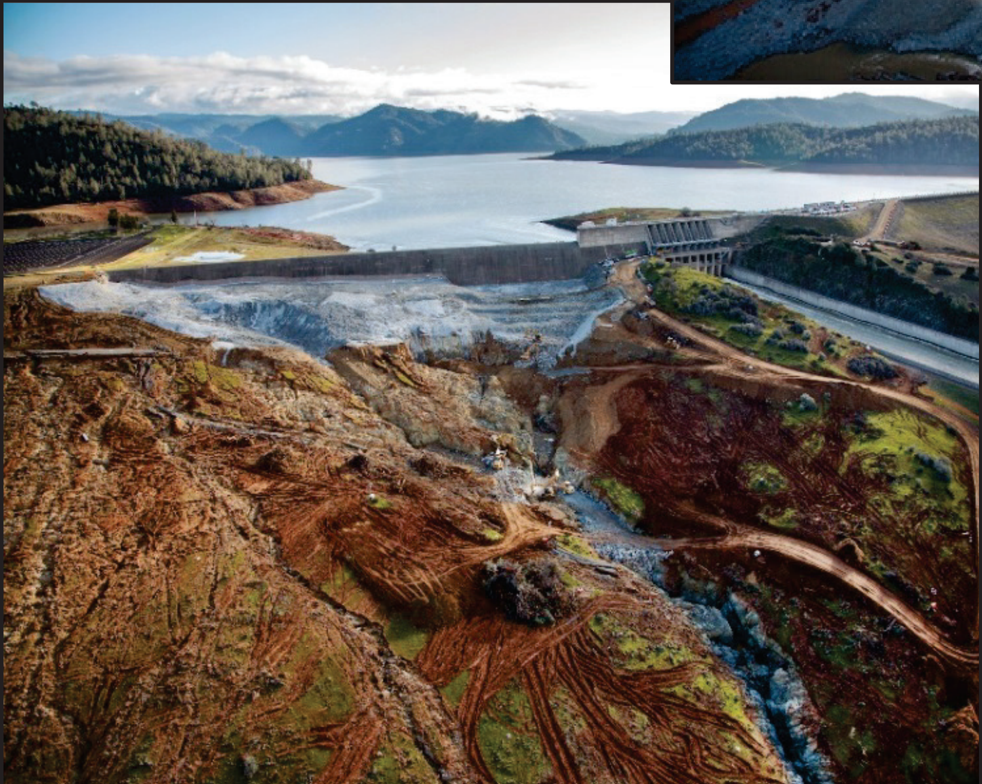
INDEPENDENT FORENSIC TEAM REPORT
OROVILLE DAM SPILLWAY INCIDENT



JANUARY 5, 2018

Appendix C

General Site Geology, Seismicity, and Site Geological Conditions

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1.0 GENERAL SITE GEOLOGY

Up until the project was constructed, only general and broad descriptions of the regional geology and bedrock types to be found at the project site were available from published sources. In the Final Geologic Report [C-1] the geology of the site area is described as comprising steeply dipping metamorphic rocks of the "Bedrock Series," ranging in age from questionable later Paleozoic to questionable Middle Jurassic. According to this report, most of the reservoir area and the foundations at Oroville Dam and Spillways involve rock units of an unnamed metavolcanic member, which is the oldest member of the "Bedrock Series." This member is indicated as being predominantly **amphibolite** or **amphibolite schist**, though in some reports it is described as "greenstone."

One of the earliest geologic maps of the region was published by California Division of Mines and Geology in 1962 (see Figure C-1). This map shows bedrock at the dam site and spillway areas to be undifferentiated Jura-Trias metavolcanic rocks.

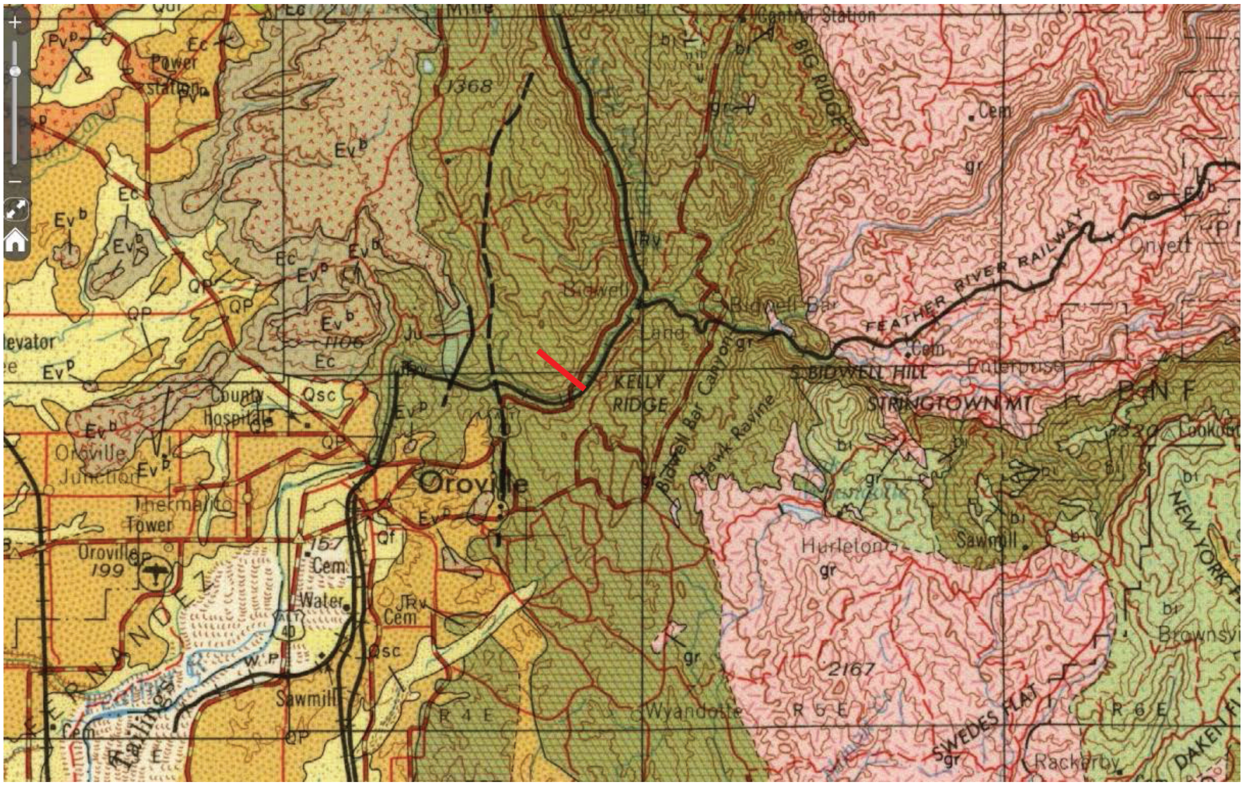


Figure C-1: Enlarged portion of the Chico Quadrangle Geologic Map [C-2], approximate location of Oroville Dam shown by red line

In addition to this source, it is likely that much of the background information and nomenclature on the "Bedrock Series" used in DWR reports on the dam and spillway geology had been summarized from the work of R.S. Creely, including his 1955 PhD thesis [C-3] and the Geology of the Oroville Quadrangle published in 1965 [C-4]. Creely provided petrographic descriptions that frequently used the term "schist" because of the fine-scale foliation he observed.

Subsequently, the bedrock units were named as part of the Smartville Ophiolite Complex and shown on geologic maps published by the California DWR [C-5], Figure C-2, and the California Geologic Survey [C-6], Figure C-3.

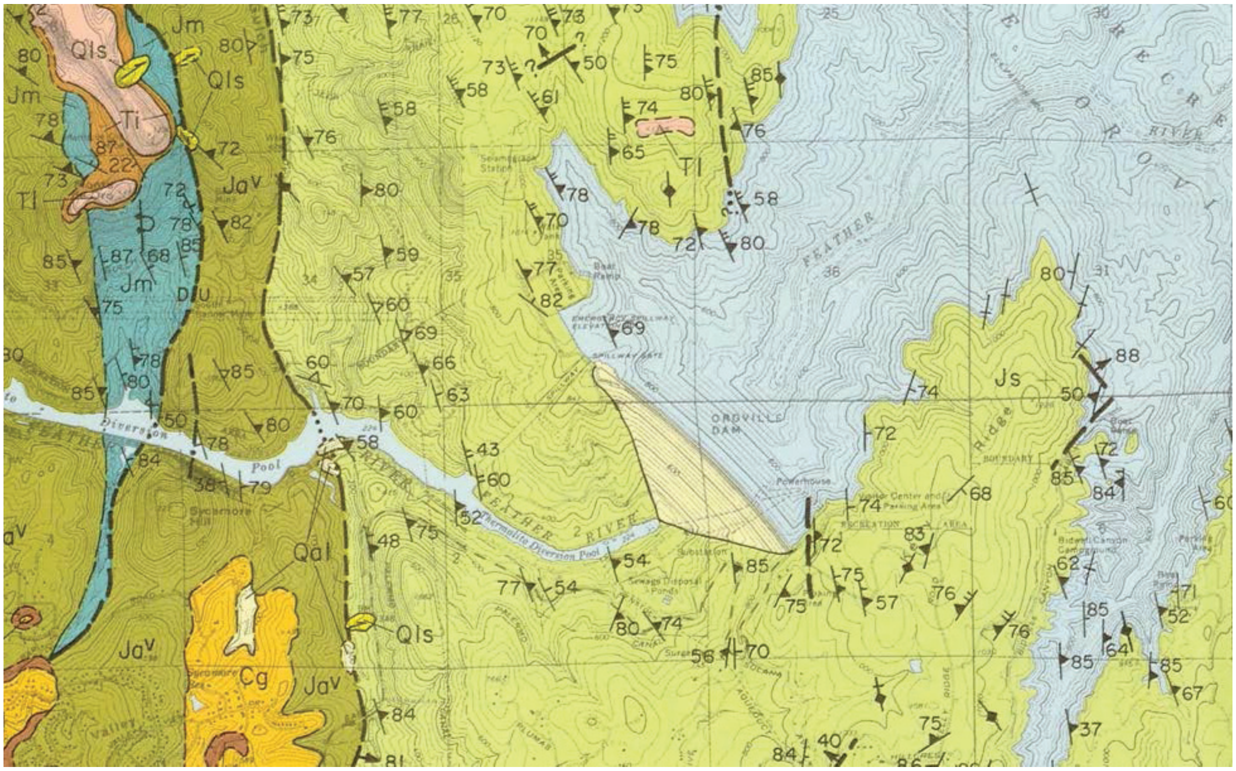


Figure C-2: Enlarged portion of the geologic map of Cole & McJunkin (1978)

Legend descriptions on these maps indicate the Smartville Ophiolite Complex as being comprised of dark gray to green gray, steeply-dipping, strongly foliated, metamorphosed, basaltic to diabasic volcaniclastic sediment, pillow lava, breccia, dikes and sills; gabbroic to felsic screen rocks occur within sheeted dikes; gabbroic plugs are rare. The bedrock units are dark gray to green gray in color, and are strongly foliated, dipping steeply to the northeast. This revised terminology of the bedrock units has been generally adopted by DWR since the 1980s, although the generic usage of "amphibolite" remains in common usage.

