DESIGN EVOLUTION OF OROVILLE DAM 1956-68

J. David Rogers, Ph.D., P.E., P.G., F.ASCE, F.GSA
Professor & Karl F. Hasselmann Chair in Geological Engineering
Missouri University of Science & Technology
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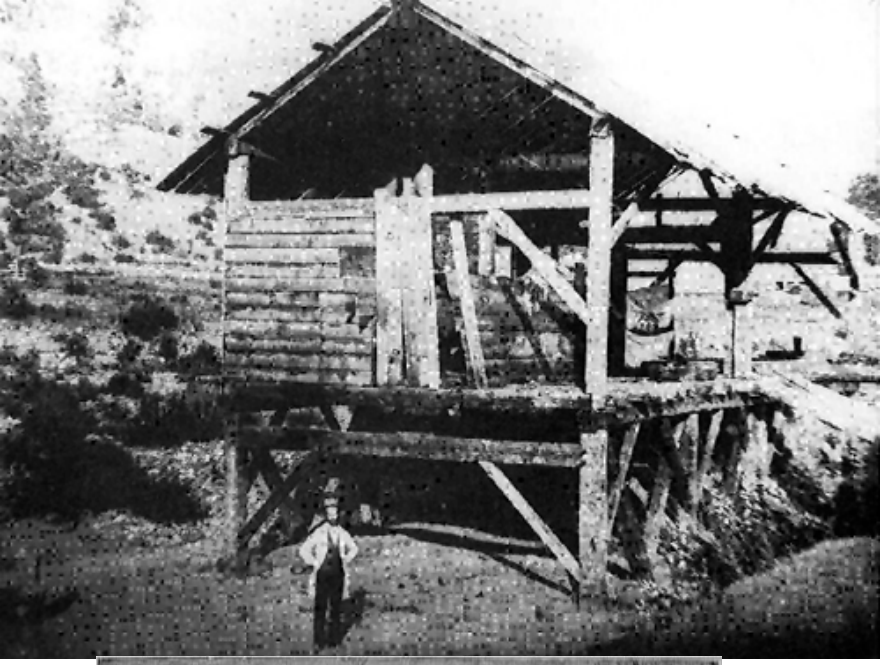
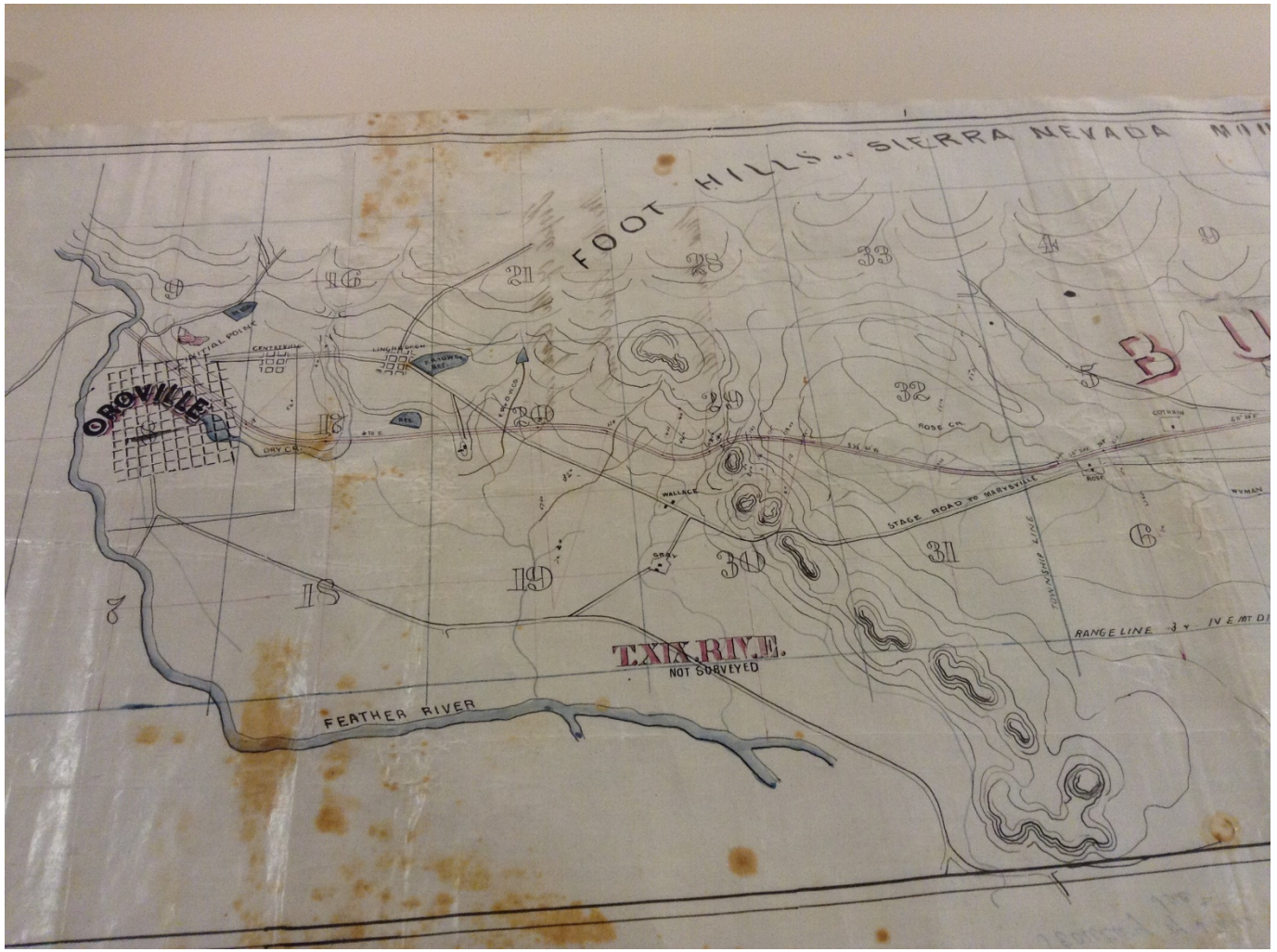
Colorado Springs



California Gold Rush

- Gold discovered at Sutter's Mill in early 1848.
- 50,000 Americans descended upon California between 1849-52, outnumbering the Mexican population by 10 to 1.
- The miners were supplied by river boats up the Feather River to Marysville.


FOR
CALIFORNIA!
DIRECT
EXTRAORDINARY INDUCEMENTS!!
THIRTY-FIVE DAYS TO THE GOLD REGIONS!
The "California Steam Navigation Co."
Will dispatch their first vessel from New-York, the NEW and SPLENDID
STEAM SHIP!
NICARAGUA
DAVID JERROLD, Master, positively
On FRIDAY, MARCH 23d, 1849,
Via. the River St. Juan and Lake Nicaragua, across the Isthmus of Leon.
Capt. BRONSON, of the U. S. Topographical Engineers,
200 JACK ASSES!
The Quickest, Safest and Cheapest!!
Price of Passage Through Ninety Dollars!
To be paid in SPECIE, Dimes and half Dimes, taken only.
For further particulars apply on board, at the foot of South Street, E. R. or to the undersigned Agents for the Company. Applications by mail, to meet attention, must be post paid, addressed to the Company's Agents.
HOBSON, BROTHERS & Co, 127 Wall Street, (opposite the Railroad.)

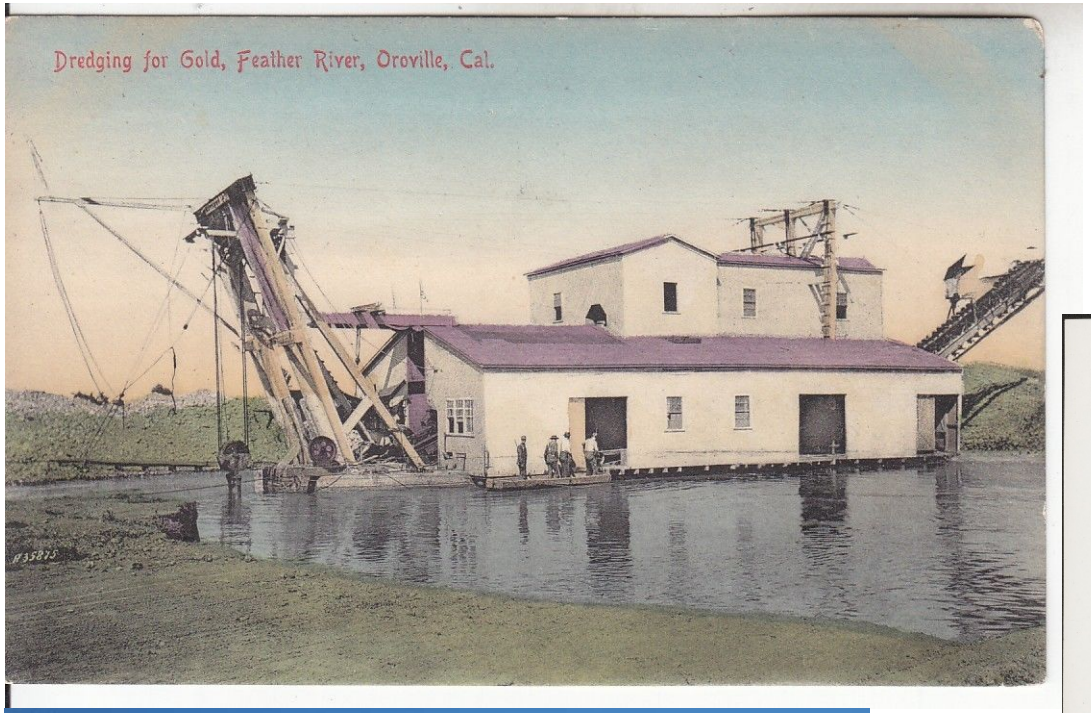


- **Oroville was established in 1850 during Gold Rush, where the Feather River emerges from the Sierra Foothills. Placer mine workings dotted the three forks of the Feather River.**

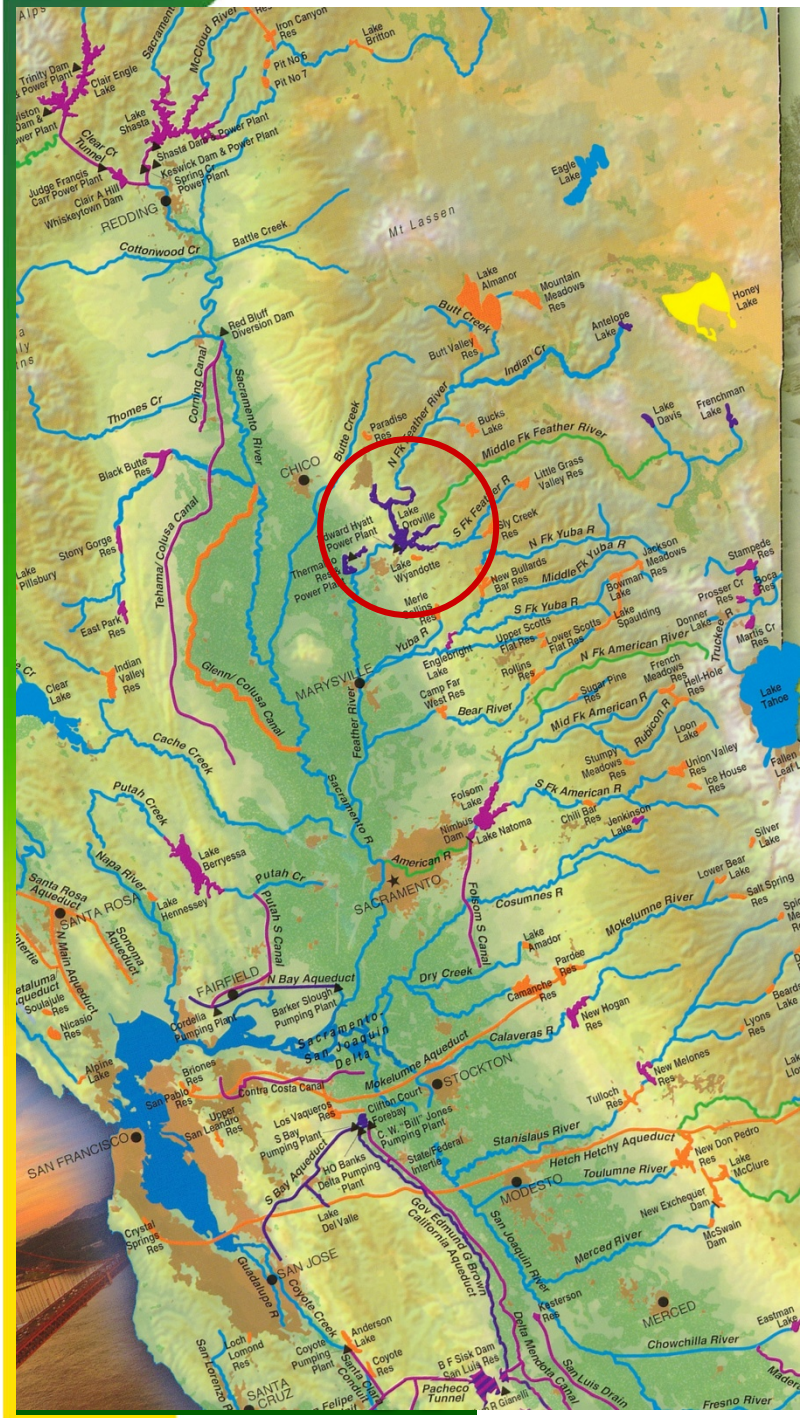
Hydraulic mining

- **In 1852-53 a French-Canadian mining engineer named Anthony Chabot and his partner Edward Matteson began using hydraulic monitors to excavate gold-bearing Tertiary age gravels at Buckeye Hill and American Hill, near Nevada City.**

