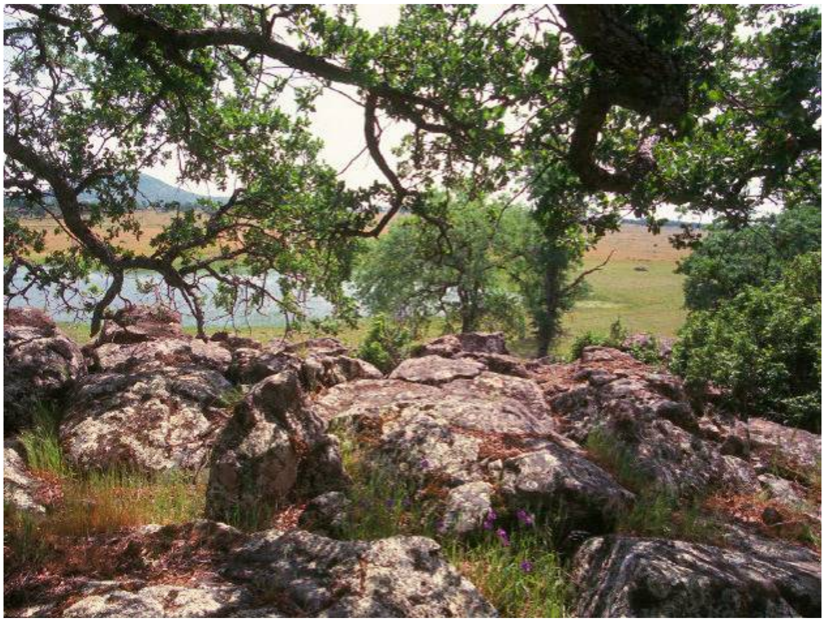
October 1, 2005

SACRAMENTO RIVER FIELD TRIP GUIDE
DEPARTMENT OF WATER RESOURCES

Introduction

This magnificent canyon is located in the Keswick Dam to Red Bluff Diversion Dam reach of the Sacramento River (Figure 1). Battle Creek, draining the Cascade Mountains on the East, and Cottonwood Creek, draining the Coast Range and Klamath mountains on the West, join the Sacramento River. Many of the naturally spawning chinook salmon in the Sacramento River use this reach.

This part of the Sacramento River has been considered for Wild and Scenic status, and is presently being considered for National Conservation Area status. There are several outstanding proposals for acquisition of fee title or conservation easements as well as existing holdings of BLM and CDFG. These include Goat Island, Bloody Island and lower Battle Creek, the mouth of Cottonwood Creek, the mouth of Battle Creek, and parts of the Jellys District. The river flows through the BLM- managed Paynes Creek Area of Critical Environmental Concern.



Sources of Information

DWR (1980) prepared the *Upper Sacramento River Spawning Gravel Study* for the Department of Fish and Game to evaluate the condition of spawning gravel in the upper Sacramento River. The report identified factors resulting in a loss of spawning gravel quality. These include gravel mining on the river and its tributaries, construction of Shasta and Keswick dams, and the loss of gravel recruitment from areas above dams.

The construction of Shasta Dam required over 7 million cubic yards of gravel for concrete. Most of this material was excavated from the Sacramento River near the Civic Center in Redding (River Miles 295 to 298). The excavation left large and deep pits that continue to trap spawning gravel transported downstream from areas above. The 1980 report estimated that about 1.3 million cubic yards a year of gravel was being mined from the alluvial deposits of the river and its tributaries. At the same time, bedload recruitment from above Shasta was reduced from an estimated 75,000 cubic yards a year to zero.

Surface and bulk gravel sampling showed that riffles in the river between Keswick and Clear Creek were armored by cobbles too large for salmon to move. The degree of armoring slowly diminished downstream. Below Cottonwood Creek, a source of a large amount of sediment, the armoring was less pronounced and the gravel in riffles was generally appropriate for salmon spawning. Look for this transition in gravel size as we float from Balls Ferry Bridge to below the mouth of Cottonwood Creek.

In October, 1995 DWR prepared the *Sacramento River Gravel Study- Keswick Dam to Cottonwood Creek* report. The report includes a discussion of historic changes in spawning gravel quality, spawning gravel restoration efforts, results of past and present spawning gravel sampling, and spawning gravel quality criteria. Results of the 1995 study suggested that spawning gravel in the reach is generally significantly coarser than what is considered ideal spawning gravel. It was recommended that spawning gravel mitigation programs be continued in areas above Cottonwood Creek.

Harwood and Helley (MF-1790, 1985) produced a series of maps showing the Late Cenozoic geology of the Sacramento Valley. The accompanying geologic map is modified from this work. The USGS Red Bluff Sheet also is a handy reference for this section of the river.

DWR (2003) produced the *Cow Creek to Jellys Ferry Geomorphic Study* for the U.S. Bureau of Land Management. Much of the text here has been derived from this report.

Location and Access

The field trip area is in Shasta and Tehama Counties. The reach begins at River Mile 276 and extends to just below the Bend Bridge at River Mile 257.8, a river distance of about 18 miles.

Towns in the reach include Bend and Cottonwood. Vehicular access is available from Jellys Ferry Road and Bend Ferry Road. The river is navigable with small craft such as canoes, rafts and jet boats. During the late-fall, low flows cause some of the riffles to be difficult to navigate.

Public boat ramps are available at Balls Ferry, Jellys Ferry, and Bend. The ramp at Jellys Ferry is unimproved and at times requires four-wheel drive. Boats can also be launched off the gravel bar near the old mouth of Battle Creek. Public access is available at Balls Ferry Bridge, Reading Adobe/Goat Island, the mouth of Cottonwood Creek, the mouth of Battle Creek, Jellys Ferry Bridge, Perry Riffle,and at Bend. Public access to Battle Creek is available at Jellys Ferry Road Bridge, and Coleman National Fish Hatchery. Additional access is available at private resorts, bridges, and a number of other places.

Wildlife and Wetland-Riparian Habitat

About 150 years ago, the Sacramento River south of Red Bluff was bordered by up to a half million acres of riparian forest and wetland. A wide array of species, including shorebirds, wading birds, amphibians, reptiles, fish, mammals, invertebrates and plants depend on this type of habitat. Fifty-five percent of the threatened and endangered species in California are associated with wetlands.

As agriculture and urban areas developed along the river, the riparian vegetation was gradually reduced, until less than five percent of the original acreage now remains. Streamside riparian vegetation along the Sacramento River between Redding and Red Bluff has not been as severely affected, with about 45 percent of the original vegetation remaining. The steep slopes and lack of access has protected the streamside vegetation in our field trip area. Native riparian forest vegetation includes mixed cottonwood, box elder, and sycamore groves as well as mature stands of valley oak and live oak. Most of the valley oak and live oak forests occurred on the flat terraces adjacent to the river, but most of these have been converted to agricultural uses. Because of the generally steep and high banks, the riparian corridor is narrow. Blue oak savannas predominate on the canyon walls.