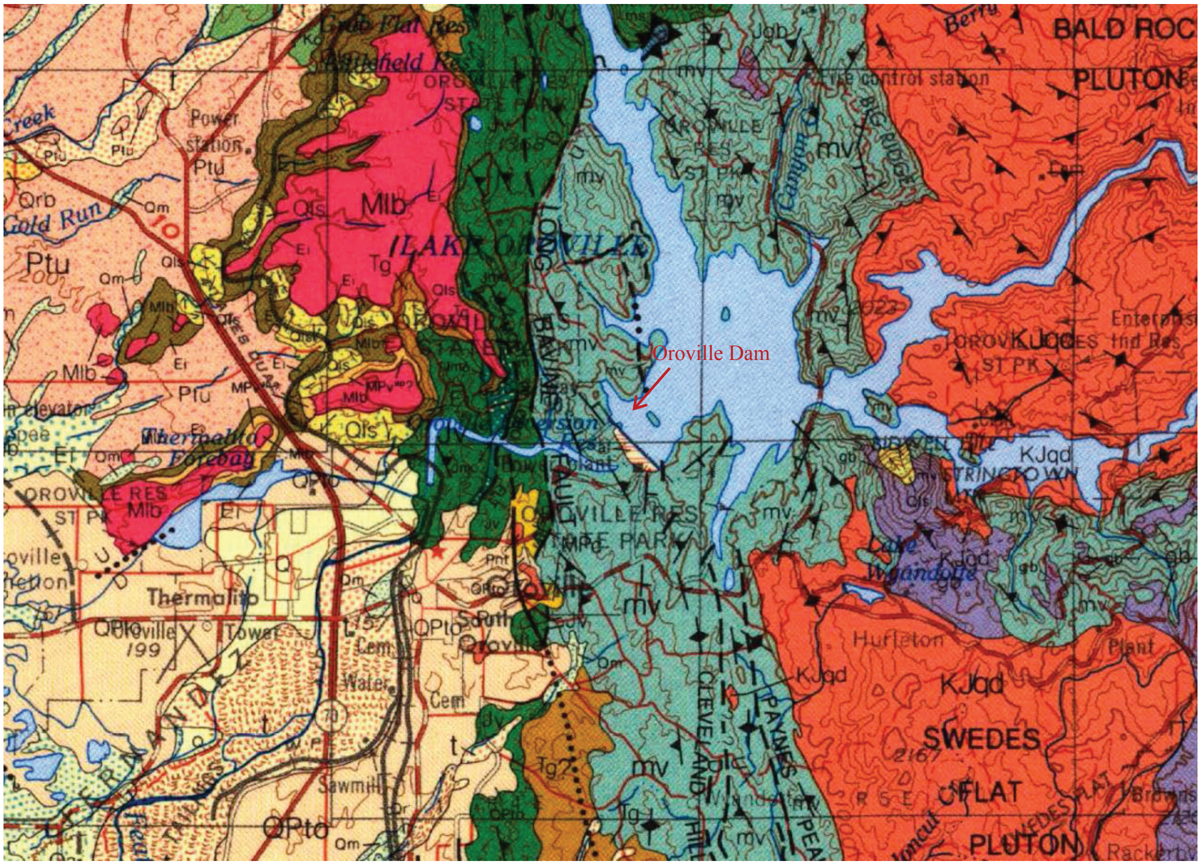


Figure C-3: Enlarged Portion of the Chico Quadrangle Geologic Map$^{C\text{-}6}$

It is evident that a thick cover of saprolite (strongly weathered and decomposed bedrock) has developed in areas underlain by the Smartville Ophiolite sequence, as observed in the erosional damage resulting from the February 2017 incident. This should not have come as a total surprise, given the nature of ophiolite and amphibolite sequences that include basic and mafic igneous rock types. Such lithologies commonly include unstable mineral assemblages that readily weather and degrade in comparison with many other lithologies.

The Smartville Ophiolite Complex is described as comprising rock types that can be placed in this category, including basalt, diabase, pillow lava, and gabbro. There are some reports that the Smartville ophiolite contains large amounts of serpentine and other ultramafic rocks, which are well-known for containing the most pervasive, unstable, and low-strength mineral assemblages. However, there are no direct reports indicating presence of ultramafics, serpentinite, or spilitic sequences in the foundation bedrock at the Oroville Project.

Nevertheless, development of thick saprolitic profiles and extensive, deep weathering is commonly observed in association with ophiolites in humid temperate to subtropical environments (similar to California), especially if the ophiolites are severely deformed and fractured. In addition, the mineralogy of many ophiolite sequences, including the Smartville Complex, has been altered by hydrothermal and/or other types of alteration processes that would also contribute to breakdown and weathering upon exposure to oxidizing groundwater close to the earth's surface.

IFT Comments: There is reasonably common knowledge in current practice that foundations involving rock descriptions as given (i.e. amphibolite, greenstone, or ophiolite) might point toward a particular susceptibility or tendency for pronounced weathering, and that the weathered by-products could be vulnerable to erosion. The IFT concludes that, since the 1980s at least, based simply on regional geological mapping, a qualified engineering geologist should have been able to recognize this potential issue at Oroville. If this recognition had been made post-construction, it should have led to (1) questioning if such conditions had been properly recognized and managed during design and construction (e.g. having provisions for appropriate adjustments in excavation depths, anchor lengths, or other measures); and (2) questioning the erodibility of the foundations, particularly if there is knowledge that weathered materials had been left in place. It is noted however that the observations made during construction were generally consistent with what the regional geology suggests and with petrologic knowledge at that time.

2.0 SEISMICITY

As part of the IFT examination of factors that could have contributed to the February 2017 incident, a brief study was conducted regarding whether earthquake activity was likely to have been a significant influence. Since the failure of the service spillway occurred several decades after the project went into operation, the IFT has examined factors that may have changed or degraded over time and possibly have helped trigger the spillway chute failure scenario. This particular enquiry into seismicity is part of this broader investigation and focused on evaluation of whether any recent earthquake events could be considered potential contributory factors.

2.1 Seismotectonic Setting

The Oroville Project is in an area of northeastern California characterized by relatively low seismic activity in historic times. Overall, the Sierra Nevada and Central Valley move together as an independent block, the eastern margin of which is formed by faults of the Sierra Nevada Fault Zone. Two fault types offset rocks in the area: high-angle reverse faults in the Sierra Nevada Geomorphic Province and normal faults in the Sierra Nevada and Cascade Range Geomorphic Provinces. The dominant structure of the Sierra Nevada metamorphic belt and the project area is the Foothills Fault System. This series of north-northwest trending, east-dipping reverse faults was formed during the late Jurassic era, when subduction along the western continental margin resulted in the Nevadan orogeny. The Foothills Fault System, although considered relatively quiet seismically, is considered an important source given the influence of this system on the geologic structure of the project region. Seismicity on these faults has been reactivated in the late Cenozoic era [C-7].

2.2 Seismic Activity

An assessment was made of seismic activity recorded in the project region since the project went into operation in 1968, with a focus on activity occurring in the periods since the last major spillway flows (prior to the February 2017 incident) took place in 2006. The purpose was to determine if any earthquake events had occurred in such a timeframe that may have generated ground motions of sufficient strength or duration to have potentially damaged or weakened the spillway facilities at Oroville Dam. Strong ground motions sufficient to have caused damage would had to have been either large events at some distance from Oroville Dam or smaller events close to the site.

The most significant recorded seismicity to have affected the Oroville Project involved a series of earthquakes occurring in the summer of 1975, about 8 to 10 miles south of Lake Oroville [C-8]. The largest event was on August 1, 1975, with a recorded magnitude M= 5.7 to 5.8, which was accompanied by surface faulting [C-9]. The earthquake sequence, consisting of five foreshocks, a main shock, and numerous aftershocks, included seven events of magnitude greater than 4.6 [C-10]. Critical facilities such as dams, pumping and power plants, switchyards, pipelines, and canals were all inspected and evaluated for safety following the earthquakes.

Several investigators proposed that the 1975 series of events was a compelling example of reservoir triggered seismicity (RTS), pointing out two factors suggesting that Lake Oroville could have contributed to both the location and timing of the events. One factor is the proximity of the seismic events to the lake, and the second factor is the occurrence of the earthquake swarm following an unprecedented seasonal fluctuation in lake levels [C-8]. During the winter of 1974-1975, the lake was drawn down to its lowest level since initial filling. This exceptional drawdown and subsequent refilling was followed by the earthquake sequence of 1975. Such phenomena have been observed at other large reservoir projects and the present-day consensus of scientists, seismologists, and dam engineers is that RTS is not only plausible, but should be taken into account in design and operation of large reservoir projects [C-11].

During the last drought period, the level of Lake Oroville dropped to 26% capacity in late 2015 and slowly started recovery in 2016, reaching 96% capacity in May before being drawn down again in the summer and fall. However, the rate of refilling in the last winter period was exceptional. Last winter (2016-2017) it took only two months to fill Lake Oroville, whereas in 2015-2016 it took five months.

Therefore, it is reasonable to ask if earthquake occurrence, including possible RTS, could have contributed to the February 2017 incident. However, based on information gathered by the IFT, there are cogent facts and explanations as to why seismicity and RTS are not considered plausible contributory factors. These include:

1. No ground motions generated by earthquake events, and strong enough conceivably to cause damage to large civil structures, have been recorded by instrumentation at the project within the last 20 years.
2. Since the 1975 events, there have been no earthquakes recorded greater than M=3.9 within 30 miles of the project. Dozens of microearthquakes (<M=2.0) are recorded every year, but these are mostly not felt by humans and are not damaging to major civil structures.
3. The service spillway chute slabs and its foundations are not as vulnerable to the effects of strong ground motions as certain other facilities at the project, such as the FCO headworks, which have had no observable seismic damage.
4. A plot of earthquakes (>M=2.5) recorded in the last 20 years and within 125 miles (200 km) of the project is provided in Figure C-4. The data set includes seven events M 4.0 to M5.7 but each was located more than 100 miles from Oroville Dam. The remainder are all

<M4.0. These earthquakes occurred during the timeframe when previous historical major flows had taken place over the spillway. In other words, no new potential damage caused by seismicity had taken place in the time between previous major spillway releases and the February 2017 spillway flows.