Dredge mining allowed until 1970



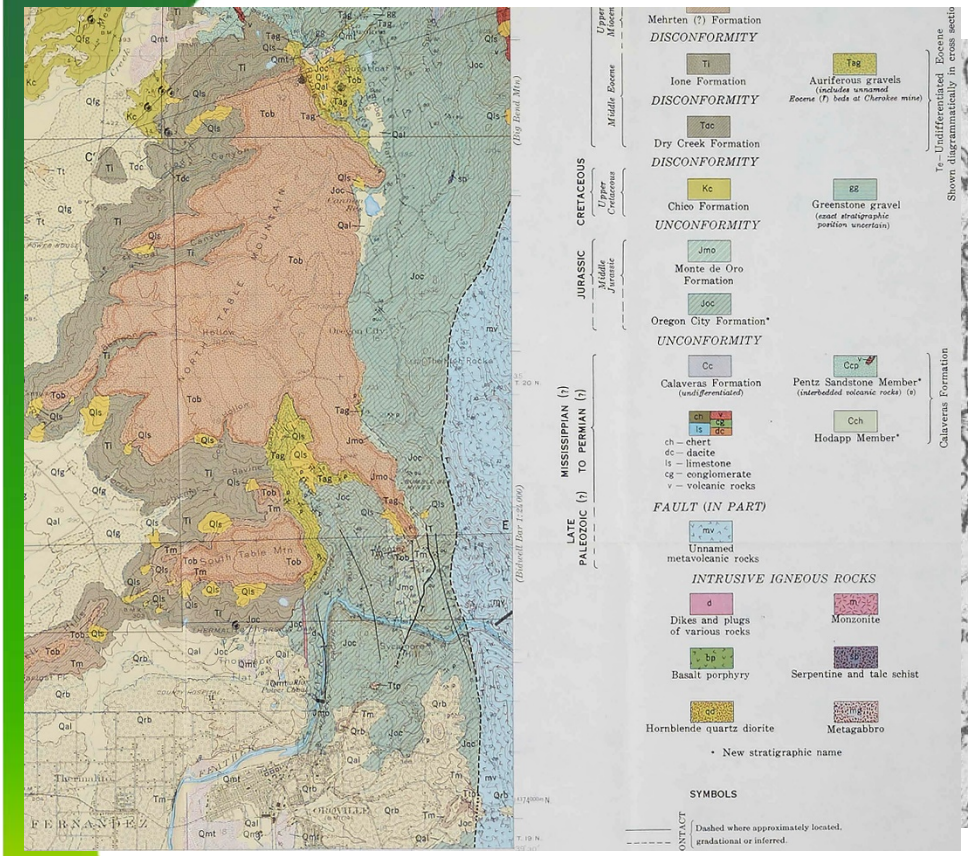
The Wright Act of 1884 allowed dredging, if the permitee could guarantee that no debris would be carried downstream. The dredge fields at Oroville (shown here) were worked between 1898 and 1918.

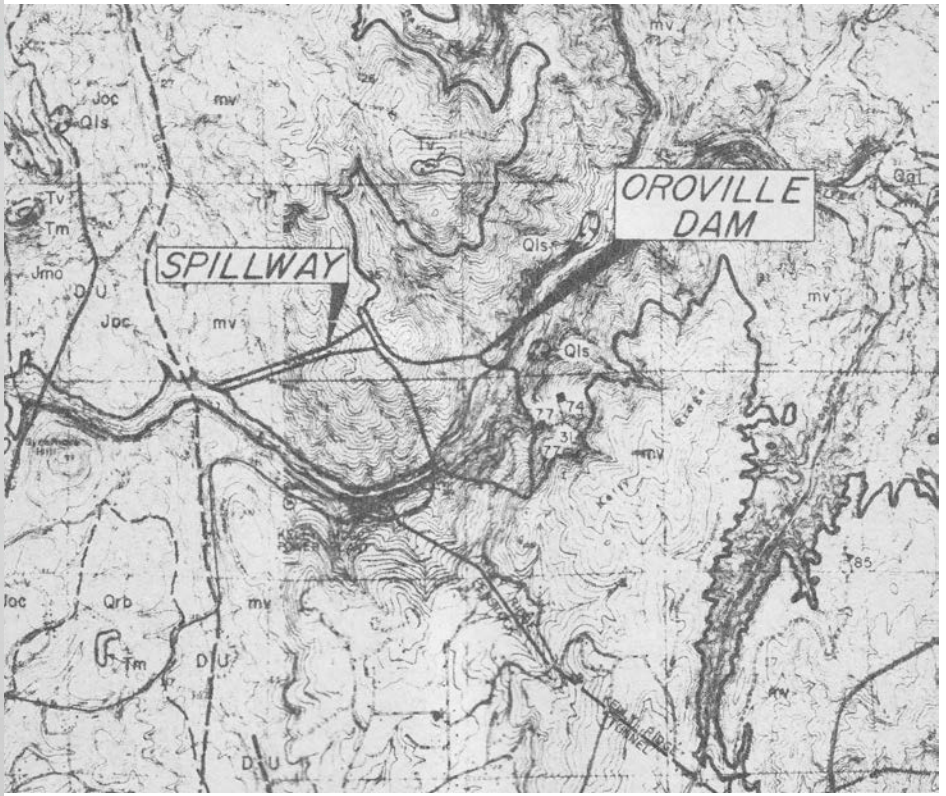


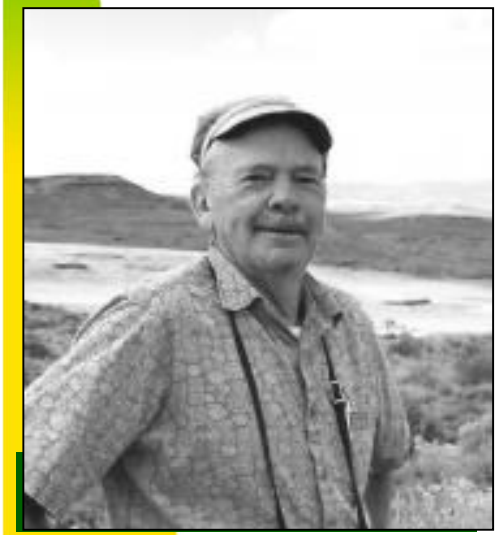
- California approved the **Central Valley Project Act** in 1933, but the state was unable to secure sufficient revenue bonds because of the Great Depression. The project was then assumed by the US Bureau of Reclamation.
- Reclamation initially built Shasta and Friant Dams, as well as the Delta Mendota and Friant-Kern Canals
- After voters approved the present **California Water Project** in 1956, the Department of Water Resources (DWR) appointed a Board of Engineering Consultants (1956-60), an Earthquake Analysis Board (1962-77), and an Earth Dams Consulting Board (1962-74).

Kingpin Structure of the California Water Project

Oroville Reservoir was configured to retain 3.48 million ac-ft of water, second only to Shasta Dam in California. The structure's projected height of 777 feet also made it the highest dam in the world.



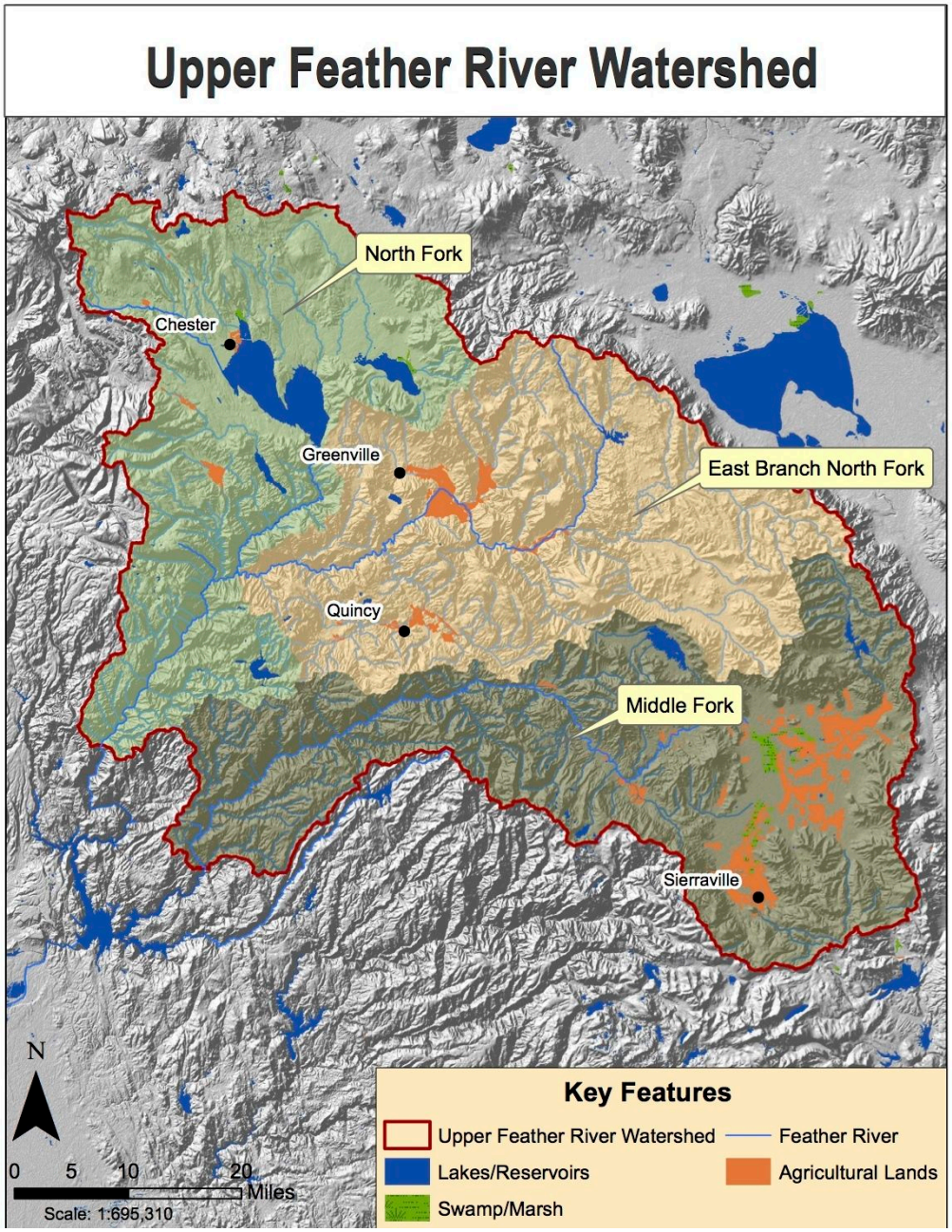




In 1952-55 San Jose State Professor R. Scott Creely, PG (1926-2011) mapped the geology of the Oroville 15-minute quadrangle for his PhD research at Cal Berkeley. The unit underlying the dam and spillway sites was an unnamed metavolcanic assemblage ("mv"), believed to be of late Paleozoic age, in a faulted contact with younger strata.

Note the small fault aligned with the lower spillway chute, at lower right margin of left pane, above.

Hydropower Schemes



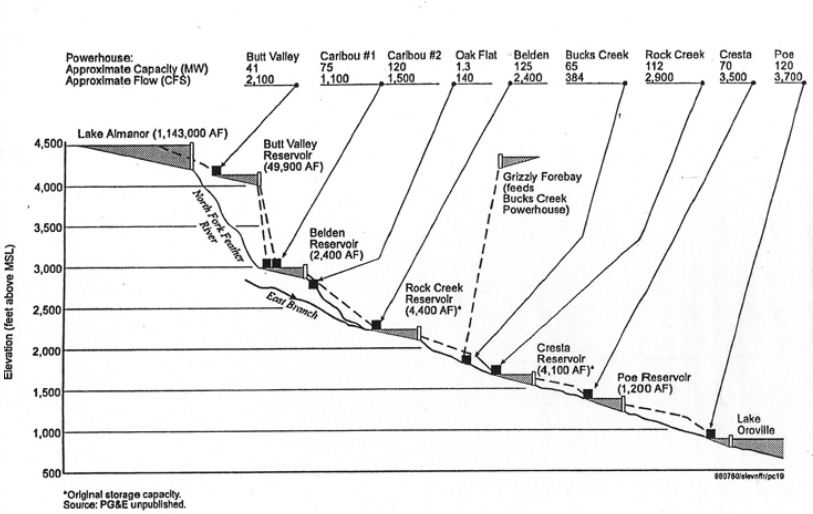


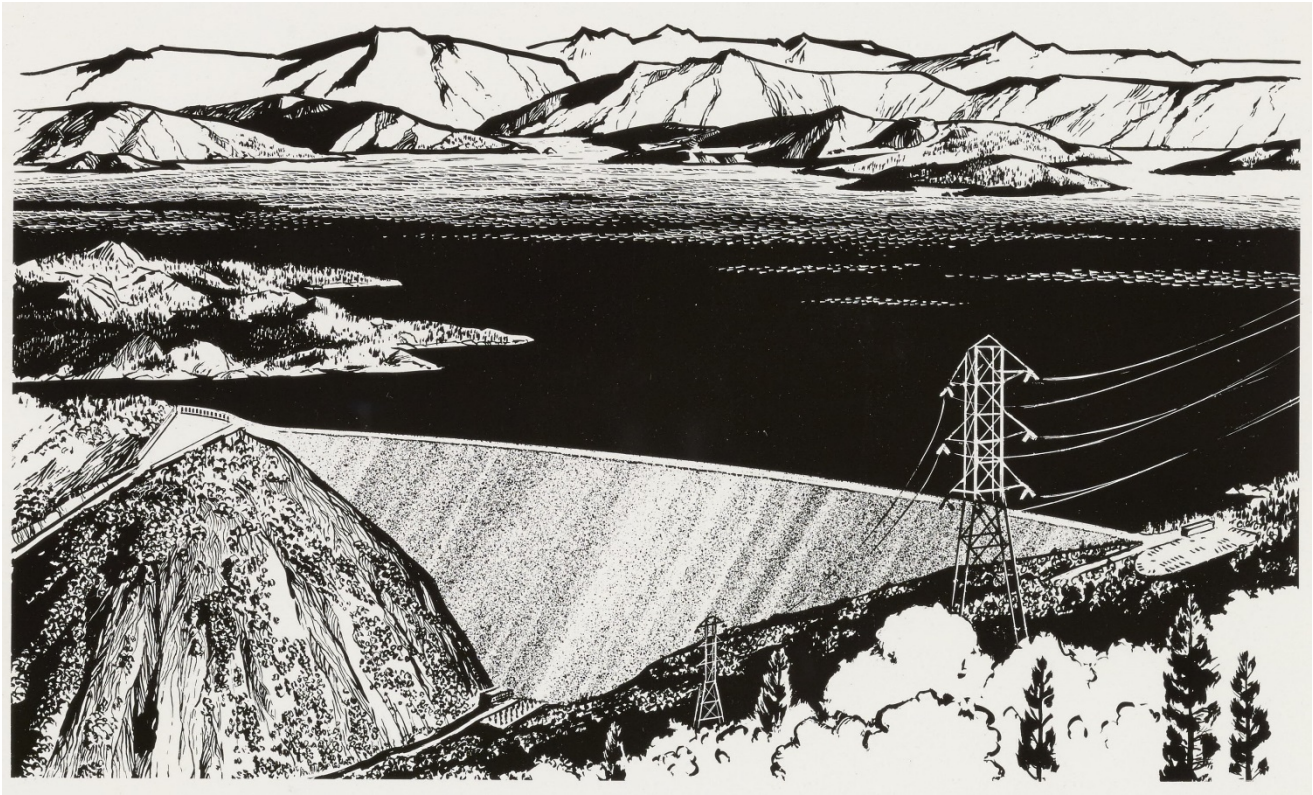
FIGURE E1-2
Hydroelectric Development in the North Fork Feather River Drainage