Riparian lands provide a multiplicity of complex, highly suitable and critical habitat for a wide range of birds, mammals, amphibians, insects, and other wildlife. State and/or Federal listed species of special concern include the bald eagle, western yellow-billed cuckoo, Swainson's hawk, valley elderberry beetle, giant garter snake and others.

Riparian habitat may be divided into a number of zones, beginning on the gravel bar next to the water surface, followed by the riparian scrub, and extending out to the riparian forest on the floodplain and terrace. Sloughs, backwaters, and tributary mouths provide warmwater fishery and wetland habitat.

The gravel bar habitat (gravel) is normally inundated and scoured by floodflows on a yearly basis. There are no soils present and the substrate consists of silt, sand, gravel, cobbles and woody debris with a minimum of woody vegetation. Bare areas are the norm, but thin lines of young willows, annual forbs and grasses occur in places. The density and diversity of the gravel bar habitat is variable and depends upon streamflow, length of time between flood events, summer moisture availability, shade, substrate, and mechanical disturbance.

The riparian scrub habitat generally extends from the gravel bar to the edge of the high water channel. The substrate is typically gravel overlain by sand and silt of varying depth. Woody debris piled up by floodflows occurs in places. The vegetation generally consists of brush and young woody vegetation of the type that occurs outside the channel on the floodplain. The density of this vegetation is also highly dependent upon the flow regime during the previous few years. The vegetation is adapted to winter flooding that scours and removes most of the growth and allows for the periodic rejuvenation of this habitat.

The riparian forest (cottonwood forest and mixed forest) is on the floodplain and on terraces outside the active channel. The substrate is generally bedrock or gravel overlain by sandy silt and organic silt. The riparian forest is normally inundated once or twice a decade. Instead of the scour that characterizes the channel, deposition of sand and silt is the norm. Typical riparian forests consist of an over-story of cottonwood, sycamore, box elder, alder, black walnut, valley oak, live oak and other tree species with an under-story of brushy vegetation such as poison oak, valley elderberry, blackberries, willows, and grapes as well as forbs and grasses. Bloody Island at the mouth of Battle Creek was the most extensive of these riparian forests, but much of the forest has been converted to orchards.

Artificial and natural ponds (marsh and part of open water), along with backwater areas and oxbow lakes provide for transitory wetland habitat. Along the lower part of Cottonwood Creek, and at the mouth of Battle Creek, the channel meanders, or moves its course from one side of a meander belt to the other. The wetland habitat is created by erosion and channel changes, but converted or balanced over time by flood deposition.

Historic Changes

Since about 1850, the field trip area has undergone a number of hydrologic, geomorphic, and environmental changes, some of which have been detrimental to locally adapted species. These changes are caused by dams and diversions, bank protection, urbanization, stream gravel removal, hydraulic mining, agriculture, and logging. Some of these changes have had long-reaching effects, including alteration of river characteristics, such as depth, width, gradient, sinuosity, sediment, bed material, and bank erosion. This in turn has reduced riparian vegetation, water quality, hydrologic diversity, and fish and wildlife resources.

A large number of chinook salmon (<u>Oncorhynchus tshawytscha</u>) migrated up the Sacramento River each year to spawn. Although there were probably four runs then, as there are today, the two largest runs were thought to have occurred in the fall and spring. The other two runs, winter and late fall, are not as well documented historically, especially their numbers. Most of the spring-run and winter-run salmon, as well as part of the fall and late fall salmon, were thought to have spawned upstream from the present location of Shasta Dam. However, large numbers of spring-run and fall-run salmon also spawned in many Sacramento tributaries. A large part of fall run spawned in the Sacramento River between Redding and Red Bluff.

Before Shasta Dam, the Sacramento River was free flowing. Late summer flows were low, averaging 3,000 cubic feet per second (cfs), and in dry years dropping as low as 1,000 cfs. The river and its tributaries, however, would fluctuate widely in response to winter rains and spring snowmelt. Large amounts of suspended sediment and gravel bedload moved from the mountains in response to intense winter storms.

In 1944, Shasta Dam was completed for flood control and water storage purposes. Regulation of the discharge has dampened low and high extreme events below the dam, resulting in a regulated flow in the summer averaging 7,000 cfs to 13,000 cfs and a regulated peak winter flow near Redding of 80,000 cfs. The reservoir was constructed by the U. S. Bureau of Reclamation on the upper Sacramento River above Redding. Shasta Dam stores 4.5 million acre-feet and, to a large extent, regulates flows from the Pit, McCloud, and upper Sacramento Rivers. Keswick Dam, 9 miles downstream from Shasta, provides power, water regulation, stops salmon migration, and acts as a fish-trapping facility. The dam traps most of the sediment in deltas in the upper reaches of the lake. Sediment-free flow below the dam scours the river channel and transports all but the coarsest sediment. The resulting substrate is armored by cobbles and boulders that are in many places too coarse for salmon to spawn.

Whiskeytown Dam controls flows on Clear Creek. Since December 1963, water has been diverted from the Trinity River Basin through the Clear Creek Tunnel and Judge Francis Carr Powerhouse to Whiskeytown Lake. The Spring Creek Tunnel then diverts Trinity water and most Clear Creek water through Spring Creek power plant into Keswick Lake. The effect of the Trinity River diversion on post-Shasta flows has been to increase average Sacramento River discharge by about 1,000 to l,500 cubic feet per second throughout most of the year. The diversion amount has recently been reduced to improve water flows in the Trinity River. Flows, particularly flood flows, in Clear Creek below Whiskeytown dam have been reduced. Recently minimum flows on Clear Creek have been increased to provide spawning and rearing habitat for anadromous fish.

Urbanization, primarily in Redding, Anderson, Cottonwood, and Red Bluff, caused additional problems in the study reach. Gravel extraction for highways, housing, and other projects averaged in excess of about 1.5 million tons per year, mostly from tributary streams (DWR, 1980; 1984). This, in conjunction with Shasta, Keswick, Whiskeytown, and other dams that prevent gravel recruitment from upstream reaches, reduced the spawning gravel available in downstream reaches. The recent trend toward offstream gravel mines has ameliorated this problem to some extent.

Dams and unscreened, or poorly screened, diversions have affected the river fishery. Early dams and diversions built by miners and farmers obstructed miles of habitat without allowance for fish passage or mitigation measures. By the 1920s, at least 80 percent of the Central Valley spawning grounds had been cut off by obstructions, according to the U. S. Bureau of Reclamation.

River Geomorphology

River geomorphology is the study of the origin and development of river form and function as a result of the underlying geology. Geology includes geologic units, structure, tectonics, and geologic changes caused by major climatic shifts.