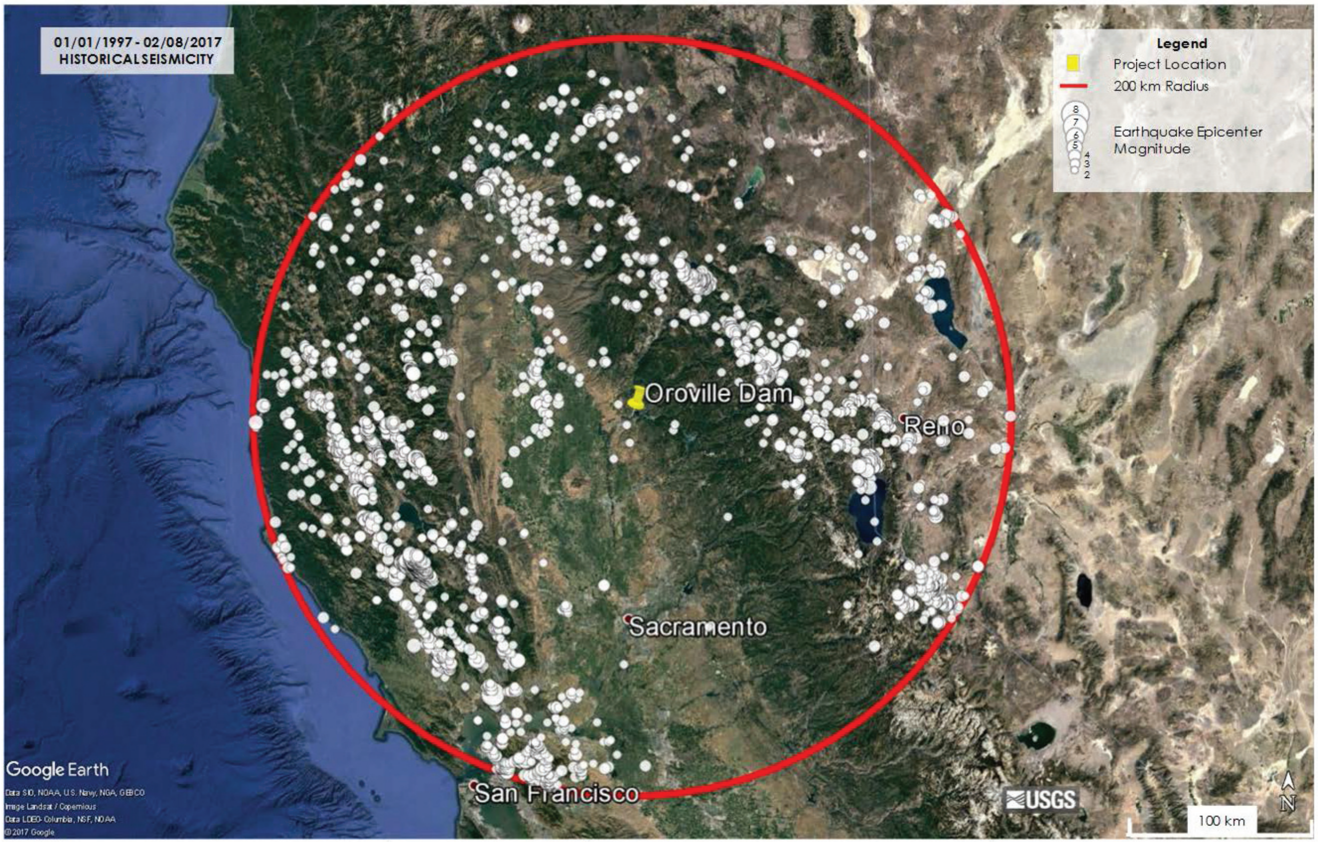


Figure C-4: Plot of earthquakes (>M=2.5) recorded in the last 20 years and within 125 miles (200 km) of Oroville Dam. Data from USGS Search Earthquake Catalog [C-12].

3.0 SITE GEOLOGICAL CONDITIONS AS DOCUMENTED (1948-2009)

The misconceptions regarding the erodibility of the bedrock along the two spillway alignments are central to the development of the Oroville incident. The remainder of this appendix traces the development of geological knowledge and geotechnical assessments of the spillway foundations from earliest investigations, through construction, and up to the point where the misconceptions were thoroughly entrenched and not seriously questioned.

3.1 Initial Explorations (Emergency Spillway Area)

The U.S. Department of the Interior, Bureau of Reclamation (Reclamation) drilled six core holes during a 1948 reconnaissance exploratory program. Their report [C-13] notes that the U.S. Army Corp of Engineers (USACE) had previously drilled two holes in the general site area, however documentation of this earlier investigation was not located by the IFT. The Reclamation report notes that there was no knowledge of any prior geological literature referring to the Oroville area "except that made before the turn of the century by the US Geological Survey," but that the regional geology had been covered in a 1938 Geological Map of California.

The Reclamation report comments on rock conditions as follows:

> "Fresh rock is exposed in the stream section. It is generally very hard, competent and watertight but contains small gouge seams, shear seams and weak zones, as well as irregular joints. Varying thicknesses of weathered and broken rock overlie the fresh rock on the hillsides."
>
> "The fresh rock is hard and resistant to normal erosion."
>
> "The site should be thoroughly tunneled to learn of the extent and subsurface condition of seams."
>
> "From the top soil to fresh rock at depth the following zones of weathered rock are generally present: (a) Zone of rock that is entirely decomposed to clay; (b) A zone of completely decomposed rock in which the weathering has not entirely destroyed the textures and structures of the rock; (c) A zone in which the rock is partly decomposed and partly fresh; (d) A zone of fresh, hard and firm rock which contains mud seams and weathered joints; and (e) A zone of fresh rock that has not been effected by the forces of weathering."
>
> "In logging the core, particular emphasis was placed on the degree of weathering and the presence of gouge seams."
>
> "In the more favorable holes the top soil is 0 to 2 feet thick; the entirely decomposed rock zone extending from 6 inches to 6 feet …; the partially decomposed rock zone extending from 11 to 40 feet …; the zone of fresh rock with weathered seams extending from 34 to 59 feet …"
>
> "On the right abutment in the vicinity of Drill Hole Nos. IF2 and 7, the effects of weathering generally extend deeper than in other areas drilled. The U. S. Engineers' Drill Hole No. IF2 was in rock with decomposed seams at a depth of 152 feet when the hole was abandoned. Drill Hole No. 7 shows … partially decomposed rock which extends to a vertical depth of 38 feet … [and] the hole reached entirely fresh rock at a vertical depth of 80 feet."

Thus, in the first preliminary explorations, the depth and extent of bedrock weathering is clearly identified and documented. However, the description provides an idealized view of a rock weathering profile, gradually increasing in quality with depth. In reality, a deep rock weathering profile is typically very complex, with occasions where much higher degrees of weathering can occur below good quality rock, and even fully surround essentially fresh rock. Rock weathering can also vary greatly over very small distances horizontally, making interpolation between boreholes quite imprecise. Later geologic reports better emphasize the great variability in rock weathering.

This 1948 report also specifically comments on the erodibility of the hillside along what is now the emergency spillway, and proposes an engineering solution:

> "Spillway for Earthfill Dam. … Drill Hole No. 5, bored at the proposed spillway gates, was logged as follows: 0 to 11 feet decomposed rock, and 11 to 23 feet fresh rock with stained joints. As shown by the numerous road cuts … decomposed rock will stand temporarily on a 1 to 1 slope ...
>
> The hard resistant rock in the proposed spillway draw will prevent spillway water from eroding back to the dam. However, the volume of material eroded and deposited in the river will be large if the spillway channel is left unlined. Therefore, deep cut-off to fresh rock at the end of the lined channel will be necessary to prevent serious erosion damage to the spillway channel and gate structure in any single flood season."

Clearly, the 1948 Reclamation investigators had a grasp of the erodibility issue, and actually proposed a solution that is now being utilized in the remediation works – a deep cutoff to fresh rock.

3.2 1950s Explorations

The future spillway areas were next investigated by way of 51 bulldozer trenches in 1952 and 1953, followed by five core holes near the spillway crest in 1956. The reports of these investigations were not available for review.

3.3 1961 Explorations (Emergency Spillway Area)

In 1961, DWR completed six seismic refraction spreads and approximately 22 diamond core holes in the general vicinity of the spillways. Results are given in two reports; a December 1961 report "Interim Report Riprap Explorations, Oroville Spillway" and a June1962 report "Interim Report of Geological Investigation."

The first report [C-14] was specifically written to summarize the potential for extracting riprap (large durable rock for placement on the upstream face of the Oroville Dam). The report notes 22 boreholes, but does not present any borehole logs. It does, however, present an interpretation of "depth to sound rock," in order to estimate the total amount of overlying material (all of which was referred to as "overburden," as distinct from quarry rock) that would have to be removed prior to establishing a quarry. Sound rock was defined as follows:

> "Sound rock will include fresh and slightly weathered rock with unstained or slightly iron-stained fractures. The rock may be slightly to moderately fractured. Material above sound rock surface will include the following:
>
> 1. All soil and decomposed rock.
> 2. All strongly and moderately weathered rock, and all slightly weathered and fresh rock that is sheared, strongly fractured, or has strongly iron-stained fractures, except zones which are shorter in drill-hole length than an overlying interval classified as sound rock."

Thus, the evaluation at the time clearly accounted for the fact that "soundness" is not only a function of the degree of weathering, but also of shearing and fracturing. The interpretation of "depth to sound rock" was carried over from this report to succeeding geological reports as discussed in later sections of this appendix.

The second report [C-15] is broader in scope, and includes consideration of foundation conditions for the spillway chute, expectations for which could be relaxed from those necessary for the production of riprap.

The service spillway alignment under consideration at the time was within the location of the current emergency spillway, and the boreholes for the spillway chute followed down a prominent topographic depression leading from the left side of the emergency spillway to the Feather River. Site conditions were summarized as follows:

> "Amphibolite is hard when slightly weathered, and very soft and crumbly when decomposed. The soil zone usually grades down into decomposed rock and the rock is generally progressively less weathered with depth. However, there may be cases where weathered zones occur below relatively fresh rock."
>
> "Depth of weathering varies from 0 to at least 76 feet, as determined from core drilling, and may extend to 95 feet beneath ground surface, as indicated by seismic exploration. Apparently, the rock along much of the lower spillway is weathered to considerable depths. Depth to weathering ranges from about 40 feet at Stations 38+00 and 50+00 to possibly 95 feet at Station 44+00. Depth of weathering appears to be shallow between Stations 30+00 and 37+00, ranging from 0 to approximately 25 feet. Except for localized areas, principally areas of rock outcrop, depth of weathering over the remainder of the spillway will generally range between 15 and 30 feet."
>
> "Because weathering is generally accentuated along structural features such as sheared or foliated zones, deeply weathered pockets or zones may exist in close proximity to outcrop areas or areas of shallow weathering."

This describes a typical deep weathering pattern in bedrock, and clearly recognizes its very irregular pattern, including the development of what would now be termed "corestones," where the weathering process has preferentially followed the rock structure, and has totally encapsulated areas of relatively unweathered rock. Thus, encountering unweathered rock at a particular depth in any borehole location is not necessarily "proof" that such conditions will persist over the general depth and area.

The report not only describes the geology, but also accurately opines on its probable behavior including erosion potential, providing what would now be called a geotechnical assessment:

> "Fresh rock will be highly resistant to scour; however, some localized zones of strongly jointed, foliated or sheared rock will probably be encountered within the fresh rock at spillway invert, and plucking from these zones can be expected. Rock bolts and/or shallow consolidation grouting could be used to stabilize such zones. Weathered rock will of course be subject to relatively accelerated erosion; where this is critical, the rock should be protected."