Report E1-5
Upper North Fork Feather River Project, FERC No. 2105

From the very outset it was planned to generate hydroelectric power to help fund the massive project

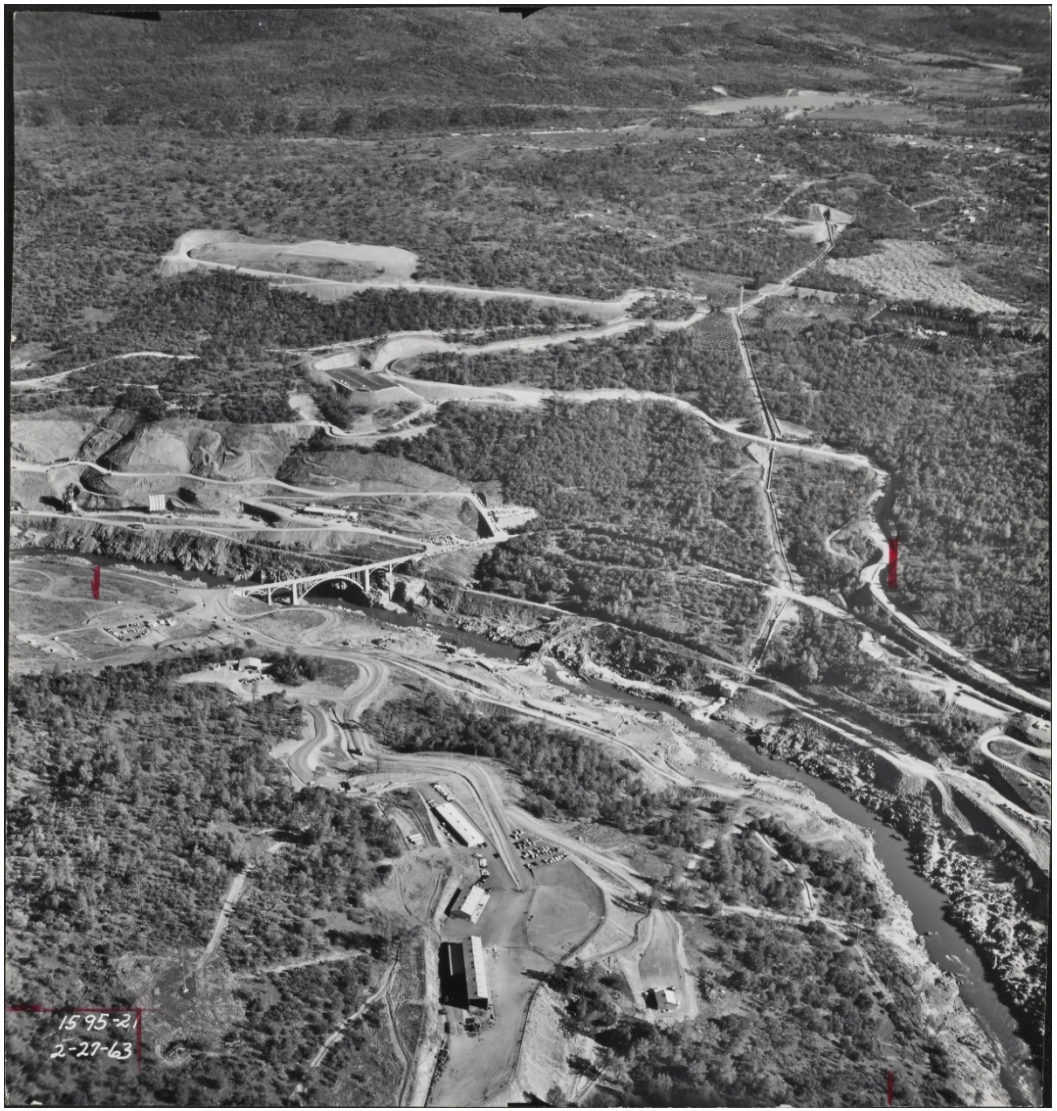
Watershed area of 3,611 square miles

- **The original design envisioned a massive concrete multiple arch dam, which was unusual. Since there was little American experience associated with this type, Prof Jerry Raphael at Cal Berkeley was retained by DWR to construct one of the largest structural models ever attempted up until that time (1957-58).**



- **The massive expanse of cobbly dredge tailings from 1898-1918, southwest of Oroville was perceived as a potential asset. The cobbles were dominated by granitic rock, with a matrix of fine grained soils that could be used in the embankment core. This allowed a much lower unit cost for aggregate.**
- **In November 1958, before Professor Raphael's work was even completed, DWR's Oroville Consulting Board recommended that the State construct an earth-rockfill embankment dam on the site, capable of retaining the second largest reservoir in California.**

The project had already been launched

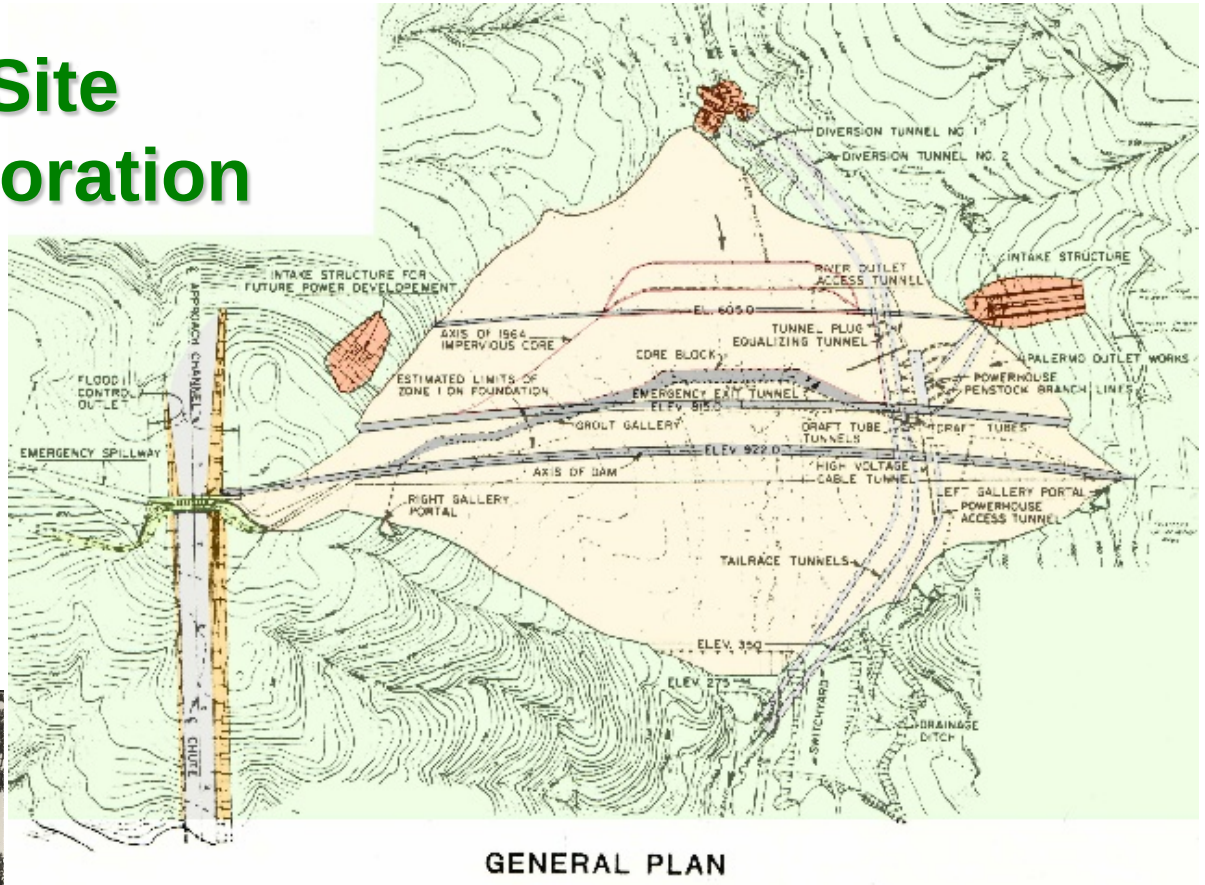


Clearing and grubbing of the dam area as seen on February 27, 1963. Over 4,500,000 yds^3 of native material blanketing the site was excavated

Governor Pat Brown at groundbreaking ceremony in May 1957, when relocation work began on the Western Pacific Railroad

Site exploration

Alan L. O'Neill, CEG (BA geology Cal Berkeley 1951) served as DWR's Chief Engineering Geologist for the project.



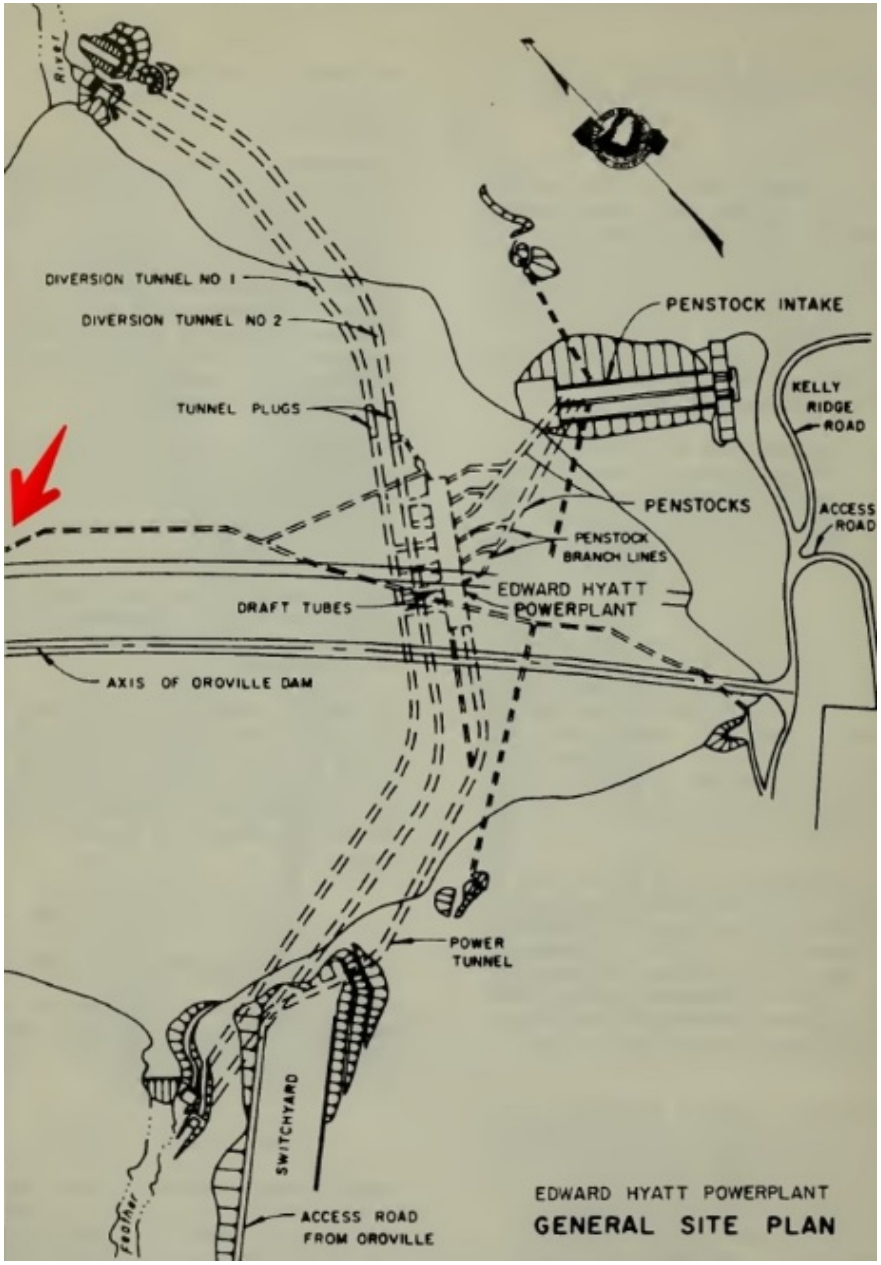
Site exploration included mapping of outcrops, drilling diamond cores, and running geophysical lines, somewhat unusual for 1960-62.