The geomorphic characteristics of the study reach are an intrinsic function not only of the geology underlying and surrounding the river, but also of the regional climate and river hydrology. Human induced changes, such as dams, levees, and diversions have also had a profound effect.

If a river has incised (i.e., eroded down below the original channel bed surface) as a result of natural or human-induced factors, the abandoned upper floodplain may become a “terrace” (former floodplain) where riparian forest may then convert to valley oak woodlands or grassland-oak savannah. The characteristic three-dimensional shape of a river (its “fluvial geomorphology” or landforms created by flowing water) is indicative of a river that is in dynamic balance with the interaction of its flood regime, sediment supply, vegetation patterns, climate, and valley slope. Rivers with a natural shape and hydrologic condition generally support the most diverse mixture of habitats and fish and wildlife species and are the most resilient to natural or human disturbance.

The river between Redding and Red Bluff has been divided into 5 reaches (DWR, 1980) two of which occur in the field trip area. Reach 3 includes the upper part of the field trip area, and extends from the mouth of Cow Creek to the Mouth of Cottonwood Creek. This short section is a transition between the upstream and downstream reaches. The valley floor remains fairly wide, but the channel pattern has sinuosity of 1.19, lower than the adjacent reaches. The river gradient is about 0.0009. A uniform deepening of the channel reduces the frequency of riffle-pool sequences. Few depositional features, such as islands and bars occur in this reach.

Reach 4 extends from the mouth of Cottonwood Creek to the north of Red Bluff. The river is mostly constrained and underlain by the Pliocene Tehama Formation, consisting of semi-consolidated fluvial deposits, and the Pliocene Tuscan Formation, consisting of inter-bedded lahars, lava, volcanic conglomerate, volcanic sandstone, siltstone and pumiceous tuff. These resistant deposits usually make up one bank and part of the channel bed, alternating between the right and left side of the channel.

The channel material is predominately composed of cobble- and gravel-size clasts with some sand, silt, and vegetation. In many instances, up to half the channel is underlain by bedrock while the remaining is underlain by gravel or cobbles.

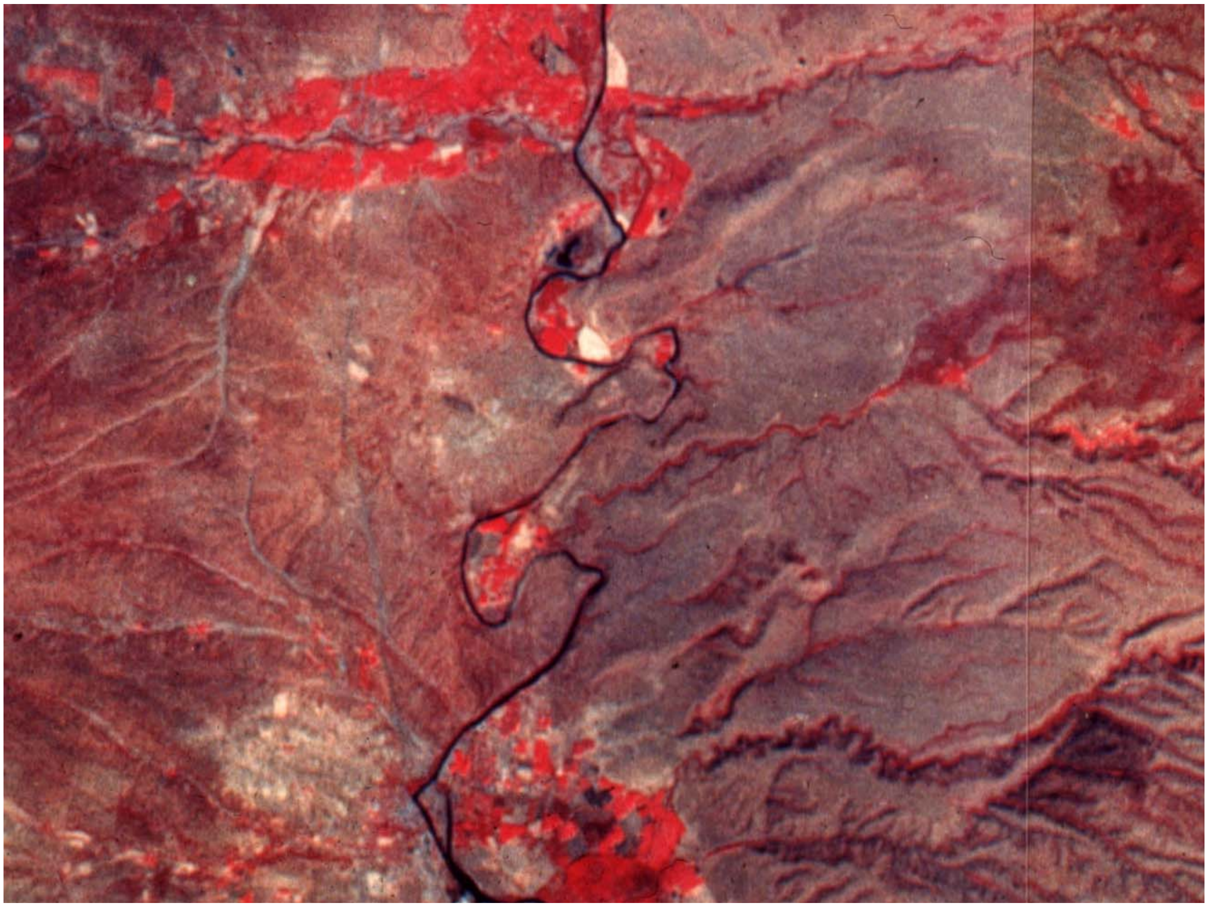
The Table Mountain basalt flow dammed the Sacramento River. The olivine basalt flow is referred to as the Basalt of Coleman Forebay. The unit is undated but underlies the Red Bluff Formation. Maximum thickness is about 10 meters. The alluvial and terrace deposits found upstream of this point are probably partially due to the sediment deposited in the lake behind the lava dam.

The photo below is a U2 infrared image of the field trip reach. Note the high sinuosity. One thought is that the bends represent entrenched meanders, essentially formed when rapid uplift of the area occurred during the Quaternary. Another thought is that the bends formed on the anticlines and synclines of the Inks Creek fold system.