"Depth to sound rock," defined similarly to that in the first report, was shown in a longitudinal section along what is now an alignment within the emergency spillway discharge channel. The proposed invert of the spillway on the profile was shown to be excavated down into "sound rock," or at the top of "sound rock" for its entirety, except for a small portion adjacent to the Feather River. A portion of the profile is shown below in Figure C-5.

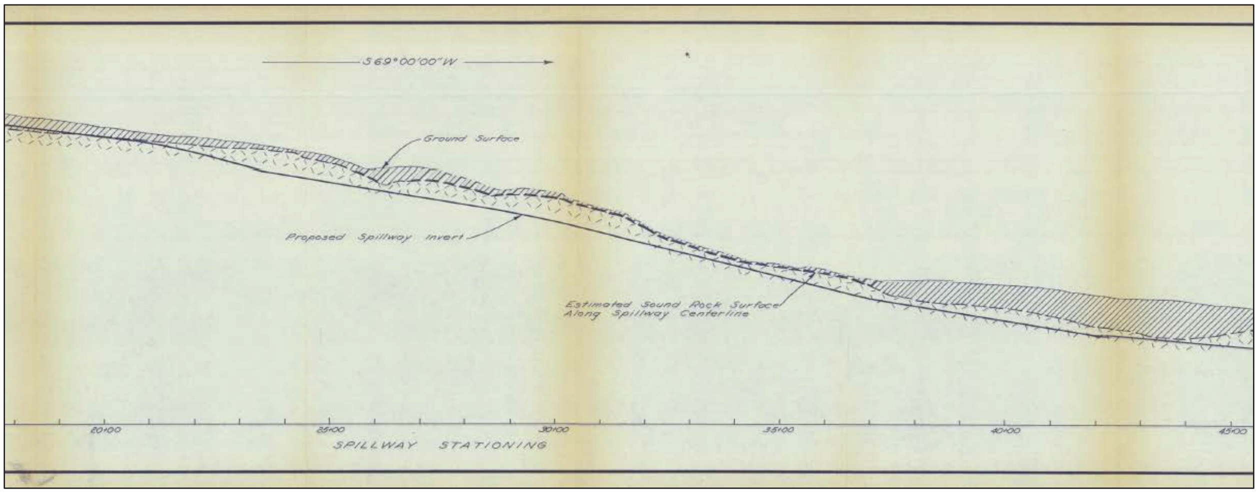


Figure C-5: Portion of a longitudinal section along original spillway alignment, based on 1961 investigations. Now downstream from current emergency spillway.

This foundation rock had been thought of as acceptable for riprap, and the IFT believes that this is the basis of not having a concrete liner in the original design, as noted later in this appendix.

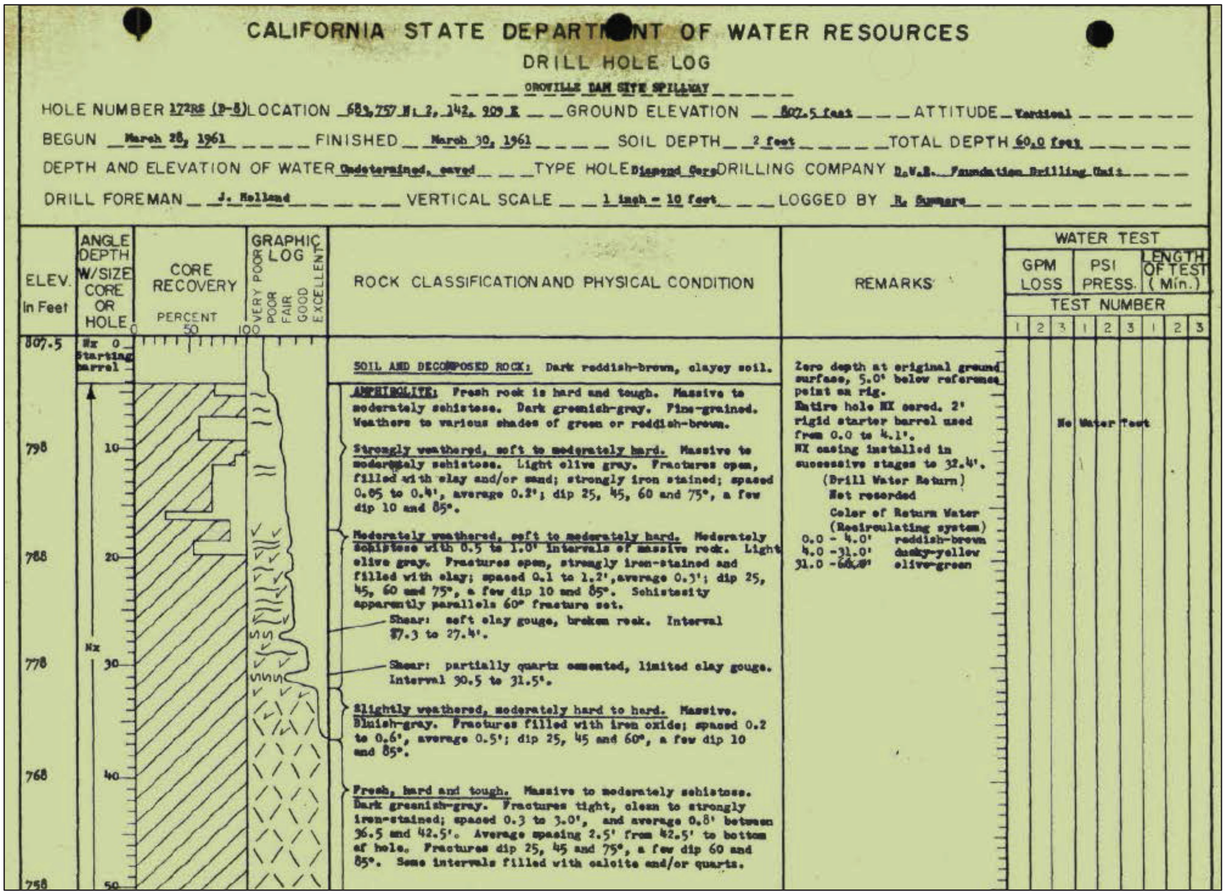
Detailed geological logs are given for all the diamond core holes. Logging at the time did not quantify overall rock quality, joints, and fractures, etc., as would be done today, however all descriptions are detailed and very precise. A general impression of rock quality was also given in a graphic chart, qualitatively ranging from very poor through excellent. Unfortunately, only an incomplete copy of this report was located, so that the legend sheet to describe this, and other various scales describing degree of weathering, jointing, etc. to accompany the logs was not available. However, descriptions on the logs are very detailed, and also included the depths to where the hole required steel casing (used to ensure the hole stayed open during drilling, and often a general indication of poor rock quality when required).

Even a cursory inspection of the borehole logs clearly indicates the significant depths of very poor to fair rock conditions. Table C-1, prepared by the IFT, summarizes the borehole logs, and indicates that the general depth of very poor to fair rock ranged from 7 to 40 feet, averaging about 22 feet. This is the same average depth of rock described on the logs as strongly weathered, soft, strongly jointed with open joints. The IFT believes that modern terminology would replace the term "strongly jointed" with the term "closely jointed." Regardless, in the experience of the IFT, any even relatively unexperienced geologist or geotechnical engineer today would immediately consider "strongly weathered, soft, strongly jointed, open joints" as conditions being very erodible, without the need for any special analysis or calculation. Table C-1 shows that these erodible conditions cover depths described as "Poor to Fair," indicating that all such defined rock should be treated as erodible.

Table C-1: Boreholes Along Emergency Spillway Alignment

Hole (xxxRS)	Approx. distance downstream from weir (ft)	Soil Depth (ft)	Strongly weathered, soft, strongly jointed, joints open		Shear zones above slightly weathered rock		Described as 'Poor to Fair '	Comments
			to depth (ft)	to elevation (ft)	#	thickness (ft)	to depth (ft)	
172	500	4	17	791	2	0.1, 1.0	17	
169	550	4	15	758	1	1.5	15	
170	800	3	10	746	-	-	17	
173	1100	1	10	707	-	-	10	
214	1400	5	13, 30 to 40, 52 to eoh at 65	667	1	1.2	40	cased to 35 ft, fractures open where slightly to mod weathered at avg 0.15 to 0.4 ft spacing
215	1700	4	9	619	1	0.05	9	
216	2100	7	0	n/a	1	0.8	7	
217	2400	11.5	16	see comment	1	20.0	33	strongly fractured and sheared to 33 (elev 387)
187	2600	4	37	374	3	4.1, 0.3, 1.3	37	cased hole to 39.5
184	2900	4	30	357	8	0.8 to 3.0	30	cased hole to 29.8
180	3200	5.5	22	345	see comment		22	major shear zone from 45 to 58.7
182	3650	5	10	284	5	1.0 to 2.4	10	cased hole to 27

Figures C-6 and C-7 are taken from some of these borehole logs as examples.



CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES

DRILL HOLE LOG

OROVILLE DAM SITE SPILLWAY

HOLE NUMBER 172RS (D-8) LOCATION 683,757 N; 2,142,909 E GROUND ELEVATION 807.5 feet ATTITUDE Vertical

BEGUN March 28, 1961 FINISHED March 30, 1961 SOIL DEPTH 2 feet TOTAL DEPTH 60.0 feet

DEPTH AND ELEVATION OF WATER Undetermined, caved TYPE HOLE Diamond Core DRILLING COMPANY D.W.R. Foundation Drilling Unit

DRILL FOREMAN J. Holland VERTICAL SCALE 1 inch = 10 feet LOGGED BY R. Summers

SOIL AND DECOMPOSED ROCK: Dark reddish-brown, clayey soil.

AMPHIBOLITE: Fresh rock is hard and tough. Massive to moderately schistose. Dark greenish-gray. Fine-grained. Weathers to various shades of green or reddish-brown.

Strongly weathered, soft to moderately hard. Massive to moderately schistose. Light olive gray. Fractures open, filled with clay and/or sand; strongly iron stained; spaced 0.05 to 0.4', average 0.2'; dip 25, 45, 60 and 75°, a few dip 10 and 85°.

Moderately weathered, soft to moderately hard. Moderately schistose with 0.5 to 1.0' intervals of massive rock. Light olive gray. Fractures open, strongly iron-stained and filled with clay; spaced 0.1 to 1.2', average 0.3'; dip 25, 45, 60 and 75°, a few dip 10 and 85°. Schistosity apparently parallels 60° fracture set.

Shear: soft clay gouge, broken rock. Interval 27.3 to 27.4'.

Shear: partially quartz cemented, limited clay gouge. Interval 30.5 to 31.5'.

Slightly weathered, moderately hard to hard. Massive. Bluish-gray. Fractures filled with iron oxide; spaced 0.2 to 0.6', average 0.5'; dip 25, 45 and 60°, a few dip 10 and 85°.