TABLE 1

SUBSURFACE EXPLORATION - OROVILLE DAM, SPILLWAY, INTAKES & POWER PLANT

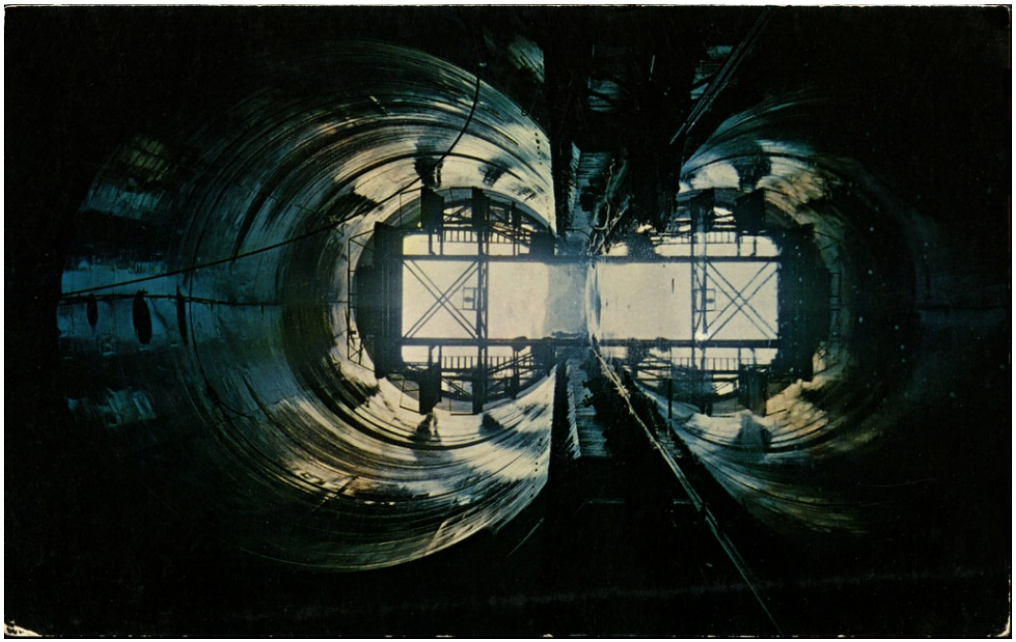
FISCAL YEAR	EXPLORATION TOTAL NO.	EXPLORATION MODE AND DESIGNATION	FOOTAGE MIN. DEPTH	FOOTAGE MAX. DEPTH	FOOTAGE TOTAL	COST	LOCATION - PURPOSE
1961-62	5	Nx diamond drill hole** Z13RS - Z17RS	50	89	367	8,520*	Spillway - determine foundation conditions, excavation characteristics a quantity of riprap available.
	-	Seismic Survey** Spreads 1 thru 5 Spillway	-	-	3200	581	Spillway - determine depth to sound rock at headgate structure and along chute.

Plan View of River Diversion Tunnels



Mouth of Diversion Tunnel #1 on December 26, 1963

Diversion Tunnels



Two 35-ft diameter diversion tunnels, 4200 and 4600 ft long, were completed between August 1961 and Dec 1963

Significant Research Contracts

- **Research contracts were also let to the University of California-Berkeley to perform triaxial tests on 3 x 7.5 feet diameter samples of the dredge cobble tailings mixtures for the dam's core and supporting shells; and model tests of the service spillway by the Bureau of Reclamation in Denver.**

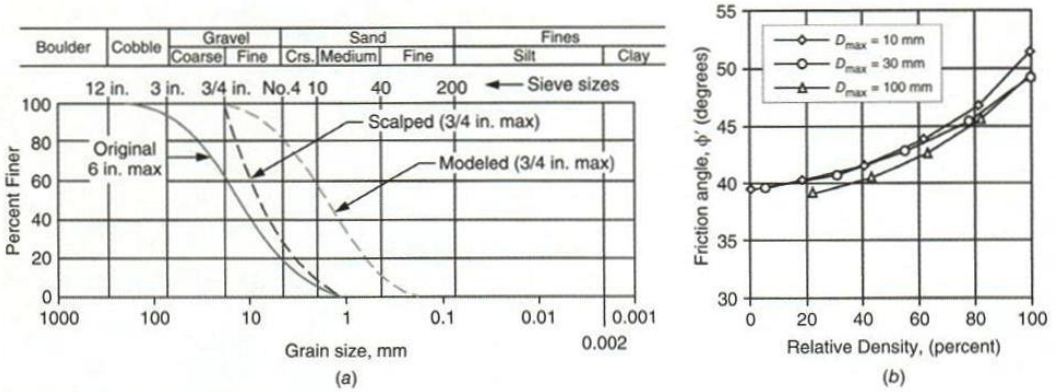


Figure 5.4 Modeling and scalping grain size curves and friction angles for scalped material: (*a*) grain size curves for original, modeled, and scalped cobblely sandy gravel and (*b*) friction angles for scalped specimens of Goschenalp Dam rockfill. Data from Zeller and Wullimann (1957).

Berkeley Professor J. Michal Duncan led these studies

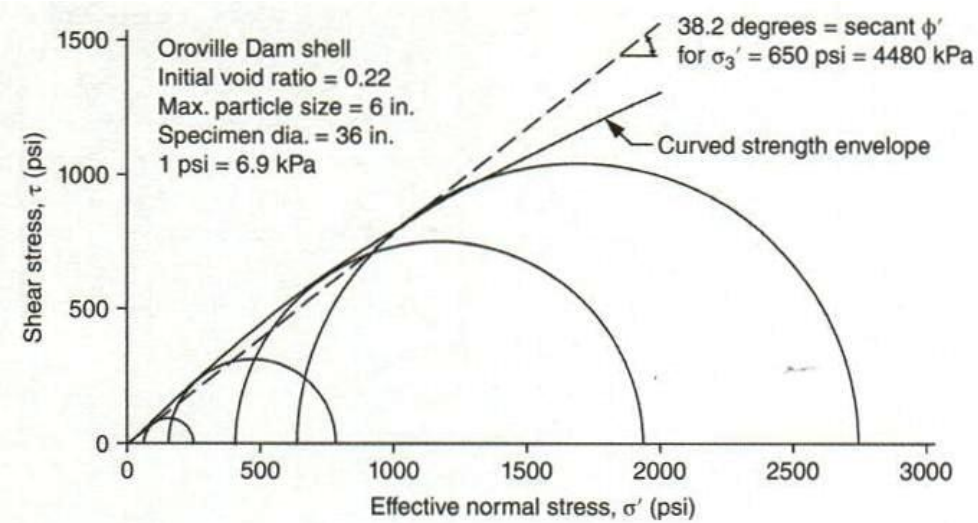


Figure 5.1 Mohr's circles of shear stress at failure and failure envelope for triaxial tests on Oroville Dam shell material.

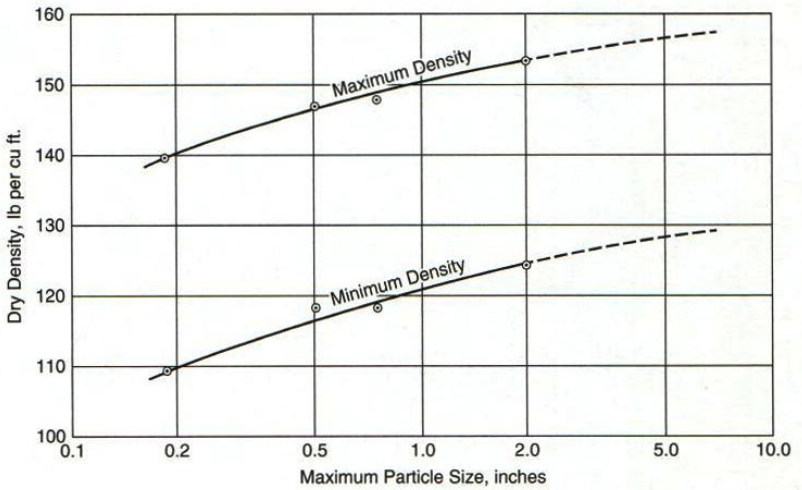
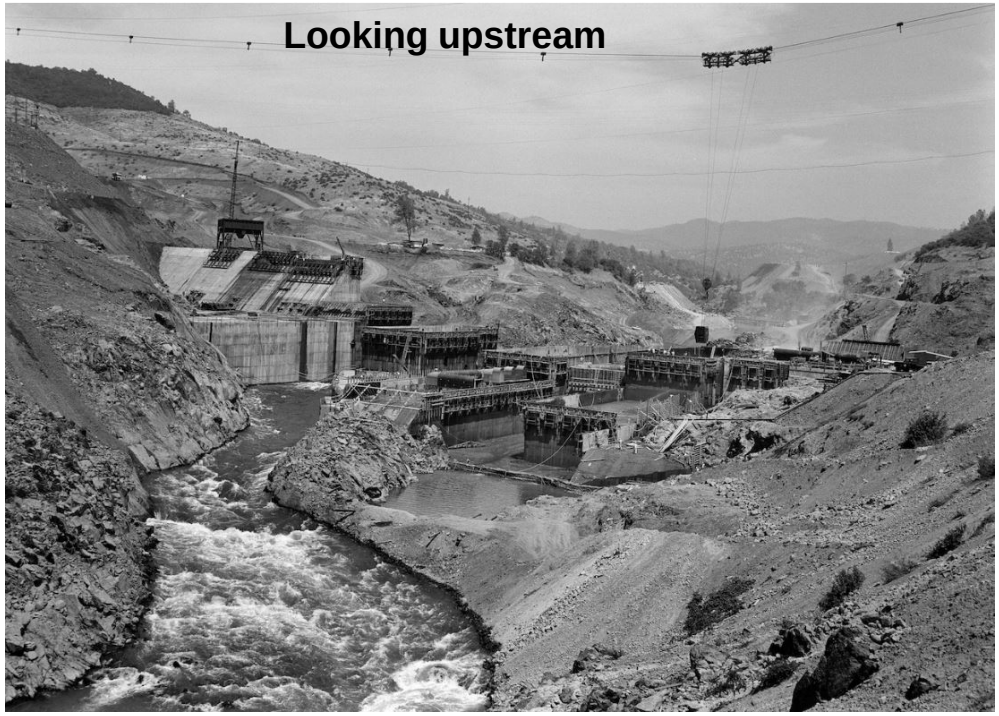
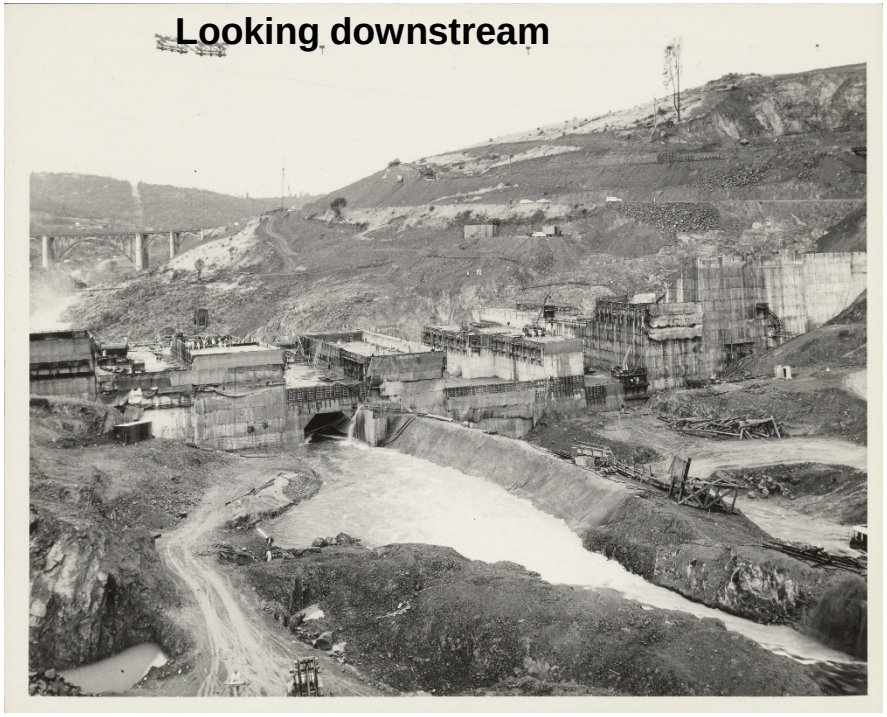


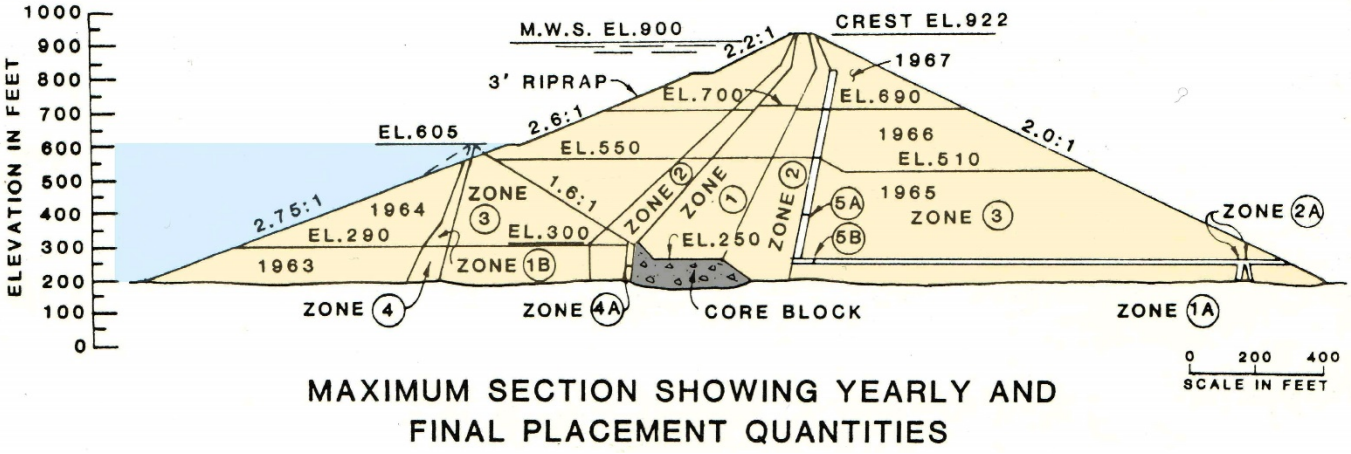
Figure 5.5 Maximum and minimum densities measured for Oroville Dam material for modeled gradations (Becker et al., 1972).