Geology

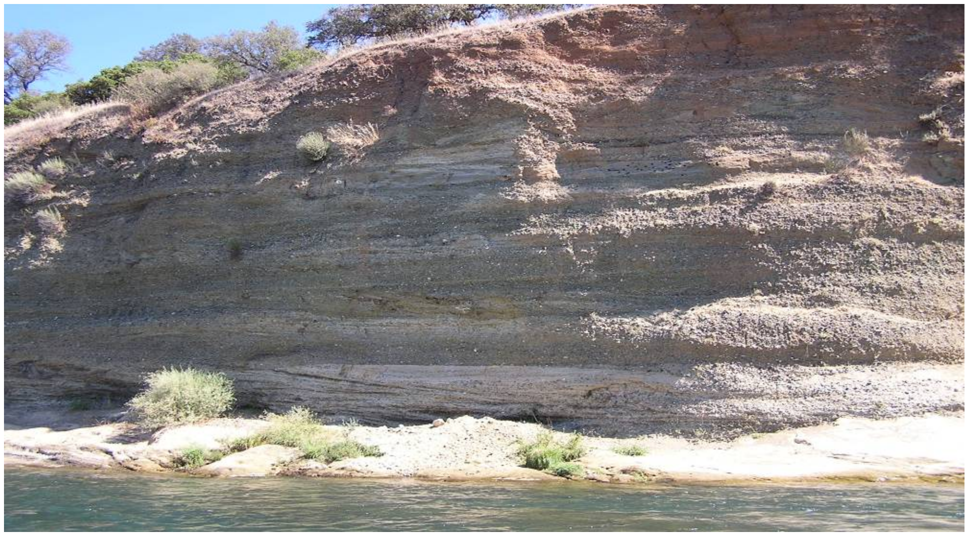
Shasta and Tehama Counties lie within the Sacramento Valley, in the Great Valley geomorphic province. The province extends throughout the Great Central Valley of California. Most of the rocks and deposits are sedimentary, ranging in age from Upper Jurassic to Recent.

The Great Valley province is a 400-mile-long by 60-mile-wide sedimentary basin. The geomorphic provinces surrounding the northern Great Valley here include the Coast Ranges to the west and the Cascade Range to the east. Geologic units cropping out consist of sedimentary and volcanic deposits of Tertiary and Quaternary age, such as the Tehama, Tuscan, and Red Bluff Formations. Terrace deposits include the Upper and Lower Modesto and Upper and Lower Riverbank formations. Quaternary alluvium, older alluvium, and landslide deposits cap the sequence. The Redding Basin is part of the Sacramento Valley, but separated by uplift along the Battle Creek fault zone and the Inks Creek fold system.



Tehama Formation. Regionally, the Tertiary Tehama Formation (Tte) is composed of fluvial sedimentary deposits of semi-consolidated pale-green, gray, and tan sand, tuffaceous sand, silt, and clay. The Tehama Formation has scattered, discontinuous lenses of gravel that are coarser and more abundant toward the west. The clast lithologies indicate that they were derived from the Coast Ranges and Klamath Mountains to the west and northwest (Russell, 1931). The formation has a low regional dip towards the center of the valley and the Sacramento River. The Tehama Formation becomes finer away from the mountains of origin. In general, the Tehama Formation forms rounded hills with moderate relief and has a thin soil cover. Along streams, exposures form 20- to 500-foot high near-vertical bluffs.

The Tehama Formation is exposed along the west bank of the river downstream of the mouth of Cottonwood Creek (RM 273.3-272.2), and downstream of Lake California to the Bend Ferry Bridge (RM 258). In the Photo below, intercalated semiconsolidated sand and gravel beds are overlain by the reddish-colored Red Bluff Formation.



***Tuscan Formation*.** The Pliocene Tuscan Formation (Tt) outcrops primarily along the eastern side of the valley to the Sacramento River. The Tuscan consists of interbedded lahar deposits, volcanic conglomerates, and fluvial volcanic sandstones and siltstones. The formation is broken up into seven members of varying thickness, and composition. The composition ranges from interbedded lahars, volcanic conglomerates, volcanic sandstone, siltstone and pumiceous tuff. The clast size distribution of the lahar units is variable and consists of angular to sub-angular obsidian, augite-olivine basaltic andesite, gray hornblende andesite and black scoria. The basal lahar member of the Tuscan Formation (Tta) also contains metamorphic clasts of Sierra Nevadan origin, but can only be found in Dye Creek to the south east. The lahar members are prominent cliff formers, which display varying vertical thickness up to 390 feet along the Chico Monocline. Separating the lahar and interbedded lahar members are three pumiceous tuff members, the Nomlaki, Ishi and Hogback Road Tuff. The tuff members are white to light-gray, pumice lapilli tuff contaminated with varied amounts of sandstone and siltstone. Average thickness of the tuffs is approximately 3 to 12 feet, but thickness increases to the east up to 75 feet in the Nomlaki Tuff Member, at Tuscan Springs.

Member D (Ttd), the uppermost member of the Tuscan Formation, is exposed along the east bank of the river near the Balls Ferry Bridge, the south east bank at the Barge Hole, the old mouth of Battle Creek, and underlies younger deposits downstream of the Jellys Ferry Bridge.

The Tuscan Formation is exposed along the east bank of the river near the Balls Ferry Bridge. It is also exposed on the south east bank at the Barge Hole, the old mouth of Battle Creek, and underlies Table Mountain downstream of the Jellys Ferry Bridge and farther downstream).

Red Bluff Formation. The Pleistocene Red Bluff Formation (Qrb) crops out in the northern part of the valley as a veneer or pediment surface overlying the Tehama and Tuscan Formations. The Red Bluff Formation consists of very-coarse gravel with a red (2.5-5YR) color, and a clay, sand, and silt matrix. The Red Bluff Formation west of the Sacramento River was derived from metamorphic rocks of the Coast Ranges and Klamath Mountains. A volcaniclastic fanglomerate on the eastern side of the Sacramento River north and south of Battle Creek, was derived from the Tuscan Formation and lava flows and is correlated with the Red Bluff Formation in the west.

The Red Bluff Formation is overlain by the Rockland ash bed that has been dated as 0.4 Ma (Sarna-Wojcicki and others, 1982). Maximum thickness of the Red Bluff is measured at 15 feet.

The Red Bluff Formation is exposed on the top of the bluff downstream of the mouth of Cottonwood Creek (RM273.3-272.4). The Red Bluff originally consisted of a uniform, gently sloping surface. Deformation of this surface is the primary indicator of Quaternary structural deformation, including the Inks Creek fold system and the Battle Creek Fault.

Terrace Deposits. The river and major tributary streams have developed a series of terrace levels flanking the stream channels. These terraces stair-step up in elevation away from the active channel, with the upper terraces being the oldest.

Terrace deposits are typically complexly intertwined, and each mapped terrace may have several minor deposits of different age and elevation associated with it. These are typically not differentiated.

The four Pleistocene terraces that occur in the area, from oldest to youngest, are the Lower Riverbank, Upper Riverbank, Lower Modesto, and Upper Modesto. These terraces have been correlated by their absolute age, soil stratigraphy, and geomorphic expression to the Riverbank and Modesto Formations of the San Joaquin Valley (USGS, 1984).