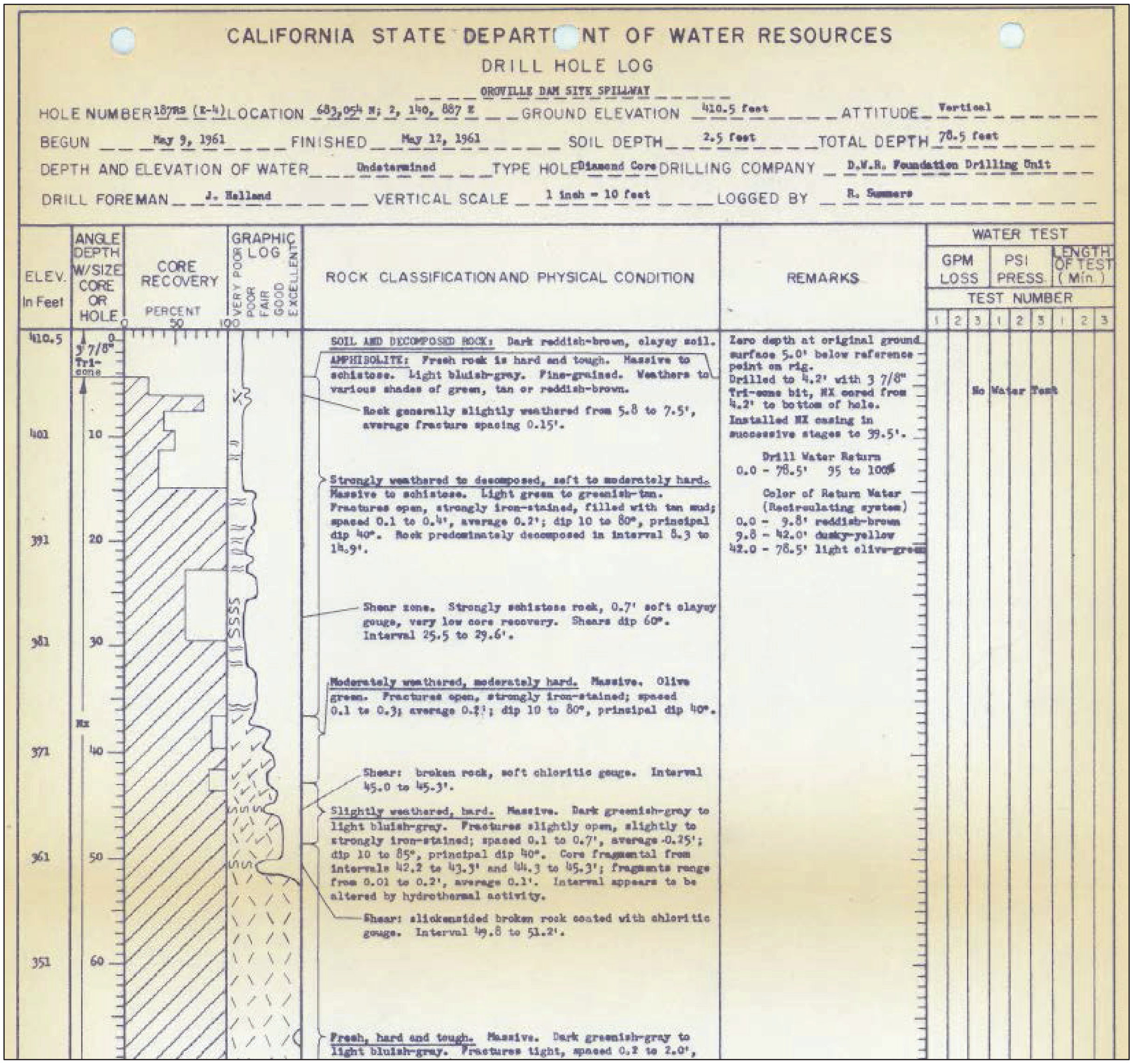
Fresh, hard and tough. Massive to moderately schistose. Dark greenish-gray. Fractures tight, clean to strongly iron-stained; spaced 0.3 to 3.0', and average 0.8' between 36.5 and 42.5'. Average spacing 2.5' from 42.5' to bottom of hole. Fractures dip 25, 45 and 75°, a few dip 60 and 85°. Some intervals filled with calcite and/or quartz.

Zero depth at original ground surface, 5.0' below reference point on rig.
Entire hole NX cored. 2' rigid starter barrel used from 0.0 to 4.1'.
NX casing installed in successive stages to 32.4'.
(Drill Water Return)
Not recorded
Color of Return Water
(Recirculating system)
0.0 - 4.0' reddish-brown
4.0 - 31.0' dusky-yellow
31.0 - 60.0' olive-green

No Water Test

Figure C-6: Borehole 172RS, approximately 500 feet downstream of Emergency Spillway Weir

Although there is a general increase in rock quality with depth, there is great variability in the degree of weathering, jointing, rock strength etc., as would be expected. Rock quality (a product of all these different variables) is thus simply represented in a subjective graphic log.


CALIFORNIA STATE DEPART[illegible]NT OF WATER RESOURCES

DRILL HOLE LOG

OROVILLE DAM SITE SPILLWAY

HOLE NUMBER 187RS (E-4) LOCATION 683,054 N; 2, 140, 887 E GROUND ELEVATION 410.5 feet ATTITUDE Vertical
BEGUN May 9, 1961 FINISHED May 12, 1961 SOIL DEPTH 2.5 feet TOTAL DEPTH 78.5 feet
DEPTH AND ELEVATION OF WATER Undetermined TYPE HOLE Diamond Core DRILLING COMPANY D.W.R. Foundation Drilling Unit
DRILL FOREMAN J. Helland VERTICAL SCALE 1 inch = 10 feet LOGGED BY R. Summers

ROCK CLASSIFICATION AND PHYSICAL CONDITION

SOIL AND DECOMPOSED ROCK: Dark reddish-brown, clayey soil.

AMPHIBOLITE: Fresh rock is hard and tough. Massive to schistose. Light bluish-gray. Fine-grained. Weathers to various shades of green, tan or reddish-brown.

Rock generally slightly weathered from 5.8 to 7.5', average fracture spacing 0.15'.

Strongly weathered to decomposed, soft to moderately hard. Massive to schistose. Light green to greenish-tan. Fractures open, strongly iron-stained, filled with tan mud; spaced 0.1 to 0.4', average 0.2'; dip 10 to 80°, principal dip 40°. Rock predominately decomposed in interval 8.3 to 14.9'.

Shear zone. Strongly schistose rock, 0.7' soft clayey gouge, very low core recovery. Shears dip 60°. Interval 25.5 to 29.6'.

Moderately weathered, moderately hard. Massive. Olive green. Fractures open, strongly iron-stained; spaced 0.1 to 0.3; average 0.2'; dip 10 to 80°, principal dip 40°.

Shear: broken rock, soft chloritic gouge. Interval 45.0 to 45.3'.

Slightly weathered, hard. Massive. Dark greenish-gray to light bluish-gray. Fractures slightly open, slightly to strongly iron-stained; spaced 0.1 to 0.7', average 0.25'; dip 10 to 85°, principal dip 40°. Core fragmental from intervals 42.2 to 43.3' and 44.3 to 45.3'; fragments range from 0.01 to 0.2', average 0.1'. Interval appears to be altered by hydrothermal activity.

Shear: slickensided broken rock coated with chloritic gouge. Interval 49.8 to 51.2'.

Fresh, hard and tough. Massive. Dark greenish-gray to light bluish-gray. Fractures tight, spaced 0.2 to 2.0',

REMARKS

Zero depth at original ground surface 5.0' below reference point on rig.
Drilled to 4.2' with 3 7/8" Tri-cone bit, NX cored from 4.2' to bottom of hole.
Installed NX casing in successive stages to 39.5'.

Drill Water Return
0.0 - 78.5' 95 to 100%

Color of Return Water
(Recirculating system)
0.0 - 9.8' reddish-brown
9.8 - 42.0' dusky-yellow
42.0 - 78.5' light olive-green

No Water Test

Figure C-7: Borehole 187RS, approximately 2600 feet downstream of Emergency Spillway Weir

In view of the high level of care and detail shown in the production of these borehole logs, it is difficult to believe that these authors did not consider these to be the conditions that they described as “subject to relatively accelerated erosion; where this is critical, the rock should be protected.” As the invert is generally shown to be lower, on or into the “sound rock,” there would be little or no rock requiring protection by a concrete lining. This could be the reason why the 1962 report shows the spillway excavation down into sound rock, and does not expressly address a concrete liner for the spillway channel. However, whether or not the invert elevation was originally designed as shown on this profile is unknown.

The IFT did infer through a memorandum [October 22, 1962, C-16] that the original concept design for the spillway had only a short length of lining and a large extent of unlined downstream channel. The memorandum expressed concern regarding this approach due to potential erosion, and expressed the belief that

> "… it should be mandatory that the spillway present no threat of artificially raising tailwater above normal."

Thus, downstream erosion was under consideration, but the possibility of headcutting back upstream to threaten the water-retaining crest structure itself was not. The concern regarding an unlined downstream channel was apparently heeded, as discussed in the next section.

3.4 Explorations for Service Spillway

In 1964, DWR completed additional investigations along the final alignment chosen for the service spillway. The 1962 report format was repeated in a new report entitled "Interim Exploration Data, Oroville Dam Spillway," [C-17] produced by many of the same personnel involved in the 1962 work.

The same degree of care and professionalism is evident in the production of the borehole logs, and geological descriptions are very similar. The IFT was given a complete copy of this report, including the legend sheet for the borehole logs that was missing from the 1962 report. A general impression of "foundation quality of rock for a concrete gravity structure" was given in a graphic chart, qualitatively ranging from very poor through excellent. Criteria considered in the classification of quality were given as:

> "Criteria for classification of the rock are rock weathering, hardness, schistosity, fracturing, and shearing. Several of these features are generally interrelated and are somewhat characteristic of a classification, although almost any one feature can have a dominant influence on the classification of the rock …"
>
> "Very Poor – Rock is characteristically very soft and usually friable. Generally, this class rock is found in sheared zones or in strongly weathered intervals.
>
> Poor – Rock is soft, but cohesive. This class is usually found in strongly to moderately weathered zones or some shear zones.
>
> Fair – Rock is moderately hard, generally coring in pieces 0.05 to 0.2 ft. in length. This class of rock is typically found in strong schistose zones or in slightly to moderately weathered zones.
>
> Good – Rock is massive to moderately schistose, and is fresh and hard except immediately adjacent to slightly weathered fracture planes. Rock generally cores in pieces 0.2 to 0.5 ft. in length.
>
> Excellent – Rock is fresh, hard, and relatively unfoliated; generally coring in pieces over 1.0 ft. in length."

It is evident that there was a full understanding that weathering is only one of a number of factors that determine the overall quality of the rock mass, and hence its performance. It is likely that this understanding was in place during the production of the earlier borehole logs, as the detailed geological descriptions in the borehole logs are quite similar to those from 1962.

A summary of the borehole logs based on the IFT's review is given in Table C-2. This is the entirety of the borehole information that was available during the development of the 1964 report. Along this new alignment, "depth of rock weathering varies from about 8 ft. to at least 52 ft. below the ground surface. Locally, weathering along shear zones may be even deeper."