A series of sophisticated large diameter (3 x 7.5 ft) triaxial tests were carried out on the dredge tailings, which were without precedent at the time (1964-68).

Concrete Core Block

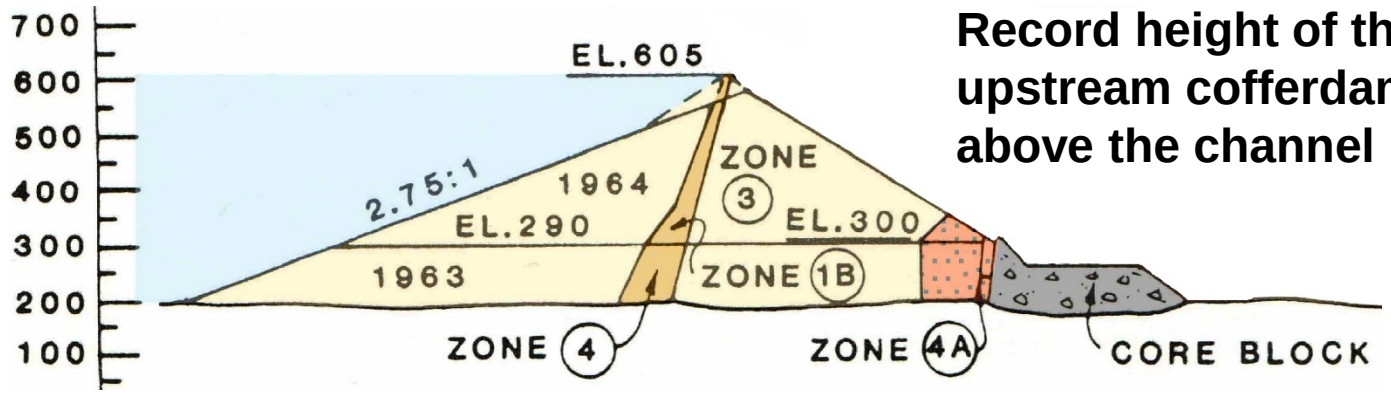




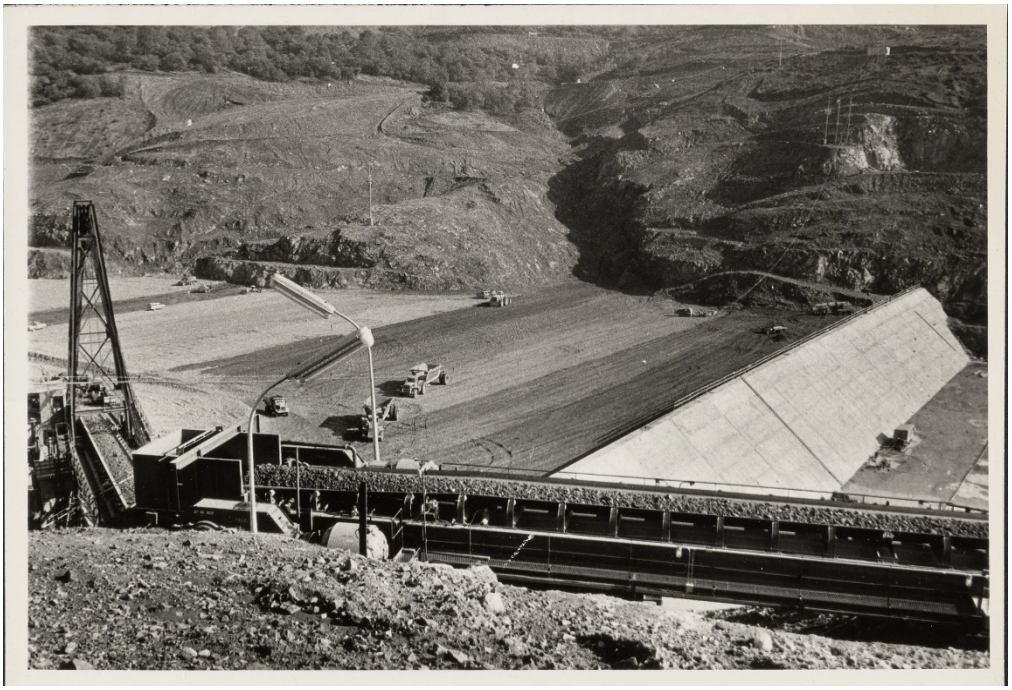


MAXIMUM SECTION SHOWING YEARLY AND FINAL PLACEMENT QUANTITIES

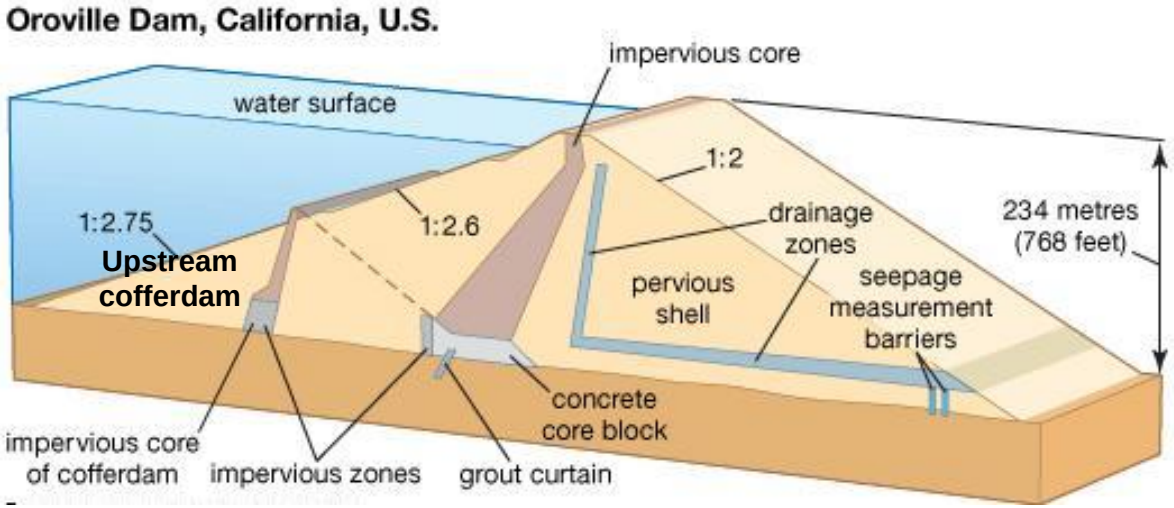
The unusual design included a concrete core block of 200,000 yds^3 supporting the toe of the upstream cofferdam, completed in May 1963



Record height of the upstream cofferdam – 410 feet above the channel

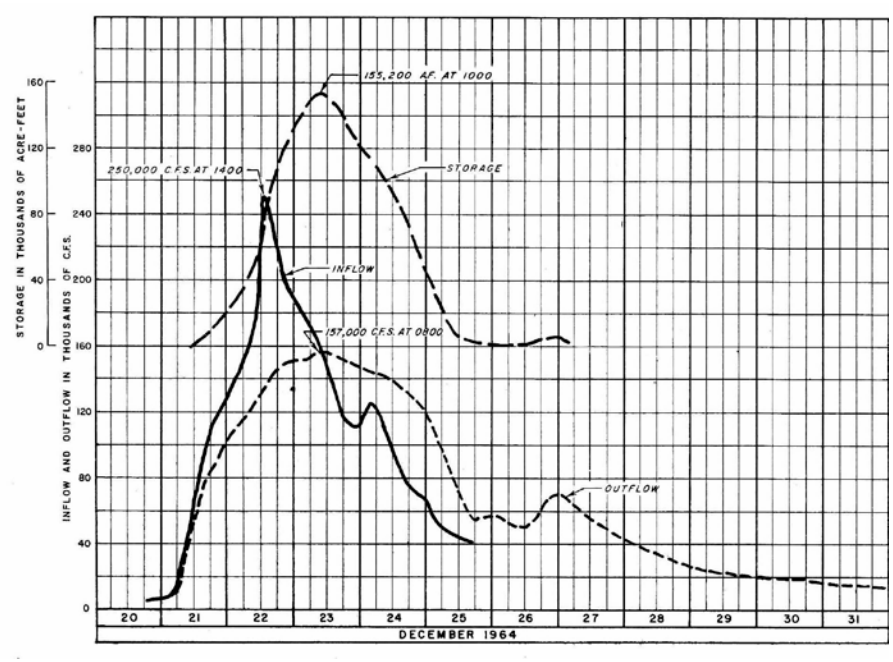


The sloping core block supported the toe of a 400 ft high cofferdam, which formed the upstream toe of the main embankment, placed in 1965-67.



The upstream cofferdam was constructed in 1963-64, and incorporated into the main embankment during 1965-67

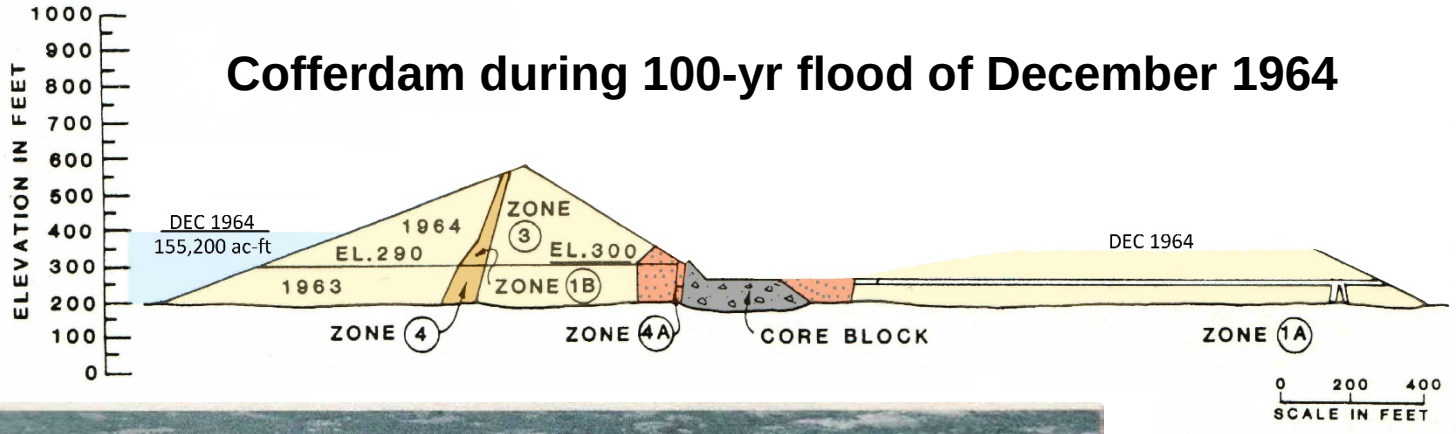
Upstream view of the massive cofferdam, completed just one month before California's most severe flood since 1862. Note the temporarily oversteepened crest section. This portion of the dam was subsequently removed.



December 1964 Flood

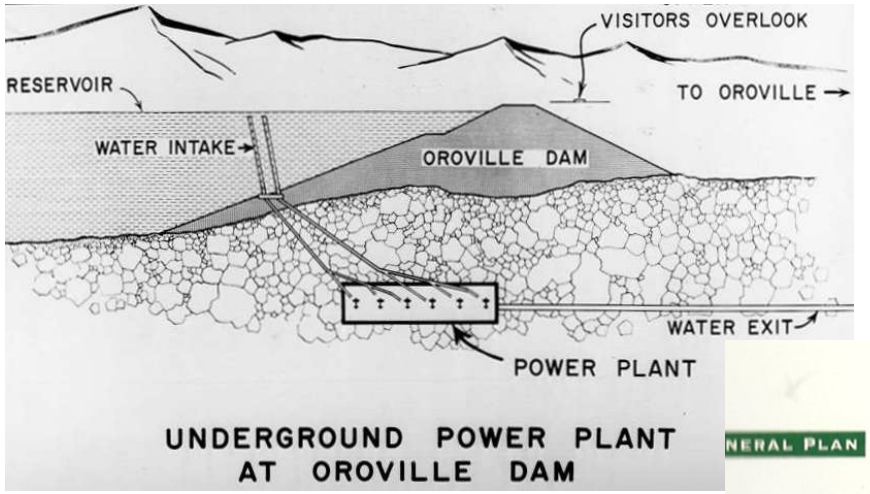
A record flood of 250,000 cfs occurred just one month after completion of the cofferdam, in December 1964. Peak outflow was 157,000 cfs, shown here