Terrace deposits are older and above present stream channel deposits. They average about 6 to 10 feet thick but may exceed 20 feet in places. The lower half or two-thirds of the deposit is similar to the stream alluvium. The upper part is generally finer, and consists of a flood plain deposit of organic material, clay, sand, and silt. Terrace deposits are abundant along the Sacramento River and westside tributaries such as, Cottonwood, Hooker, and smaller creeks, and some eastside tributaries.

The lower member of the Riverbank Formation (Qrl) is lithologically similar to the Red Bluff Formation and has nearly the same red color. It consists of gravel, sand, silt and clay. It occurs on the higher of two flat terraces that have been cut and filled into the surface of the older Red Bluff and/or Tehama and Tuscan Formations. The deposits are generally weathered and have a matrix generally rich in clay and silt.

The upper member (Qru) is younger. It formed during a long period of stable climatic conditions. This member occurs as extensive flat stream terraces along most of the westside and some of the eastside tributaries. Soils developed on the member display medial development with strong textures. The soil contains a B-horizon and local hardpan but profile development is not as great as on the lower member.

The lower member occurs extensively east of Anderson and Cottonwood and is mapped as the upper terrace at Lake California. The upper member occurs lower and closer to the river in the Anderson/Cottonwood area, at Lake California, and along the east side of Battle Creek Ranch.

The lower member (Qml) of the Modesto Formation consists of unconsolidated, slightly weathered gravel, sand, silt, and clay. It generally has a silt layer on top that is several feet thick.

It is similar to the Upper member except that the soils created from this unit do contain a faint B-horizon. The unit varies in thickness, but is generally less than 20 feet thick.

The lower Modesto occupies the higher terraces along the tributaries of Cow, Bear, and Cottonwood Creeks as well as the higher surfaces on Bloody Island and in the Jellys District.

The upper member (Qmu) is composed of unconsolidated, unweathered gravel, sand, silt, and clay. It forms alluvial fans along the east side of the Sacramento Valley from Red Bluff to Oroville. Extensive deposits also occur along the Sacramento River and most westside streams. Soils at the top of the member have A/C horizon profiles, lacking the B-horizon. Both the upper and lower members border existing channels and are generally less than 20 feet thick. Upper Modesto deposits are mined for concrete aggregate along Clear, Cottonwood, and Hooker Creeks.

The upper Modesto is the low terrace along the river and tributaries including the northern and eastern parts of Anderson valley, lower Battle Creek and Bloody Island, Lake California, and the Jellys District.

Volcanic Units. Basalt of the Coleman Forebay (Qcb) is dark-gray olivine basalt, which weathers to a light rusty-gray. The basalt contains large irregular vesicles and voids that form large rounded pits on weathered surfaces. The formation is undated, but is older than the Red Bluff Formation and has a maximum thickness of approximately 30 feet. The Basalt of the Coleman Forebay caps Table Mountain and the hill across the river to the north, and forms the flat surface along the axis of the Inks Creek anticline.

Rockland Ash/Ash of Mt. Maidu (Qar) is a loosely aggregated pumice lapilli ash with scattered coarse pumice fragments up to 8-inches in diameter, forming a major dacitic to rhyolitic ash-flow tuff deposit between Digger Buttes and the Battle Creek escarpment. The ash has been dated at 0.45 m.y. using fission-track methods (Meyers and others, 1980). The ash flow is at least 180 feet thick at Digger Buttes, but is generally less than 15 feet thick in scattered outcrops to the west. The Rockland ash is exposed at Round Hill southwest of the Jellys District.

Basalt of Shingletown Ridge (Qbs) is dark-gray, fine-grained porphyritic basalt with rounded phenocrysts of brownish-green olivine. The basalt flows overlie the Tuscan Formation and have a total thickness of about 90 feet north of Manton but are only about 15 feet thick near Bear Creek. The Basalt of the Shingletown Ridge forms the volcanic plateau north of Ash Creek and east of Bear Creek.

Surficial Deposits. Surficial deposits in the area include Quaternary alluvium, overbank deposits, mine tailings, and active stream channel deposits.

Alluvium (Qa) is unweathered gravel, sand, and silt deposited by present day stream and river systems. The alluvium tends to be somewhat older than the stream channel deposits. Differentiation from Qsc is based on its position in the stream channel.

Over-bank Deposits (Qo) are sand, silt and minor lenses of gravel deposited by floods and during high water stages. These deposits form low terraces adjacent to present-day alluvial stream channels and usually do not exceed nine feet in thickness. These deposits are mapped in the flood plain at Anderson River Park and Lake California.

Stream Channel Deposits (Qsc) are deposited in open active stream channels without permanent vegetation. These deposits are being transported under modern hydrologic conditions; consequently, they are unweathered and make very good sources for gravel. Stream channel deposits are mapped along the river and the major tributaries.

Tectonic Setting. The study area is in the northern part of the Sacramento Valley in the Great Valley Geomorphic province. This province includes a thick sequence of marine and continental sedimentary and volcanic rocks in a large, elongated northwest-trending structural trough. The trough is floored with basaltic and ultramafic oceanic crust and mantle. The age of the deposits ranges from Jurassic to Recent. The trough is a region of relative tectonic stability that has persisted in approximately its present structural form throughout most of Cenozoic time.

Plate tectonics have played a major role in the tectonic development of California. From late Jurassic to mid-Tertiary, the eastern Pacific oceanic lithosphere (Farallon plate) was subducted beneath the western margin of the North American continental plate. This subduction resulted in the formation of an arc-trench system that included an accretionary prism, a forearc basin, and a volcanic-plutonic magmatic arc. Today these terranes are represented by the Franciscan Complex, the Great Valley Sequence, and the Klamath and Sierran plutonic/metamorphic belt. Throughout Cretaceous time rocks eroding from the surrounding plutonic and metamorphic belts were deposited by submarine turbidity currents into the deep forearc basin. These sediments, the Great Valley Sequence, continued to accumulate, filling the forearc basin to near sea level by Paleogene. During this same period, ocean floor and trench deposits of the Franciscan Complex were being dragged down by the Pacific plate, and under thrust in a wedge against the continental margin and beneath the Great Valley sediments (Ingersoll, 1983). As more oceanic material was deposited beneath the continental plate, the accretionary wedge increased in size. Subsequent under thrusting resulted in the sediments of the forearc basin to be uplifted and tilted to the south and east (Harwood and Helley, 1987).

As subduction ceased during mid-Tertiary, uplift became more rapid and the transition to a strike-slip regime began offshore in southern California. This transition led to the formation of the San Andreas Fault. As the San Andreas Fault evolved, the Mendocino triple junction between the Pacific-Farallon, North American, and Gorda lithospheric plates began to develop and migrate slowly northward. During this period, the Great Valley experienced several episodes of uplift and subsidence, until by early Miocene, most of the northern valley had emerged from the inland seas and was subjected to fluvial erosion and deposition. Concurrently, volcanic eruptions were occurring along the northern Sierra Nevada, damming streams and filling narrow valleys with volcanic debris.