Of the 10 borehole locations, two holes indicated good quality rock conditions at invert level, three holes terminated in good quality rock above invert elevation (which, as noted above, is not necessarily proof of continued sound rock with increasing depth), four holes (highlighted in yellow) indicated moderately weathered conditions, and one hole (highlighted in red) noted strongly to moderately weathered conditions (at about Sta. 22+00). Interestingly, the major shear at about Sta. 30+00 and downstream was not recognized at this time, due to the large spacing between boreholes.

It is noted that "Since drill hole data are more reliable than seismic data, 'Depth to Sound Rock' as presented in this report is based primarily on drill hole data." Sound rock is defined the same as in the 1962 reports, so that it is apparently based on its acceptability for use as riprap, although it was no longer the intent to establish a quarry in this area.

Based on the above information, a profile along the service spillway was developed, a portion of which is given below in Figure C-8. Note that, at the scale of the profiles, the elevations of both "sound rock" and the spillway chute invert as shown do not appear to correlate well with actual design conditions. It is possible that the geologists preparing these sections were not using finalized invert elevations. Also, as the profile was based primarily on drill hole data, in some cases more than 500 feet apart, the "sound rock" profile itself is quite unreliable, including in the area where the service spillway chute failure initiated. However the profiles do indicate what the geologists expected in terms of foundation conditions. In contrast to the 1962 profile along the older alignment, the spillway invert is now shown to be in both sound rock and overlying rock.

Table C-2: Boreholes Along Service Spillway Alignment
See text for description of color highlights

Hole (xxxRS)	Approx Station (ft)	Offset from Centerline (ft)	Soil Depth (ft)	Strongly weathered, soft, strongly jointed, joints open		Shear zones above slightly weathered rock		Described as 'Poor to Fair '	Approx Excavated Elevation (ft) taken from foundation cleanup maps (Final Geology Report)	Comments	Elevation at end of hole (ft)	Conditions at end of hole
				to depth (ft)	to elevation (ft)	#	thickness (ft)	to depth (ft)				
290	16+00	140R	2	23	840	1	1.8	27	794	? Likely fresh, hard, massive: Hole terminated above grade	805	20 ft of fresh, hard, tight joints above end of hole
291	17+00	130L	0.5	n/a	858.5	1	0.02	7	787	? Likely fresh, hard, massive: Hole terminated above grade	824	20 ft of fresh, hard, tight joints above end of hole
289	17+00	140R	2	27	816	1	2.0	27	787	? Hole terminated above grade	799	moderately to slightly weathered, tight to open, 0.05 to 0.8:
286	18+50	94R	2	38	781	2	1.0, 1.6	44	🟨 780	moderately to slightly weathered, tight to open fractures, 0.05 to 0.4 spacing, just at contact with overlying strongly weathered zone	766	4 ft of slightly weathered to fresh
294	22+00	75R	4	38	742	1	6.8	45	🟥 757	strongly to moderately weathered, soft, strongly fractured another 15 ft to reach slightly weathered, fair to good quality, tight fractures	713	12 ft of fresh, hard, massive
283	26+15	C	3	23 to 45	725	3	1.0, 2.0, 2.2	60	🟨 722	mod weathered, moderately hard, tight fractures 0.05 to 0.4 , major shear 5 ft below	710	4 ft of fresh, hard
282	31+00	C	2	23	633	2	thin	23	615	fresh, hard, massive	616	10 ft of fresh, hard
278	33+00	103R	3	36	572	4	0.5 and less	36	🟨 567	at very bottom of strong weathered zone: moderately weathered, moderately hard, fair, tight to open fractures	542	10 ft of fresh, hard
277	38+25	80L	6	n/a	n/a	2	0.5, 0.3	6	🟨 437	slightly to moderately weathered, tight to open, 0.05 to 0.8	406	11 ft fresh hard massive
275	42+70	C	4	31 to 43	342	2	1.5, 1.5	45	327	fresh, hard, massive	322	fresh, hard, massive

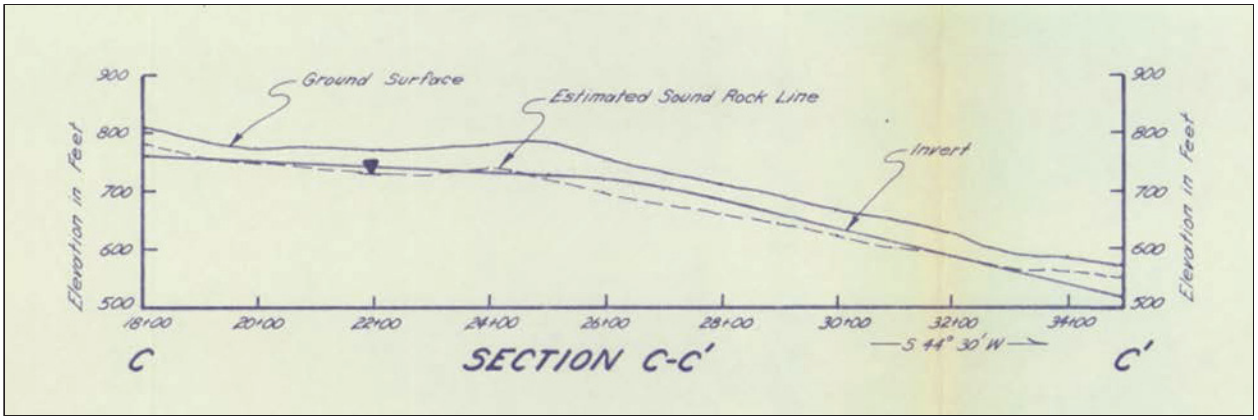


Figure C-8: Portion of a longitudinal section along final service spillway alignment, based on 1964 investigations.

There appears to have been a major change in opinion regarding the geotechnical acceptability of moderately weathered rock. The 1964 report states that:

> "Moderately weathered rock should also be adequate foundation for most of the structures, but may require some special treatment. Irregularity of foundations excavated in fresh or slightly weathered rock will provide good keying against sliding of the concrete apron or lining. Fresh or slightly weathered amphibolite is also very resistant to scouring and/or plucking."

The IFT believes that this major change in opinion may be due to the change in design that now included a concrete liner over the entire length of the spillway channel. The liner appears to have been added to the design in response to the concerns raised in October 1962, and thus is apparently to protect the moderately weathered rock.

The above statements cannot be reconciled with the fact that the exploratory boreholes showed worse than moderately weathered rock conditions at the spillway invert elevation. Figure C-9 clearly shows that strongly weathered rock conditions would have been expected at the level of the spillway chute excavation. However, it may be that the invert elevation was modified from that under consideration at the time of the development of the profile given in Figure C-9.

No mention is made of potential rock scour of weathered rock, as was documented in 1962; only the original observation regarding fresh and slightly weathered rock is repeated in 1964. In this later report, it is noted that moderately weathered rock "may require some special treatment," but this special treatment is not defined further.

Excavation and Drainage Considerations: As the profile clearly shows moderately weathered rock as an acceptable foundation condition, the text opines on how it will be excavated – being either blasted with explosives or ripped out by heavy machinery. However, a basic inconsistency arises in the text in regard to the rippability versus blasting of the moderately weathered rock, an inconsistency that became the basis of a major claim during construction. Most moderately weathered rock is described as rippable:

> "Rippable material will include all overburden, all decomposed and strongly weathered rock *and most moderately weathered rock.* Average depth of rippable rock is about 20 ft …" (italics added for emphasis)

Since the profile shows a large portion of the chute founded on moderately weathered rock, it could be inferred that this portion of the chute would be rippable. However, it is inferred (but not explicitly stated) that where the spillway chute cannot be founded on sound rock, it should be founded on *non*-rippable rock:

> "The lining (walls and invert slab) of the spillway chute should be founded on sound rock wherever possible, but most of the non-rippable rock will be adequate for this structure"

In the following excerpt, there is a possible explanation for this apparent contradiction:

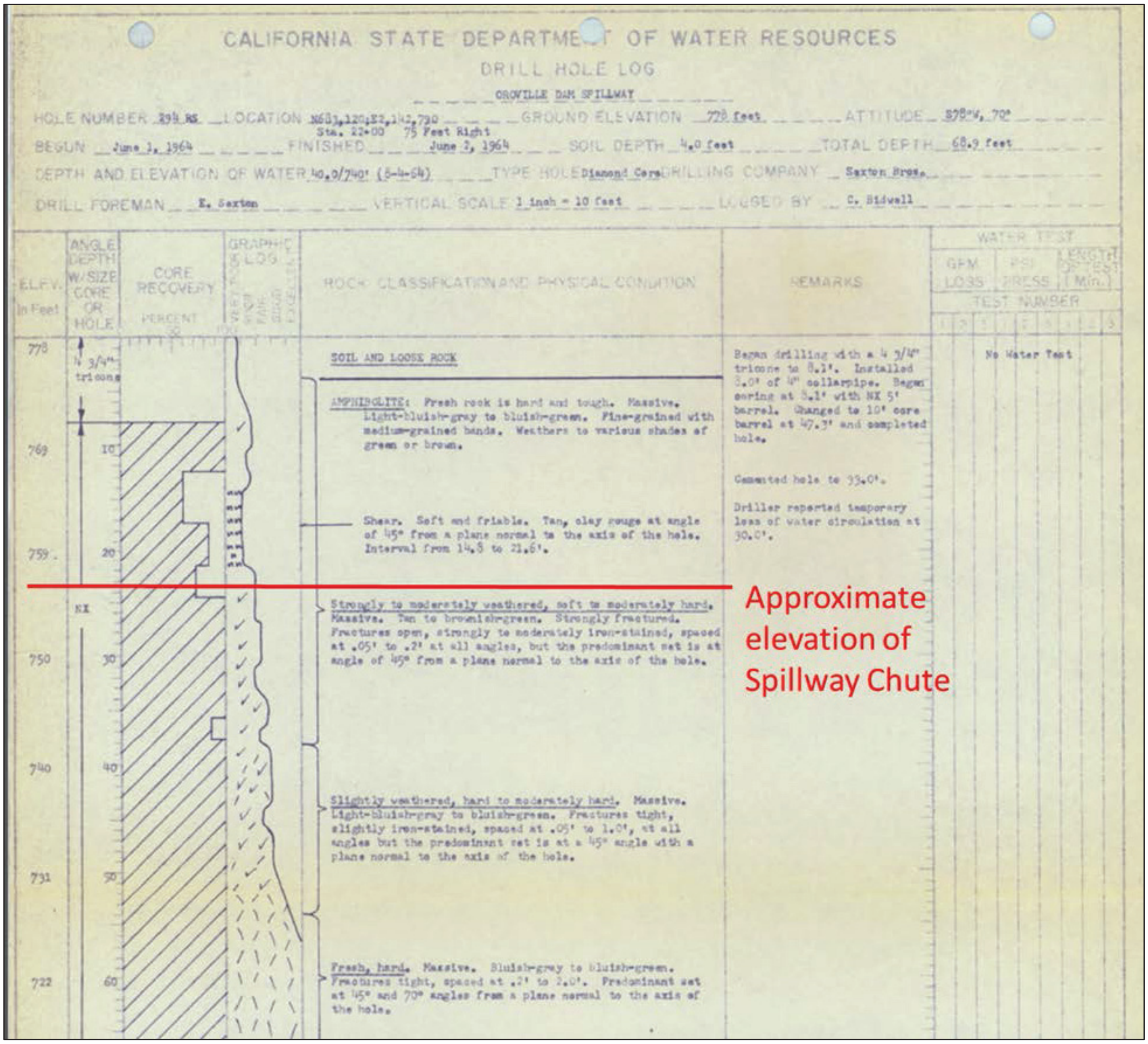
> "Sound rock (fresh and slightly weathered rock that is relatively massive and slightly to moderately fractured) will require drilling and blasting for removal. Blasting will also be required to excavate portions of the moderately weathered rock. Because protruding ribs of hard rock (sic), it may be advantageous to blast much of the rippable, moderately weathered rock to facilitate excavation."