Cofferdam during 100-yr flood of December 1964

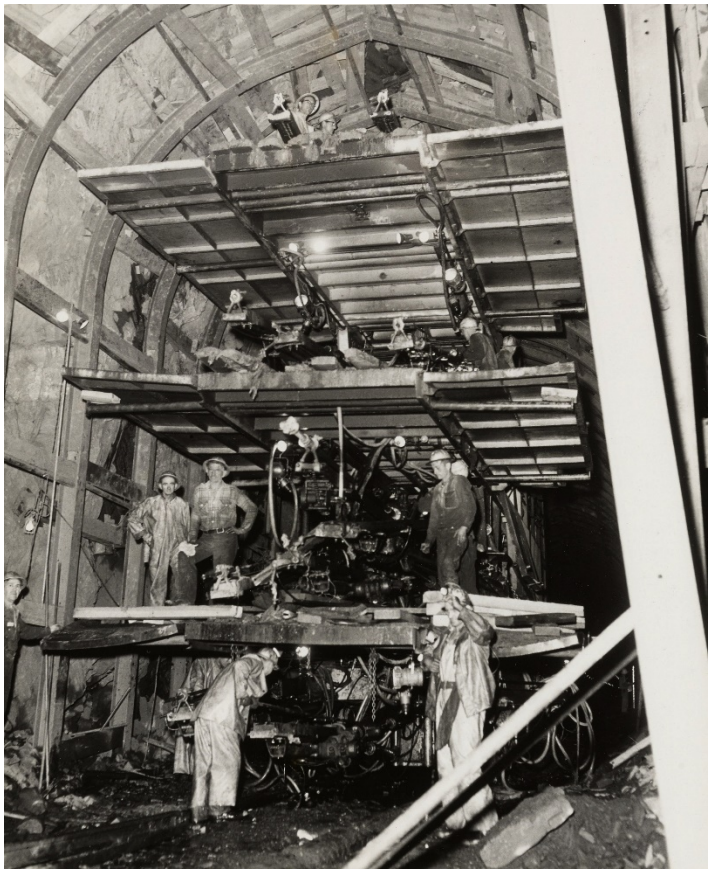


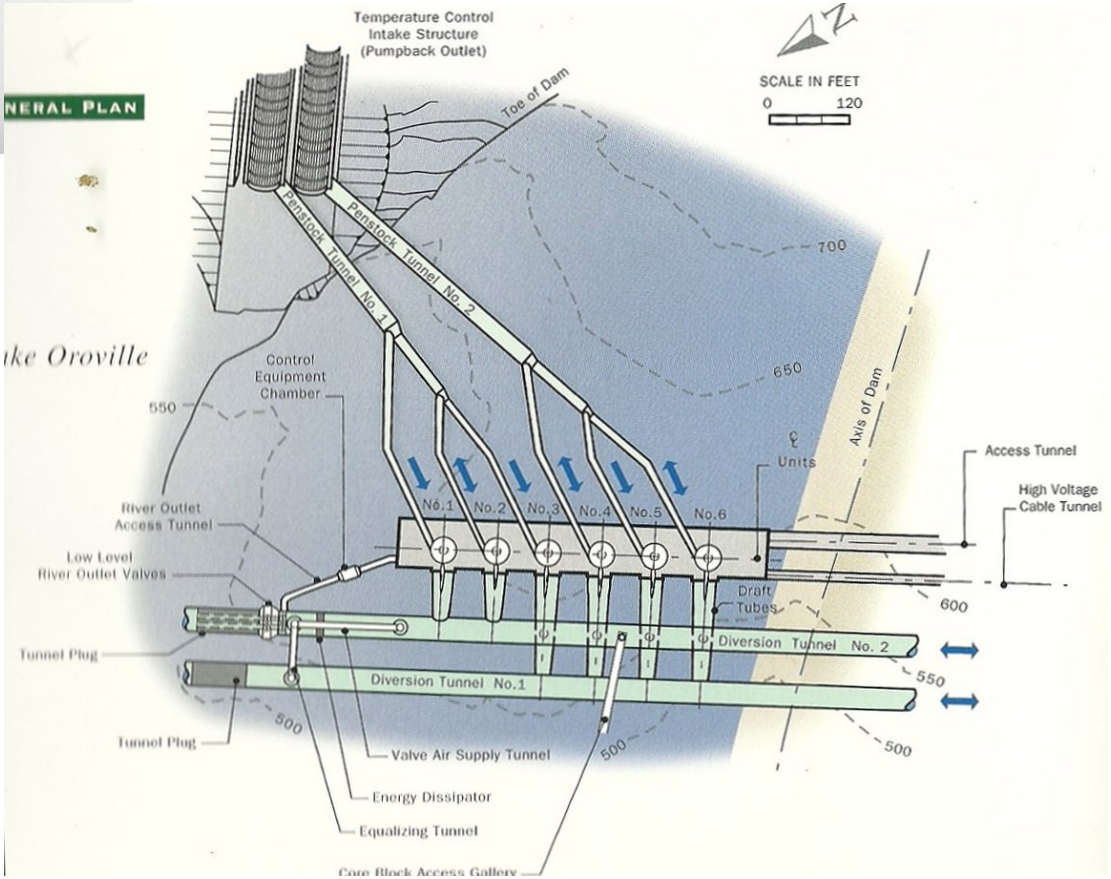
The cofferdam managed to store more than 155,000 acre-feet of water during the December 1964 storm event, with a maximum discharge of 157,000 cfs downstream, much less than what occurred during the December 1955 storm that flooded Yuba City.

California's first underground powerhouse and pumped storage scheme



UNDERGROUND POWER PLANT AT OROVILLE DAM

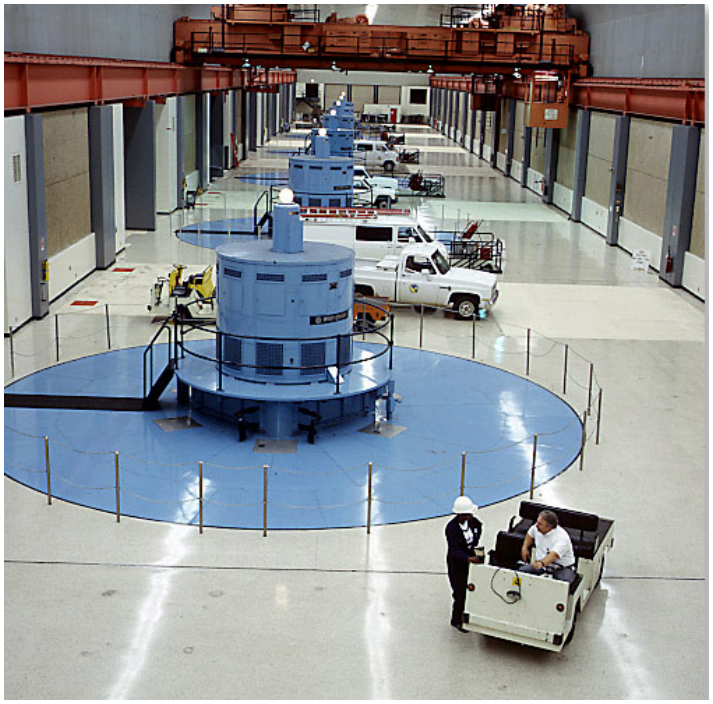


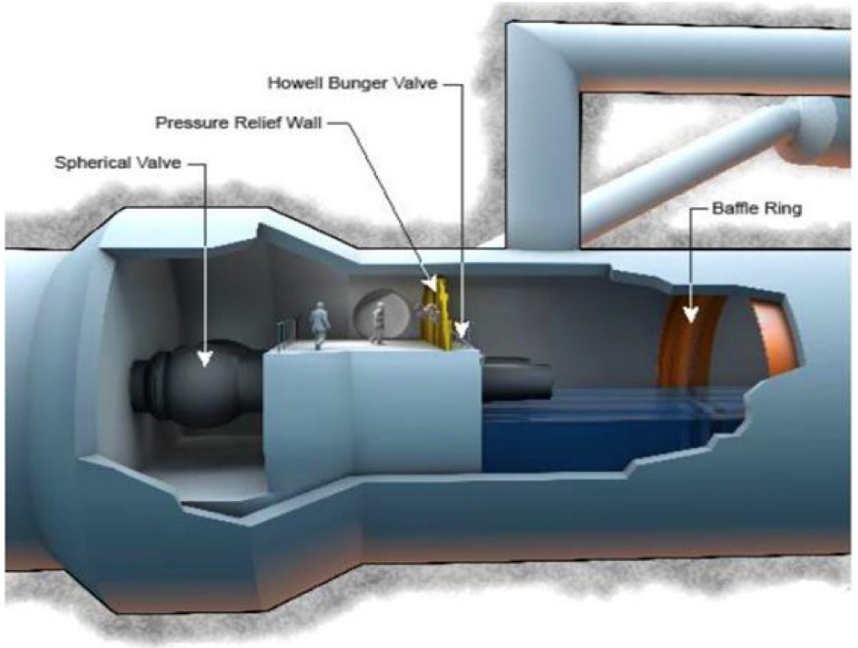


The underground powerhouse reduces the friction losses during both pumping and generation cycles

Edward Hyatt Powerhouse

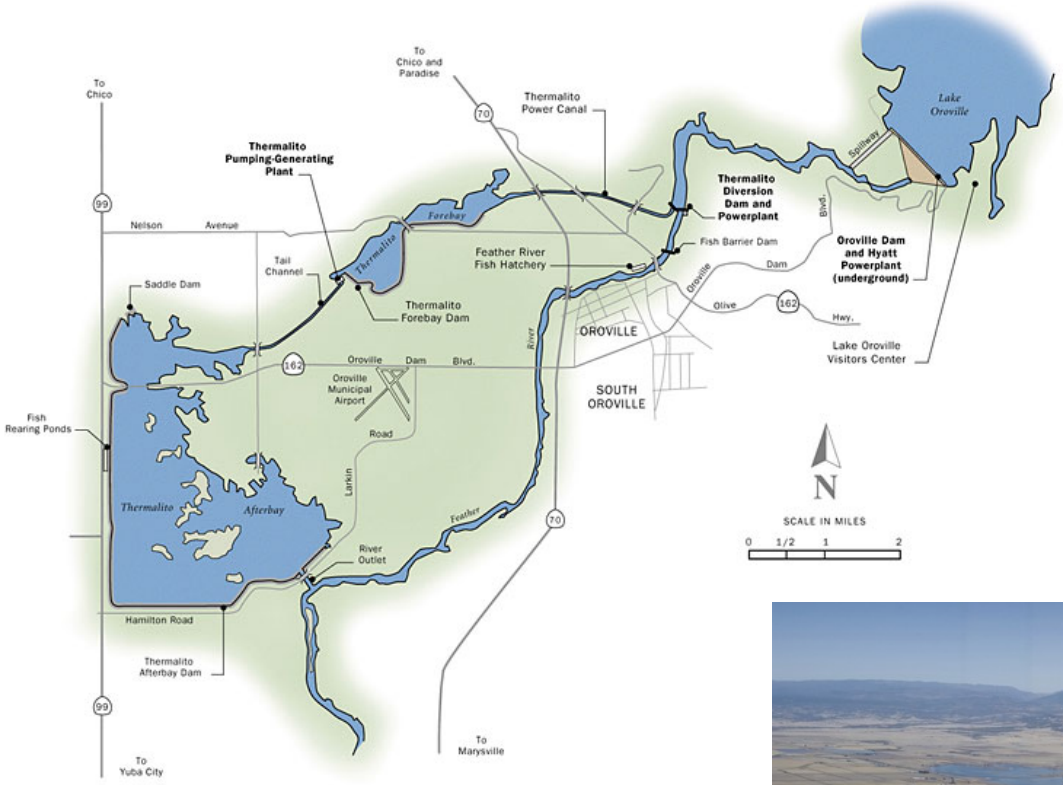
6 turbines and pump-turbines producing 1288 Mw





Two 54-inch diameter river outlet works valves, capable of discharging 3700 cfs

Thermolito Pumping-Generation Plant



Thermolito Forebay (above) and Afterbay (below)

The Thermolito facilities were part of the pumped storage power generation schemes

Oro Dam Constructors

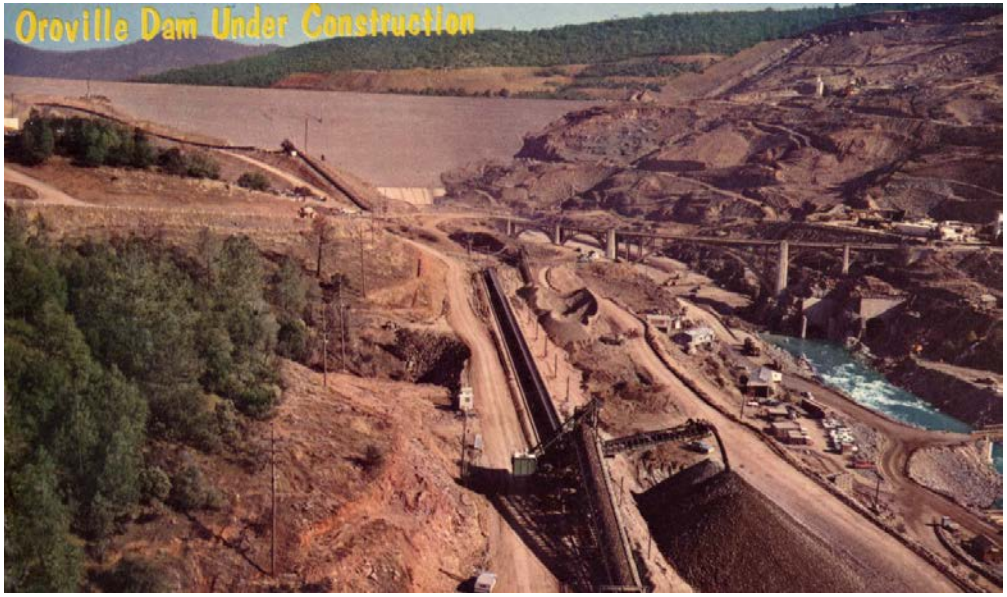
Contract awarded August 13, 1962 for $121 million. Trains hauled 155 million tons of aggregate over 12 miles during day and night operations for four years

Accident of October 7, 1965

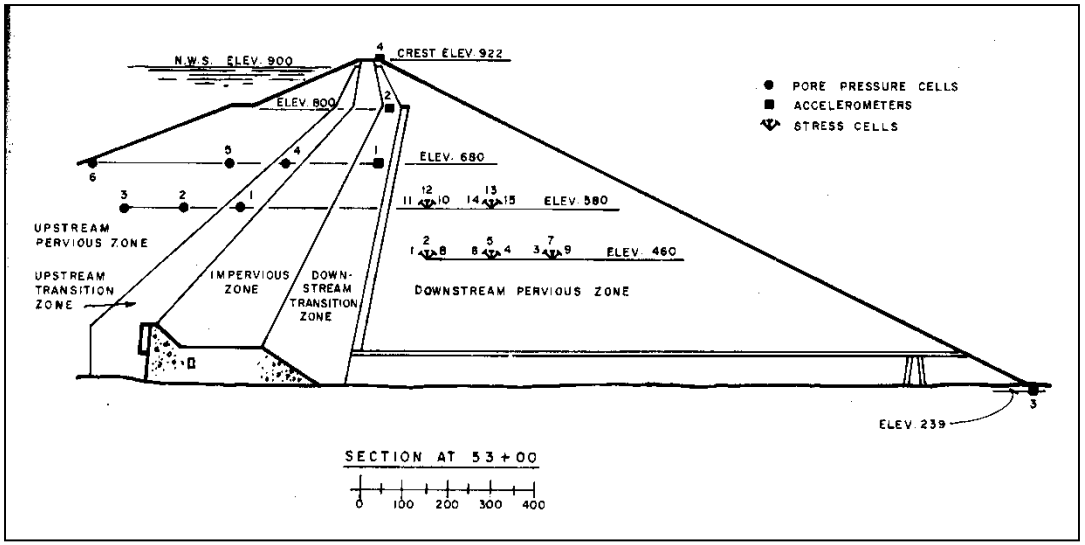
5,500 acres of dredge tailings were a remnant of hydraulic dredge mining between 1898 and 1918.