During the Pliocene, continental stream lain sediments of the Tehama and Tuscan formations were deposited as large coalescing alluvial fans over the Great Valley Sequence sedimentary rocks at the foot of the emerging Coast Ranges. The Nomlaki Tuff Member, which occurs locally at or near the base of the Tehama, is an ash fall from volcanic eruptions that blanketed much of the northern valley about 3.4 million years ago. Lava flows and mudflows flowed down the Cascades into the Sacramento Valley from the east.

Eventually the Tehama and Tuscan formations filled the valley with sediments to a depth of 0-2500 feet. Subsequent erosion and re-deposition have formed the present outcrop patterns of geologic units.

The Mendocino triple junction continued to move northward offshore, structures in the valley began to simultaneously exhibit compressive deformation along a similar northward-progressive pattern (Harwood and Helley, 1987). Beginning with activity at the Sutter Buttes (2.5 my) and continuing to the recent activity in the Battle Creek Fault region (0.5 my), the progressive northward pattern of valley deformation correlates with the latitudinal positioning and late Cenozoic movement of the Mendocino triple junction.

North of the Mendocino triple junction, the Gorda plate is presently subducting beneath the North American plate. Activity associated with this movement can be seen in the surface folding, faulting and uplift of the northern Coast Ranges, and in the 152-mile long zone of intermediate-focus earthquakes dipping eastward below the North American plate. Beneath the northern Sacramento Valley, several intermediate and deep-focus micro seismic events correlate with the Gorda plate subduction (Cockerham, 1984; Walter, 1986).

Presently, the northern Sacramento Valley lies between the large-scale right-lateral transform tectonism of the San Andreas Fault to the west, and the major east-west crustal extension of the northern Basin and Range province to the east. The current state of compressional stress is a result of regional forces manifesting their stress regime upon the valley, rather than localized forces originating within the valley. The direction of stress may vary locally, but in general, the direction of maximum compressive stress is approximately northeast-southwest.

Evidence of this stress regime manifests itself as a series of northwest trending folds and faults along the western Sacramento Valley. The faults dip steeply east, with reverse and minor left-lateral movement. In the north and northeastern valley, the structural trend shifts and, folds and faults become oriented in a more east-to-northeasterly direction. These faults typically dip steeply to the south, with normal offset and minor right-lateral movement.

Recent studies suggest that uplift along folds paralleling the western valley is active, and may represent the shallow expression of deeper thrusting. Interpretation of seismic reflection data (Unruh, 1991) indicates that these folds are due to active thrusting along a very large triangular wedge of rocks. This imbricate zone of detachment faults may represent the boundary between the rocks of the Coast Ranges, Great Valley, and Sierra Nevada. Additional evidence suggests that this zone of faulting (commonly referred to as the Coast Ranges-Sierran Block boundary zone) extends the full length of the western valley and is most likely responsible for the two 1882 Winters/Vacaville earthquakes (Magnitude 6-7) and the 1983 Coalinga earthquake (Magnitude 6.7).

Fluvial processes and regional uplift have formed the terrace and alluvial deposits as they appear today.

The major tectonic features included in the study area include the Battle Creek fault system, the Inks Creek fold system and Hooker Dome. These structures in this part of the Sacramento Valley serve as tectonic control along the Sacramento River. These features trend northeast southwest with the Inks Creek fold system plunging to the southwest.

A pronounced escarpment extends from the river to the northeast toward Lassen Peak marking the Battle Creek Fault Zone. The Battle Creek fault system continues along the South Fork of Cottonwood Creek, but no surface expression is mappable. The fault zone consists of several northeast trending normal faults that branch and intersect along the escarpment. Between the Coleman Powerhouse and Black Butte the faults are closely grouped along the escarpment, whereas east of Black Butte the faults are more widely spaced and veer off from the trend toward the northwest. Displacement along the fault zone varies depending on location and has been measured from 420 ft at the Coleman forebay up to 1440 ft at Black Butte north of Manton. West of the Sacramento River, the Battle Creek Fault Zone runs along the valley of Cottonwood Creek. No recent traces or linear features are present except for the east-west trend of the valley itself. Lineaments, scarps and linear trough-like features can be found in the Red Bluff Formation as well as both members of the River Bank Formation. The vertical displacement in the terrace levels ranges from 30 to 90 ft. To the southwest discontinuous lineaments can be traced through the Tehama Formation and Cretaceous rocks and merge with the Sulphur Springs fault near the west end of Red Bank Creek.

The Inks Creek fold system consists of a northeast trending syncline and anticline just south of the Battle Creek fault zone. These folds probably structurally control the major bends in the Sacramento River at Jelly School and Table Mountain. The axial trace of the syncline is nearly coincident with the main channel of Inks Creek. The anticline in the fold set has uplifted the Battle Creek fanglomerate and the Coleman Forebay basalt northeast of Jelly School. It is believed the fold dies out to the east somewhere within the fault zone. The syncline in the fold set also seems to change strike near the Battle Creek fault zone before dying out north of the Inks Creek volcanic center.

Detailed aging of the displacement of the Battle Creek fault zone and the Inks Creek fold system have yet to be successful, but age constraints on the major events have been dated. The Battle Creek fault zone is believed to postdate the deposition of the Mount Maidu ash, which has been dated at 0.45 my (Meyers and others, 1980). The occurrence of the Mount Maidu ash at Round Mountain approximately 3km southwest of Jelly School suggests that initial folding occurred on the Inks Creek fold system before the eruption of the ash. In contrast to the occurrence of the Mount Maidu ash at Round Mountain, the alluvial deposits of the lower part of the Riverbank Formation are found along the flanks of the present sinuous course of the Sacramento River through the structurally controlled loops of the river at Jelly School and Table Mountain. Clearly the Sacramento River had been forced into its course around the Inks Creek fold system by early Riverbank time. This evidence leads to the conclusion that the Battle Creek fault and the Inks Creek fold system developed in the time span between the Mount Maidu ash at 0.45 my and the 0.40 my date of the lower Riverbank Formation.

SACRAMENTO RIVER TRIP LOG
BALLS FERRY BRIDGE TO BEND FERRY BRIDGE

River Mile 276.0: Balls Ferry Bridge- Put-in for the river trip. Make sure to wear your life jacket. The river appears placid but swift current and snags may result in unwelcome submergence……

On the left bank, note the bank erosion as you float down the river. The height of the gravel in the bank changes markedly. This is typical of point bar deposits, since they taper in a downstream direction.

Note the channel fill or clay plug. The deposit is about as wide as the channel. This channel was abandoned at some time in the past, more than one hundred years ago. Note the thin depositional layers, similar to glacial varves. These layers represent deposition in the abandoned channel. Clay plugs are erosion resistant, and affect bank erosion rates when exposed in the river bank.