It appears that the authors considered that *blasting* of rippable moderately weathered rock would produce an acceptable foundation that would not require special treatment, perhaps due to the heterogeneous mix of weathered and non-weathered rock.

It is evident that only the strongly to moderately weathered material encountered in Borehole 294RS (Sta. 22+00) was considered as being rippable:

> "Rippable material at and below invert grade should be anticipated in the chute between Stations 19+00 and 23+00."

The detailed borehole log for 294RS, located closest to this area, is given in Figure C-9.



CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES

DRILL HOLE LOG

OROVILLE DAM SPILLWAY

HOLE NUMBER 294 RS LOCATION N631,120;E2,142,790 Sta. 22+00 75 Feet Right GROUND ELEVATION 778 feet ATTITUDE S78°W, 70°

BEGUN June 1, 1964 FINISHED June 2, 1964 SOIL DEPTH 4.0 feet TOTAL DEPTH 68.9 feet

DEPTH AND ELEVATION OF WATER 40.0/740' (6-4-64) TYPE HOLE Diamond Core DRILLING COMPANY Sexton Bros.

DRILL FOREMAN E. Sexton VERTICAL SCALE 1 inch = 10 feet LOGGED BY C. Bidwell

SOIL AND LOOSE ROCK

AMPHIBOLITE: Fresh rock is hard and tough. Massive. Light-bluish-gray to bluish-green. Fine-grained with medium-grained bands. Weathers to various shades of green or brown.

Shear. Soft and friable. Tan, clay gouge at angle of 45° from a plane normal to the axis of the hole. Interval from 14.8 to 21.6'.

Strongly to moderately weathered, soft to moderately hard. Massive. Tan to brownish-green. Strongly fractured. Fractures open, strongly to moderately iron-stained, spaced at .05' to .2' at all angles, but the predominant set is at angle of 45° from a plane normal to the axis of the hole.

Slightly weathered, hard to moderately hard. Massive. Light-bluish-gray to bluish-green. Fractures tight, slightly iron-stained, spaced at .05' to 1.0', at all angles but the predominant set is at a 45° angle with a plane normal to the axis of the hole.

Fresh, hard. Massive. Bluish-gray to bluish-green. Fractures tight, spaced at .2' to 2.0'. Predominant set at 45° and 70° angles from a plane normal to the axis of the hole.

Began drilling with a 4 3/4" tricone to 8.1'. Installed 8.0' of 4" collarpipe. Began coring at 8.1' with NX 5' barrel. Changed to 10' core barrel at 47.3' and completed hole.

Cemented hole to 33.0'.

Driller reported temporary loss of water circulation at 30.0'.

No Water Test

Figure C-9: Borehole 294RS, approximately Sta. 22+00 along Service Spillway, offset 75 feet

Although rippable conditions were called out in the report, apparently associated with strongly to moderately weathered rock of poor to fair quality (as per Figure C9), apparently no special treatment for such fully rippable foundations was considered, and the following general statement was given:

> "Excavation of the chute will produce a rough, irregular rock surface and shear keys are not thought to be necessary to prevent sliding of the chute lining. Blasting for shear key trenches in the foundation would only tend to weaken the rock by shattering."

The IFT does believe that this statement is valid. However shear keys could have been constructed by other less destructive methods, such as the use of jackhammers, as discussed further in Appendix E. This statement may have been the basis for not providing foundation keys even in areas where the foundation was in strongly and moderately weathered rock.

The report also notes the potential for uplift pressures; the main concern being leakage through the foundation past the grout curtain at the upstream end of the spillway chute. It recommends an underdrain system along the entire chute:

> "The possibility of uplift pressure is most likely to occur near the headgate, but could occur at any point on the chute. A close-spaced drain-hole system should be provided in the vicinity of the headgate structure, immediately downstream from the grout curtain, to reduce the possibility of uplift pressures on the chute invert slab. A drainage ditch paralleling each side of the chute, with longitudinal and lateral drains in or under the slab should prevent damaging pressures from developing. The longitudinal underdrains should be spaced no more than 30 ft. apart, and the lateral underdrains should be spaced no more than 60 ft. apart. Underdrains should be designed which would eliminate the necessity of blasting trenches in the rock. Installation of rock anchor bars would provide added protection against damage due to uplift pressure and subsequent destruction of the slab by high velocity flow."

The report fails to connect the geological descriptions of the "rippable" moderately weathered rock with the potential for scour of this "rippable" rock due to flow in the underdrains. One wonders whether, if the 1962 comments on potential scour had been carried forward to the 1964 report, this now-obvious connection would have been made. Regardless, it is evident that there was no intention of placing the underdrains on a *strongly* weathered rock foundation, and that blast damage to the foundation rock was to be avoided, both likely in recognition of potential damage due to seepage flows.

Geophysical Information: The 1964 report also includes a summary of both the 1961 and 1963 geophysical investigations. A summary plot of the earlier investigations along the alignment of the emergency spillway is given in Figure C-10.

This summary shows large depths to sound rock, as defined for the purpose of riprap exploitation. The relevance to the current discussion is that the report indicates that there was no discernable difference in velocity from the surficial soil and decomposed rock layer until the "sound" rock layer was reached in most surveys, i.e. the measured velocities of the moderately to strongly weathered rock were not different enough from the measured velocities of the soil and decomposed rock to be interpreted as a separate layer. This would be yet another indication that significant depths of erodible material could be expected downstream from the emergency weir.

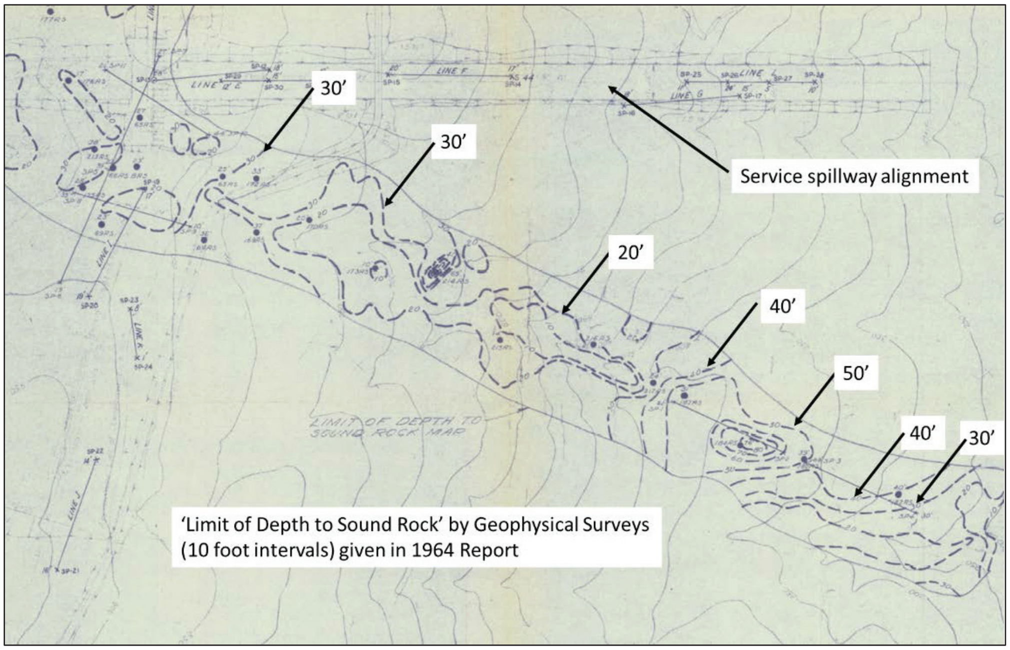


Figure C-10: Summary of 1961 Geophysical Results downstream from current emergency spillway weir

3.5 Specifications

Based on the above reports, the design and specifications for the work were developed. The contract specifications[C-18] for spillway excavation are quite brief; relevant sections follow:

> "Surfaces against which concrete is to be placed shall be cleaned of all loose and objectionable material by means of high velocity air or air and water jets, or by other approved means …"
>
> "Shear zones extending below the excavation payment lines for concrete structures shall be excavated to remove decomposed, weathered, or crushed rock and similar unsuitable foundation materials, as directed. Excavation shall include the use of pneumatic tools, hand barring and wedging …"
>
> "Excavation for the chute shall be to fresh or moderately weathered rock that *cannot be further removed by heavy duty power excavating equipment*, but shall be excavated to a minimum of the excavation limit lines shown on the drawings, regardless of the excavation methods used. Sharp points of undisturbed rock will be permitted to extend not more than 3 inches within the excavation limit lines provided they do not occur along the alignment of foundation drainage pipes …" (italics added for emphasis)

Note that the specifications do not cover the conditions in which moderately or strongly weathered rock *can* be easily removed without heavy duty power excavating equipment beyond the excavation limit lines.

3.6 1965 Design Review

On January 12, 1965, an internal DWR civil/structural design review of the spillway was documented by J. E. Halstead [C-19]. Foundation conditions were apparently well understood:

> "The foundation consists of amphibolite rock. This rock is hard when fresh or slightly weathered and very soft when crumbly or decomposed. The soil zone usually grades down into decomposed rock and the rock is generally progressively less weathered with depth. However, there are places where the weathering extends down into and beneath the rock outcroppings along shear and strongly fractured zones. Deep weathering pockets may exist between rock outcrop areas.
>
> The specifications provide for excavating to rock which is no less competent than moderately hard or moderately weathered. Therefore, backfill concrete will probably be required for the purpose of filling deeply weathered pockets. The flood control structure is founded on sound rock."

However, it does not seem to be recognized that the specifications do not adequately cover the situation where "backfill concrete will probably be required for the purpose of filling deeply weathered pockets."