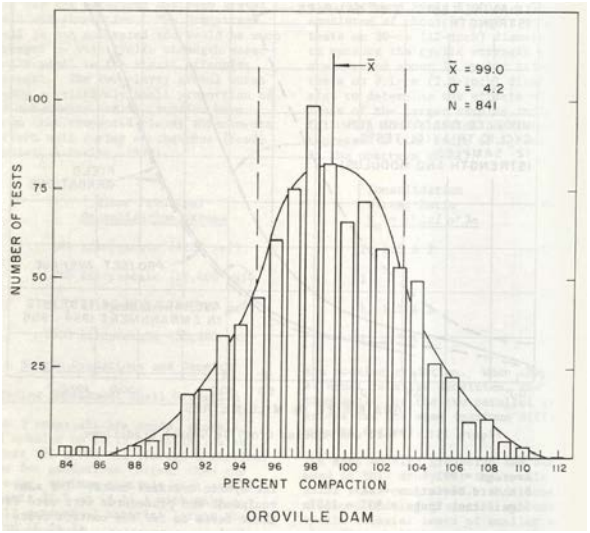
80 million cubic yards of these materials were excavated with a bucket wheel and transported 12 miles to classification plants situated around the dam site

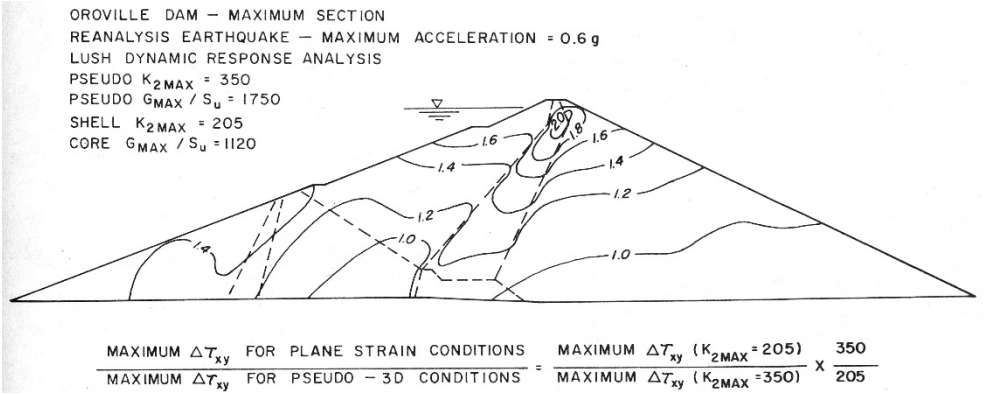
Rock and soil classification, transport, and placement

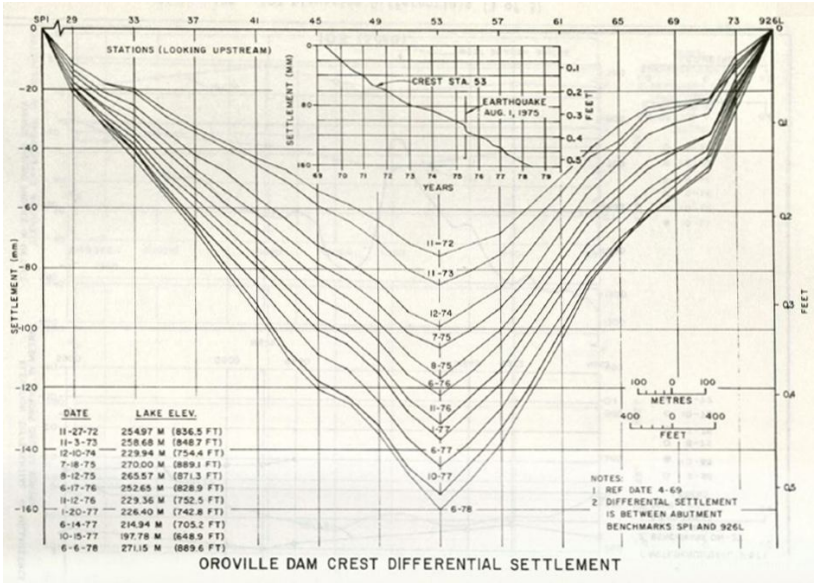


Most heavily instrumented embankment dam up till 1968



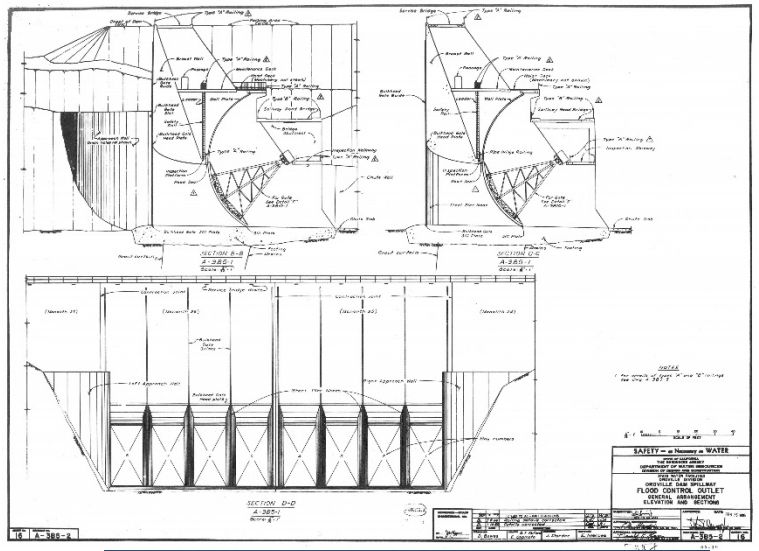


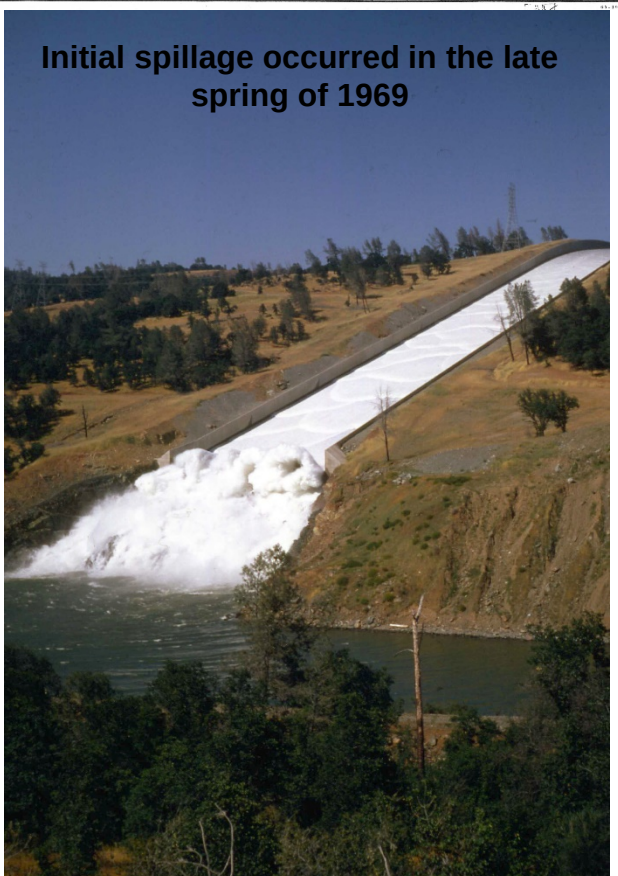




- **It was the most heavily instrumented earthen dam up to that time**

Upstream view of the submerged gate service spillway at low water



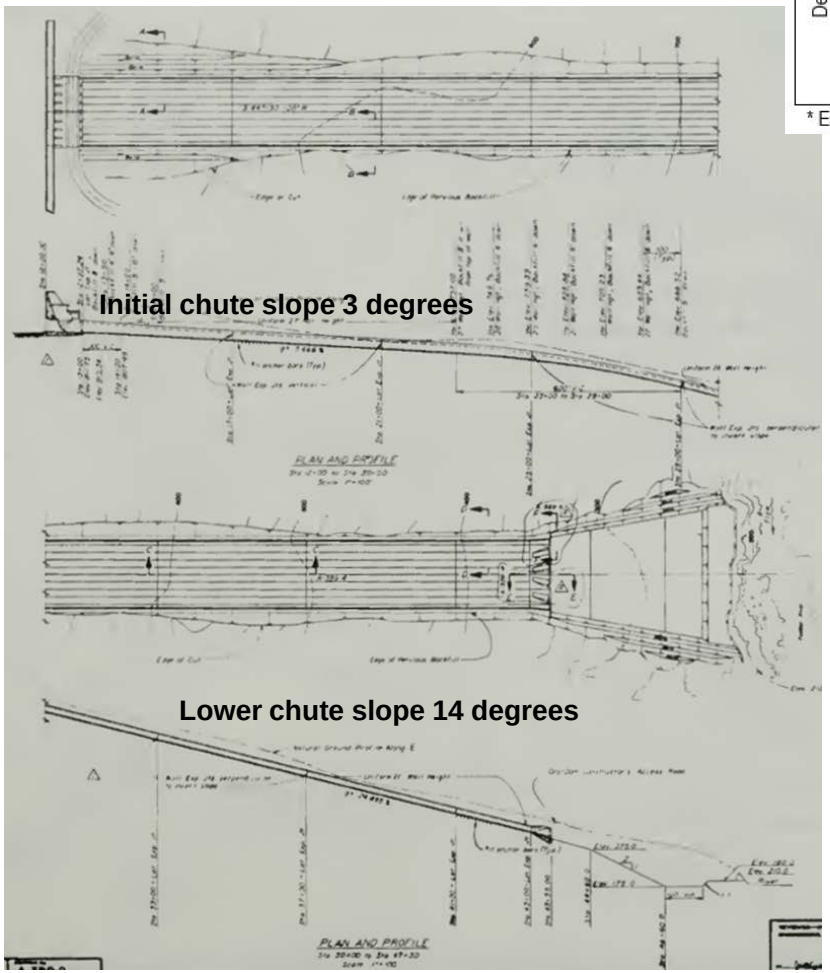


Initial spillage occurred in the late spring of 1969

Top Seal Radial Gate Service Spillway

Stage	Agency	Fiscal Year	Exploration		Footage			Cost	Location - Purpose
			Total No.	Mode & Designation	Min. Depth	Max. Depth	Total		
Design	DWR	1961-62	5	Nx diamond drill hole** 213RS – 217RS	50	89	367	8,520*	Spillway-determine foundation conditions, excavation characteristics and quantity of riprap available
			-	Seismic survey** Spreads 1thru 5 spillway	-	-	3200	581	Spillway-determine depth to sound rock at headgate structure and along chute

* Estimated; ** DWR Operation



The spillway chute was poured onto saprolite developed on the ophiolite

Photo 37. Chute foundation in vicinity of Sta. 27+75, 20'L. Compacted, clayey fines cover most of the rock (hard & fresh) in this area. View east.
Neg. No. 4632 9-28-66