Keep an eye on the bank profile. Here the bank is mostly gravel. In other places the bank is mostly silt, and others it is older geologic units or "geologic control". There are Modesto and Riverbank terrace deposits represented. Some of these terrace deposits are "nested", meaning that are adjacent to each other and closely related. Can you tell the difference? Riverbank deposits have a light reddish color, gravelly sublayers, and tends to have the highest banks. The Modesto has a gray color, with banks taller than the floodplain deposits, but lower than the Riverbank. The Modesto generally has some soil development, clay, and calcification in the lower layers. Recent floodplain and point bar deposits tend to be loose and unconsolidated, and lower in overall height.

The sandy banks are the most erodible, followed with composite banks consisting of sand and gravel at the base and silt on top. Silt banks are erodible, but erosion rate is heavily dependent on the clay fraction and amount of consolidation. Clay banks and geologic control (Riverbank, Modesto, Tuscan, and Tehama formations) are the least erodible.

River Mile 274.4: Reading or Goat Island- This land is owned by the Bureau of Land Management and is a fishing access point on the right bank.

Goat Island is a good example of a climax floodplain riparian community of Great Valley Oak Riparian Forest, mostly consisting of valley oak, black walnut, and cottonwood. This type of habitat is now extremely rare in the Sacramento Valley, with less than 1 percent of this type of habitat surviving. Most of this vegetation has been removed for agriculture.

Note Lower Riverbank Formation terrace deposit on left bank. This formation is identified by the light reddish hue, with clayey gravels in the sublayers. The several hundred year-old oak tree and exposed roots indicate that bank erosion rates are real low here. Note changes in bank height. Generally the higher the bank, the older the deposit. There are exposed Riverbank, Modesto, and higher floodplain deposits nested along this short stretch of river.

Note low section of bank on the left. This is the 1896 channel, abandoned during a major channel shift shortly thereafter. We will discuss this farther downstream.

River Mile 274.2: Battle Creek Fault Zone - A pronounced escarpment extends from the river to the northeast toward Lassen Peak marking the Battle Creek Fault Zone. The Battle Creek fault system is believed to continue along the south fork of Cottonwood Creek to the west, but no surface expression is mappable. The fault zone consists of several northeast trending normal faults that branch and intersect along the escarpment. Between the Coleman Powerhouse and Black Butte the faults are closely grouped along the escarpment, whereas east of Black Butte the faults are more widely spaced and veer off from the trend toward the northwest. Displacement along the fault zone varies depending on location and has been measured from 420 ft at the Coleman forebay up to 1440 ft at Black Butte north of Manton. West of the Sacramento River, lineaments, scarps and linear troughlike features can be found in the Red Bluff Formation as well as both members of the RiverBank Formation. The vertical displacement in the terrace levels ranges from 30 to 90 ft. To the southwest discontinuous lineaments can be traced through the Tehama Formation and Cretaceous rocks and merge with the Sulphur Springs fault near the west end of Red Bank Gulch.

River Mile 273.3: Note the size of the cobbles in the bed of the river. The bed is a coarse cobble pavement, dark from algae and mineral deposition. Shasta Dam, by cutting off the gravel supply from above, has resulted in the bed becoming progressively coarser and forming a bed armor layer. Note that the river is deepening as we approach Cottonwood Creek. This is from gravel deposition and narrowing caused by the deposition of the creek delta.

This area is a good example of riparian ages and stages. Compare and contrast the tree species found in the streamside vegetation on the left bank. This is a relatively stable river environment. Typical species are box elder, alder, cottonwood, and black willow. The riparian zone is generally narrow, only a few tens of feet wide. Now look downstream to the mouth of Cottonwood Creek. Here we have a dynamic depositional environment, characterized by cyclic deposition and erosion. The forest is structurally more complex, with Great Valley Riparian Scrub Forest near the bank, and a developing Cottonwood Riparian Forest directly behind. In the Sacramento Valley, 5 different forest types develop as a result of the dynamic river processes of bank erosion, deposition, and meandering.

River Mile 273.2: Mouth of Cottonwood Creek on Right Bank- Cottonwood Creek is a major Westside tributary, providing the first major source of bedload to a sediment-starved river. The deltaic deposits at the confluence are good indicators of the material provided to the river. Note the change in Sacramento River bed material above and below the confluence. The actual fining of the bed material begins several miles above Cottonwood Creek because of deposition in the backwater caused by flooding in the creek. Although nearly half a million yards a year are still mined from the channel of Cottonwood Creek, most of the mining activity has moved to off-channel pits.

River Mile 273.1: Folding in the Tehama Formation on the Right Bank- Note the gentle dip to the south. The folding is part of the Inks Creek Fold system, described in further detail below.

Note the color of the Tehama, and the variety in grain size. The Tehama was deposited in a dynamic river environment, as suggested by the coarse, cross-bedded lenticular deposits of gravel. The amount of fines in the Tehama increases toward the center of the valley and downstream. The top of the Tehama hills are commonly capped by the red colored Red Bluff Formation.

Because of the interbedded nature of the Tehama, caves can be found where resistant layers cap more erodible layers. A number of caves, some used by native Americans, can be found along the river and Cottonwood Creek.

The Tehama underlies much of the Sacramento Valley. Tehama outcrops along the river in a number of places,. The geologic control provided by the Tehama affects bank erosion, meandering, river depth and width even as far south as the town of Princeton.

Observe the bed material. In places you can observe the dark cobble pavement, with newer shiny gravel from Cottonwood Creek. Cottonwood bed material transports past these armored areas, but collects on riffles. Salmon preferentially spawn in these areas. Salmon prefer fresh gravel, in the size between 1 to 5 inches. Riffles provide the appropriate velocities for the salmon to construct a nest, or redd. Riffles also allow for intragravel flow of water, thus providing oxygen for the eggs.

River Mile 273: Bloody Island on the Left Bank- The Site is named for a bloody massacre that occurred in the 1850s. The “island” is no longer, since the Sacramento River abandoned its channel and moved several thousand feet farther west. Battle Creek now occupies part of the old river channel. A conservation easement was recently purchased by the Trust for Public Lands on the Gover Ranch, protecting from development a large portion of the island.

Bloody Island is a point bar deposit. Note the size of the material is decreasing as we move downstream. This is characteristic of most point bars, where the head may have coarse gravel and cobbles, and the tail has sand.

River Mile 272: Lake California on the Right Bank- A large development consisting of several thousand lots, Lake California was developed by a large timber company in the 1960s. The development went through a number of owners, each becoming bankrupt. Presently a success, many houses are being built, including some expensive houses along the river. The lake on the floodplain was excavated for gravel road base, and subsequently developed for home sites in the manner of the "Tahoe Keys".

Exotic species, such as bamboo (Arundo), and Tree of Heaven, have invaded the riparian corridor. The problem seems to get worse the farther downstream you go. Calfed has programs now to identify and eradicate some of these species.

Snags were once considered a nuisance, to be removed to improve navigation. Now referred to as Large Woody Debris, or LWD, they are recognized as important contributors to fish habitat, providing feeding stations and cover for fish. LWD may also serve as bank protection in some areas.

Note walnut orchard on right bank. It is not a happy, healthy grove. It is subject to flooding, and the soils are shallow with gravel underneath. Part of the Gover Ranch Conservation easement is to replace parts of these orchards with riparian vegetation as they approach the end of their useful life.

River Mile 271.4: Mouth of Battle Creek on the Left Bank- One of the several "meandering" parts of the Sacramento River occurs here at Bloody Island. The lower two miles of Battle Creek is an abandoned Sacramento River channel. The creek is nearly 200 feet wide and has a sandy

bottom. The Coleman National Fish Hatchery is about 5 miles upstream. An average of about 50,000 salmon a year migrate up the creek. In October, the old stories about "walking on the backs of salmon" come true here. The Barge hole occurs just below the mouth. Salmon hold here, waiting for some signal (flow and temperature) to proceed up the creek. Hundreds of fishermen congregate here during the fishing season, resulting in a comical charade of dancing boats, flying insults, and tangled tackle.

River Mile 271: Bank Erosion- Bank erosion is not common in this reach of the river. Farther south in the Sacramento Valley, the river may move thousands of feet in a hundred years. Geologic control limits river movement in most places. Here the river is eroding river deposits, resulting in river movement, channel shifting, multiple channels, and islands forming during major flood events. The picture below shows bank erosion below the mouth of Battle Creek.

Channel complexity creates more diverse habitat for both plants and animals. There are more riffles, LWD, more gravel recruitment (from bank erosion).

Note the size of the gravel here in the riffles. It is much less coarse and more appropriate for spawning salmon. Deposition here in a straight reach of the river demonstrates how bank erosion can be triggered by the deflection of water directly into an alluvial bank. If this continues, the houses on the bank may be affected.

River Mile 269: Saron Fruit Colony on the Left Bank. The fruit colony was a commune………. The colony was established on Modesto Formation deposits, part of a large terrace on the inside bend of the river. Much of the fruit colony would go under floodwaters prior to the construction of Shasta Dam.

River Mile 268.8: Rio Alto Water District Sewer Discharge from Lake California on the Right Bank- Good reason not to drink the water. About 30 of these side channels were identified in DWR (1980) Upper Sacramento River Spawning Gravel Investigation as alternative spawning areas that could be enhanced by the placement of gravel. Side channels are more likely to keep the gravel during a major flood event.

River Mile 268: Axis of the Inks Creek Fold System- Can you see any folding? Well, of course not, you are on the axis.

River Mile 267.2: This is our first view of the Tuscan Formation at River level. The outcrops above the bridge are river lain, with semi-rounded clasts and stream derived bedding. Below the Bridge are volcanic mudflows, or lahars, consisting of an ash-rich matrix of mud. The mud's high viscosity allowed the flow to transport large particles, including boulders the size of houses. The large boulders creates turbulence and rapids, making navigation more interesting. The mudflows seen here were probably derived from eruptions of Lassen (Mt Tehama) over a period ranging from one million to 3 million years ago.

River Mile 266.8: Jellys Ferry Bridge and Fishing Access- Old Mr. Jelly operated a ferry here for many years before the bridge was constructed. We will stop here for the bathrooms.

River Mile 266: Lava Cliffs on Right Bank- Basalt of the Coleman Forebay (Qcb) is a dark-gray olivine basalt, which weathers to a light rusty-gray. The basalt contains large irregular vesicles and voids that form large rounded pits on weathered surfaces. The formation is undated, but is older than the Red Bluff Formation and has a maximum thickness of approximately 30 feet. The Basalt of the Coleman Forebay caps Table Mountain and the hill across the river to the north, and forms the flat surface along the axis of the Inks Creek anticline. An ephemeral lake or large vernal pool forms during winter and spring months on the top of Table Mountain, resulting in a cacophony of color and sound when migrating birds and flowers compete for the limited water supply.

River Mile 264.5: Synclinal Axis of the Inks Creek Fold System- The axis crosses the river in a NE direction. Tehama beds are flat-lying and well-exposed here.

River Mile 263: Axis of the Proposed but Abandoned Table Mountain Dam- This dam was explored by the USBR as an alternative to Shasta Dam and to Iron Canyon Damsite, a few miles north of Red Bluff. Both Table Mountain and Iron Canyon were abandoned because of the large expense of relocating the towns of Cottonwood and parts of Anderson. Note the lava on both sides of the river. The Lava of the Coleman Forebay flowed across the river at this point. The most likely scenario is that the lava formed a temporary natural dam, doing what USBR failed to do. The wide alluvial plains found above the damsite, but not below, are possibly the result of deposition behind the dam. Note old gage on left bank and pedestral rock on right bank.

River Mile 261: Paynes Creek Area of Critical Environmental Concern on Left Bank- The ACEC is managed by the BLM and consists of about 17,000 acres (with possible expansion to 37,000) set aside for environmental considerations. The area is open for recreation, and thousands of visitors use the area for horseback riding, hiking, boating, mountain biking, hunting, and fishing. The ACEC has been proposed as a National Conservation Area, an honor that would improve funding and increase visitors. Perry Riffle Fishing Access provides direct access to the Sacramento River for boating, swimming, and fishing.

River Mile 260.1 U.S. Geological Survey Cableway- The cableway is used for the "Above Bend Bridge" gaging station, one of four gages that have been used to measure Sacramento River streamflow and sediment on the river in this area. The photo below shows the general stable, non-erodible conditions in this part of the river. Note the large boulders, remnants of the Tuscan mudflows from the Lassen Peak area.

River Mile 259.2: The Bend Area on the Left Bank- The Bend was named for the prominent bend in the river that wraps around a large Modesto Terrace complex, as shown in the picture below. The Bend confused Peter Lassen, an early explorer mapping the location of the river. Gazing down from the cliffs above the Bend, Mr. Lassen assumed the river continued to the northeast toward his namesake Mt. Lassen. The river, however, curved around to the west, and then northward to Mt. Shasta. The Bend is a bucolic community consisting mostly of gentleman farmers, but includes the Driscoll Strawberry Farm. The farm surprisingly does not produce strawberries, rather strawberry plants that are shipped south to be planted on more valuable farmland.

If we are lucky, you will be able to see a soaring bald eagle in this area, a testament to the Endangered Species Act. The nest is on the left bank.

River Mile 257.8: Bend Ferry Bridge and the takeout.