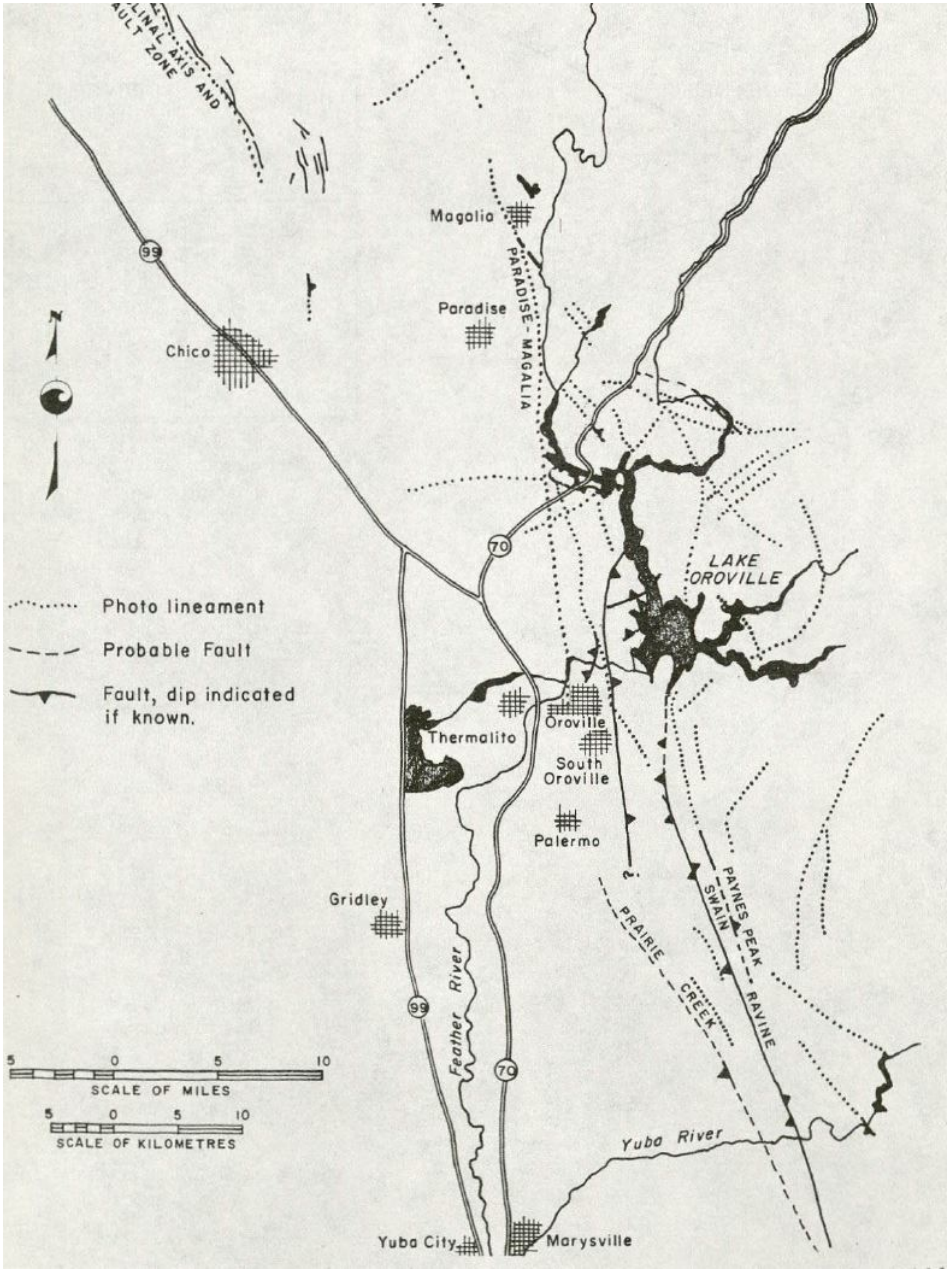
"Chute foundation in vicinity of Sta. 27+75, 20'L. Compacted, clayey fines cover most of the rock.."

Herringbone terracota uplift relief drains were embedded in the spillway chute slab, with just 5 to 6 inches of unreinforced cover.

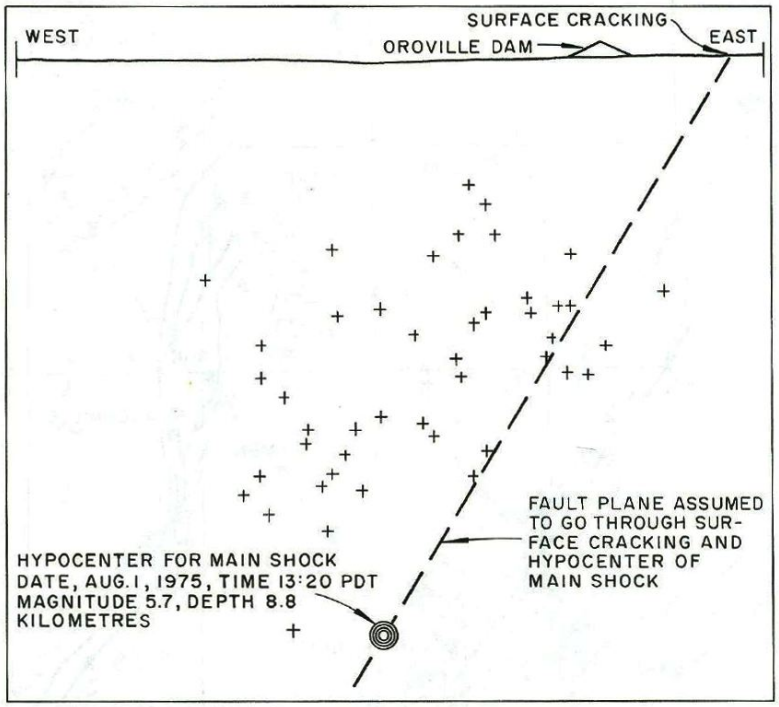
Oroville Dam was formally dedicated on May 4, 1968 by Governor Ronald Reagan

- **Oroville Dam was the first embankment dam to consider scale and mass effects of well-graded soil-rock mixtures, with a final volume 80 million yds^3 of material.**

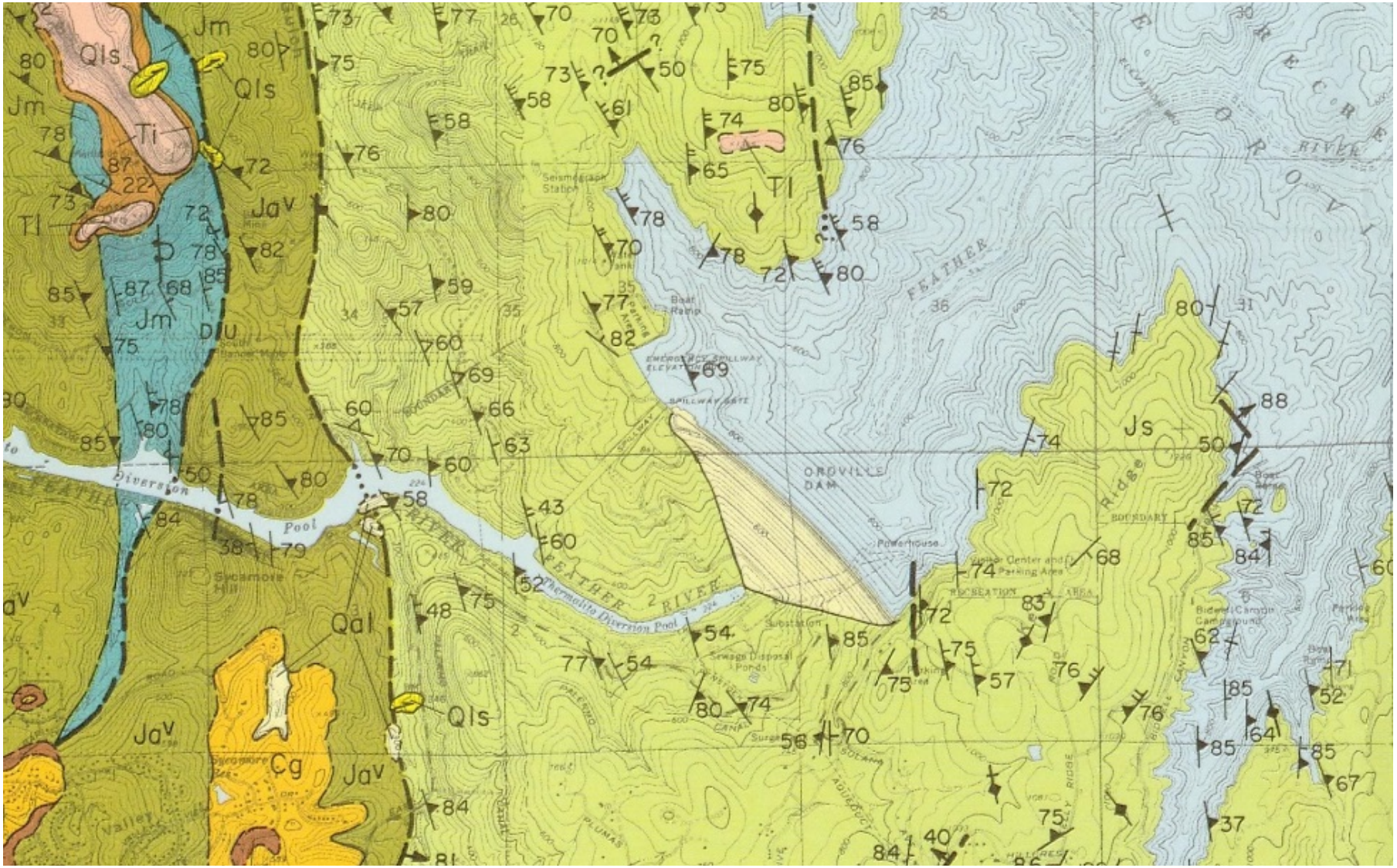
The OROVILLE EARTHQUAKE



- **On August 1,1975 a M_b 5.9 (later upgraded to M6.1) earthquake occurred a few miles downstream of Oroville Dam, ushering a new cognizance of seismicity in the Sierra Foothills**



CROSS SECTION AT MAIN SHOCK HYPOCENTER
PROJECTED NORTHWARD IO KILOMETRES



In 1978 Scott Creely's Paleozoic metavolcanic unit was redesignated as the Smartville Ophiolite of upper Jurassic age.

Smartville Ophiolite

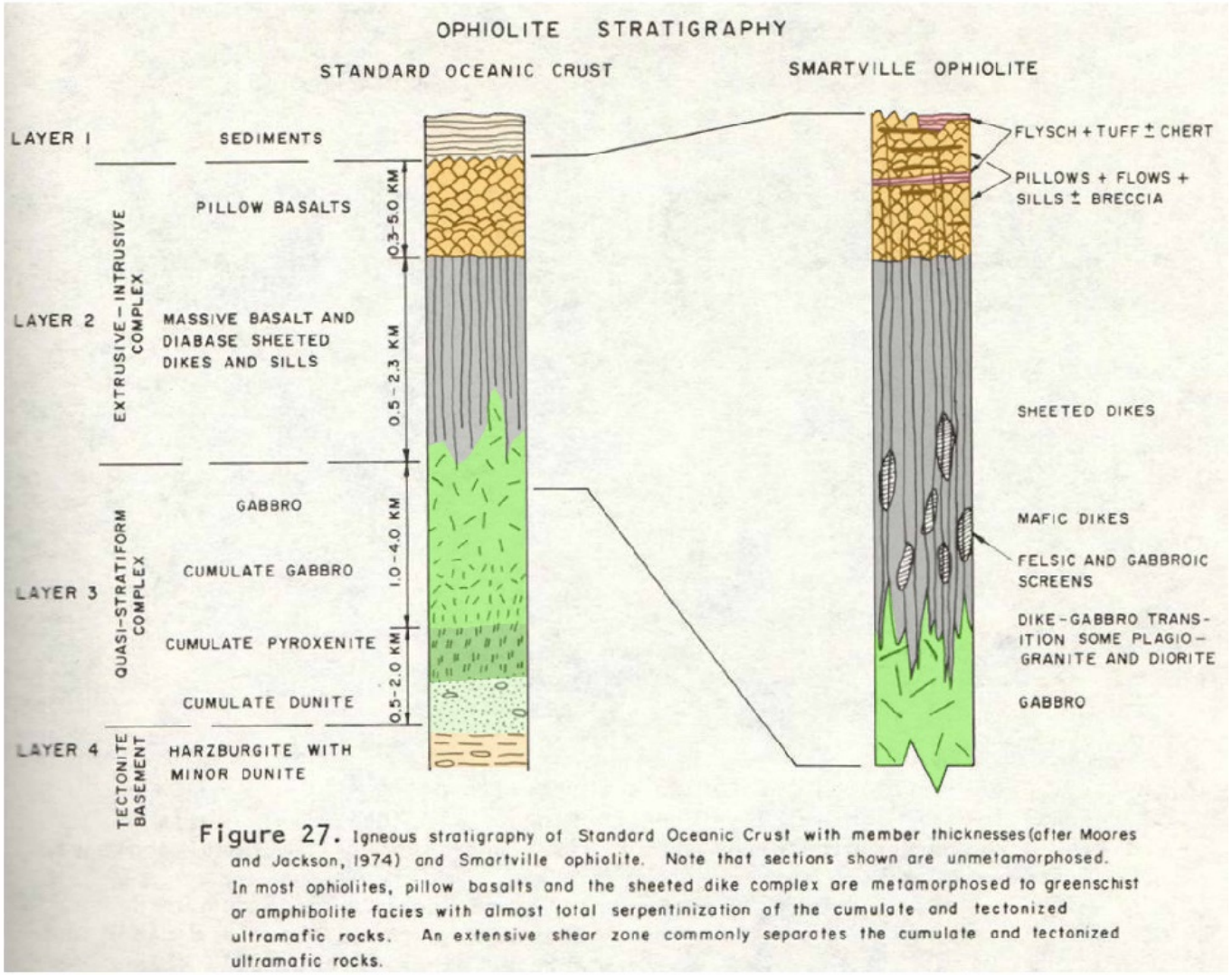


Figure 27. Igneous stratigraphy of Standard Oceanic Crust with member thicknesses (after Moores and Jackson, 1974) and Smartville ophiolite. Note that sections shown are unmetamorphosed. In most ophiolites, pillow basalts and the sheeted dike complex are metamorphosed to greenschist or amphibolite facies with almost total serpentinization of the cumulate and tectonized ultramafic rocks. An extensive shear zone commonly separates the cumulate and tectonized ultramafic rocks.

In the mid-1970s geologists at U.C. Davis began recognizing ophiolite complexes formed in forearc basins

Pillow basalts commonly found in ophiolite deposits are subject to deep weathering and development of saprolite, like that exposed in this past winter's high flows around the troubled spillway chute.