3.7 Conditions Encountered During Construction

The omission noted above, related to deeply weathered pockets, led to significant issues arising during final inspections of the spillway chute foundation prior to placement of the concrete; from the 1968 Spillway Final Construction Report [C-20]:

> "Excavation for the chute shall be to fresh or moderately weathered rock that cannot be further removed by heavy duty power excavating equipment." The Contractor considered that this statement gave him the right to overexcavate material several feet below grade and then get paid for backfill concrete at $30.00 per cubic yard to restore the subgrade to the elevation shown on the drawings. The Field Engineer directed the Contractor to excavate to the grades shown on the drawings unless ordered otherwise by himself or one of his subordinates …"

It is not stated in this report whether the moderately weathered rock could be easily removed to below invert elevation, although this was most certainly the case according to daily reports during construction. The following statement by DWR appears in documentation associated with Change Order #21 [C-21], relating to a major claim by the Contractor due to the bedrock conditions encountered in the chute foundation:

> "Originally our position has been that payment and any excavation with heavy power equipment beyond the minimum excavation limit lines would be considered as overexcavation. However, after discussion with the Contractor and our field personnel, it was determined that it was reasonable for the Contractor to take literally Subarticle (5) and to expect to excavate at least all shear zone material that could be removed by heavy duty power excavating equipment. Accordingly, it was agreed that payment was due for all the

> shear-zone excavation and the concrete backfill costs for that material so excavated by heavy duty power equipment."

Note that the above pertains specifically to shear zones, which were carefully mapped and numbered, and to material excavated by heavy duty power equipment. It does *not* apparently include areas of moderately or highly weathered rock unless excavated by heavy duty power equipment. However, removal of *all* the highly weathered rock was certainly the original intent of the field geologists, and would have been required to meet the specification noted above whereby surfaces were to be cleaned of "all loose and objectionable material."

In notes from a meeting held on September 6, 1967 [C-22] in which the claim was settled, the following is stated:

> "Mr. Mims (Contractor representative) then stated, I spent $1,200,000 over the payments made to me for the work on the chute… The foundation rock was shattered and could be excavated with a monitor to a depth of 25 ft. I have an independent geology report and colored photos of every inch of the bottom. Dynamiting breaks the rock lower by reason of numerous fractures. We stopped at grade but couldn't control raveling out below grade… At this point Mr. McCune (DWR) entered the discussion stating that you drilled and shot the chute, but the overbreak was due to your methods and nothing else… Mr. Mims countered with the statement that you have to assume the geological information was correct… The geological information did not resemble what was out there."

It is clear that portraying foundation conditions at the invert as being acceptable was central to DWR's defense against the Contractor's claim. It is possible that the field geologist was over-ruled by the project office during the foundation preparation in the area of 33+00, where there was no means to deal with the as-found conditions within the contract, and moderately to strongly weathered rock was left in place. However, this remains speculation.

It also remains speculation as to whether a DWR corporate reluctance to acknowledge out-of-specification foundation conditions became entrenched as part of oral organizational history. Alternatively, institutional memory may have been overly influenced by assertions in the report that implied more favorable foundation conditions than expected and also by the title of the report which includes the word "Final" under the assumptions that all previous observations and interpretations had been taken into account. From the Spillway Final Construction Report[C-19]:

> "In the chute, there was very little extra excavation directed. This consisted of a few clay seams in the foundation and the areas where the slope failures occurred."

Daily reports of construction activities were examined by the IFT, and these reports support the Contractor's claim of poor foundation conditions, and not necessarily the comment regarding direction by DWR for extra excavation. This is discussed further in Appendix A.

In regard to the rock anchors in the chute, the following excerpts are from the Spillway Final Construction Report[C-19]:

> "In order to determine what depths would be necessary to obtain the required tension (of the chute anchors), three sets of two holes were each drilled in the chute foundation; two

> 5-foot holes, two 6-foot holes, and two 7-foot holes. In each case, one hole was located in the worst foundation available, that is, clay seams, and the other hole was for average conditions. It was determined that the minimum depth of 5 feet would produce over 30,000 psi regardless of the type of foundation."
>
> "… Other problems were loss of holes due to the fractured rock and keeping the holes free of water."

The report either did not recognize, or chose not to comment, on the fact that the anchor tests were not conducted in the worst foundation, but rather the "worst foundation available" at the time of the tests (they included sections with clay seams), which were completed near the start of construction, and would not have included large areas of strongly weathered rock. Later problems noted due to loss of holes in fractured rock would indicate worse conditions than were tested, however, the assertion that the 5-foot anchors were sufficient "regardless of the type of foundation" remained unchallenged.

3.8 Board of Consultants Involvement

DWR convened an external Board of Consultants (BOC) during the design and construction of Oroville Dam. This BOC consisted of six members reporting directly to the Chief Engineer of DWR, and covered the design and construction aspects of all the Oroville facilities.

In review of the available BOC documents, there are very few comments covering the spillway chutes. However, comments from an April 1963 meeting [C-23] appear to support the IFT's belief that the concrete lining was only added to the design after the 1962 Interim Report on Geologic Investigation.

> "… (the BOC) concurs generally in the selection from among other alternatives of a concrete lined chute …"

One interesting comment appears regarding the area downstream of the emergency spillway. Notes from a September 20, 1963 meeting [C-24] include the passage:

> "The Board concurs in the finding that nothing be done to minimize erosion in the natural channel downstream from the auxiliary spillway beyond ensuring that this discharge be kept away from the concrete lined chute below the flood control outlet structure."

Of note regarding the service spillway, a memorandum [C-25] notes that the "foundation treatment in the weathered rock area around Station 31+00" was discussed in an April 1966 BOC meeting. After an exhaustive search by DWR staff, unfortunately the minutes of this meeting could not be located. However, it is apparent that during the ensuing discussions, the adequacy of the underdrain system was questioned, and this led to a Change Order (#21), issued October 16, 1967, as previously discussed. All of the drain pipe sizes were increased, the herringbone pattern was developed to provide positive drainage throughout, and vertical risers were added to the longitudinal drains.

3.9 Foundation Conditions as Documented in Final Geologic Report

A Final Geologic Report [C-1] was prepared in 1970 for the Spillway, following completion of construction. The report is under the signature of J. W. Marlette, a new Chief Project Geologist.

> “Periodic inspections of foundation, excavation and grouting were made by D.J. Gross, who made recommendations as required. Daily inspections of rock conditions encountered during excavation were made by O. L. Huber.”

Both Gross and Huber were involved with the 1964 investigations; but apparently Gross was the only geologist that was involved throughout the project from the 1962 investigations.

The report covers the service spillway only; the only mention of the emergency spillway is in the Introduction:

> “The ungated weir (emergency spillway), which will probably never be used, provides assurance that Oroville Dam will ever be overtopped.”

It is clear that documentation of geologic conditions downstream of the emergency overflow weir was considered to be relatively unimportant, and that use of the emergency spillway for cases other than extreme floods was not being considered.

The report is very detailed and provides an excellent record of as-found conditions along the service spillway chute, including:

- Foundation geological mapping sheets showing Geologic Units and Engineering Properties, including 124 specific shear zone tabulations along the chute, and
- Detailed drawings showing cleanup of the chute foundation, where the foundation rock was left partly covered with “ compacted clayey fines.”

Full descriptions of the as-found weathered rock are included, and the factors that affected the quality and appearance of the foundation rock are also well explained:

> “Even though there is only one rock type exposed in the spillway foundation, several factors affect the quality and appearance of this foundation rock. Foremost among these factors is the degree of weathering of the rock at final grade. Other factors which affect the quality of the foundation to a lesser degree are (1) spacing and orientation of joints and shears, (2) thickness, orientation and composition of materials in the wider shear and schist zones (3) the presence of strongly fractured or crushed zones (many of which were created by blasting, as shown in Photo 123), and (4) the degree of schistosity or foliation exhibited by the rock.”

The mapping details the areas where strongly weathered rock was encountered, described as

> “Strongly weathered to decomposed rock – soft, samples easily broken by hand, dull thud when struck with hammer, most of the minerals are partially or entirely altered”

There is no moderately or strongly weathered rock noted in the foundation for the first 600 feet downstream from the headworks structure. The most upstream locations where such conditions were found are documented on the right side of the chute near Sta. 19+00 to 20+50, followed by an area on the left side at Sta. 27+00, with the largest areal extents from Sta. 31+00 to 38+00, in the area of the initial failure in February 2017. Figures C-11 and C-12 are excerpts from drawings in the Final Geologic Report showing the large extents of the moderately and strongly weathered rock, and the degree of compacted clayey fines left upon foundation cleanup in the vicinity of the initial spillway slab failure (colorized by the IFT). These aspects are discussed further in Appendix I.

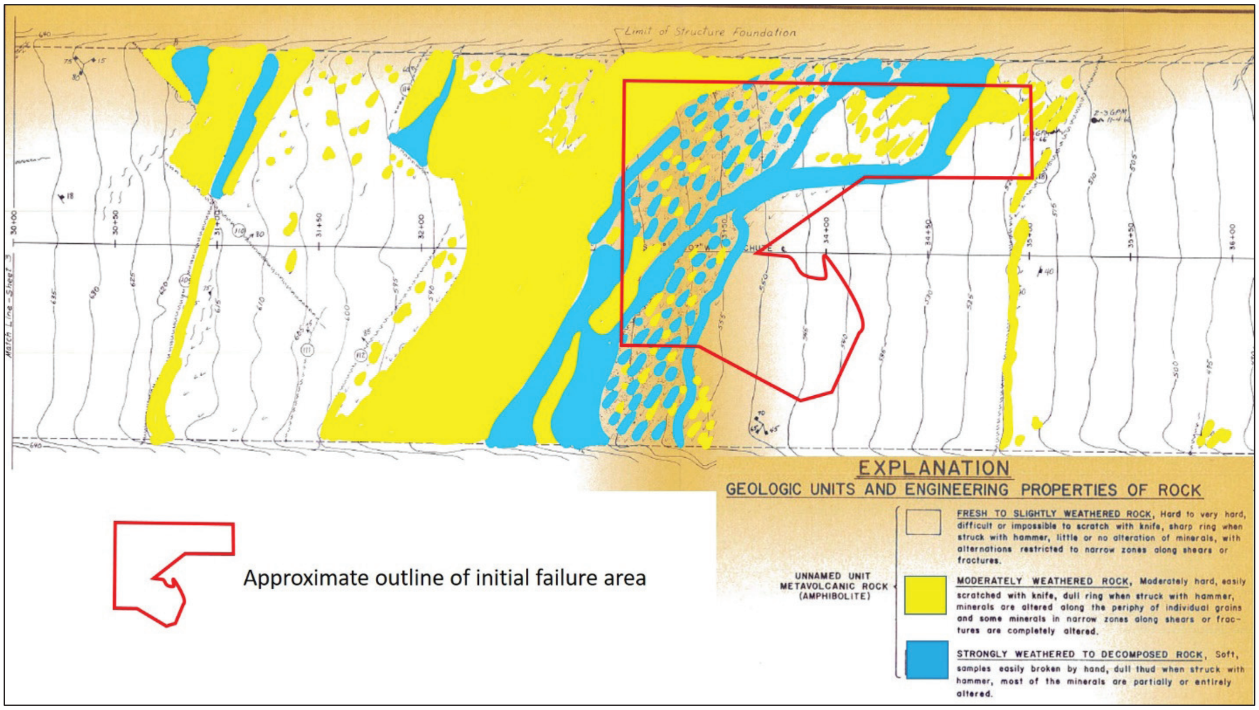


Figure C-11: Extents of Moderately and Strongly Weathered Rock. Geologic mapping from Final Geologic Report [C-1]

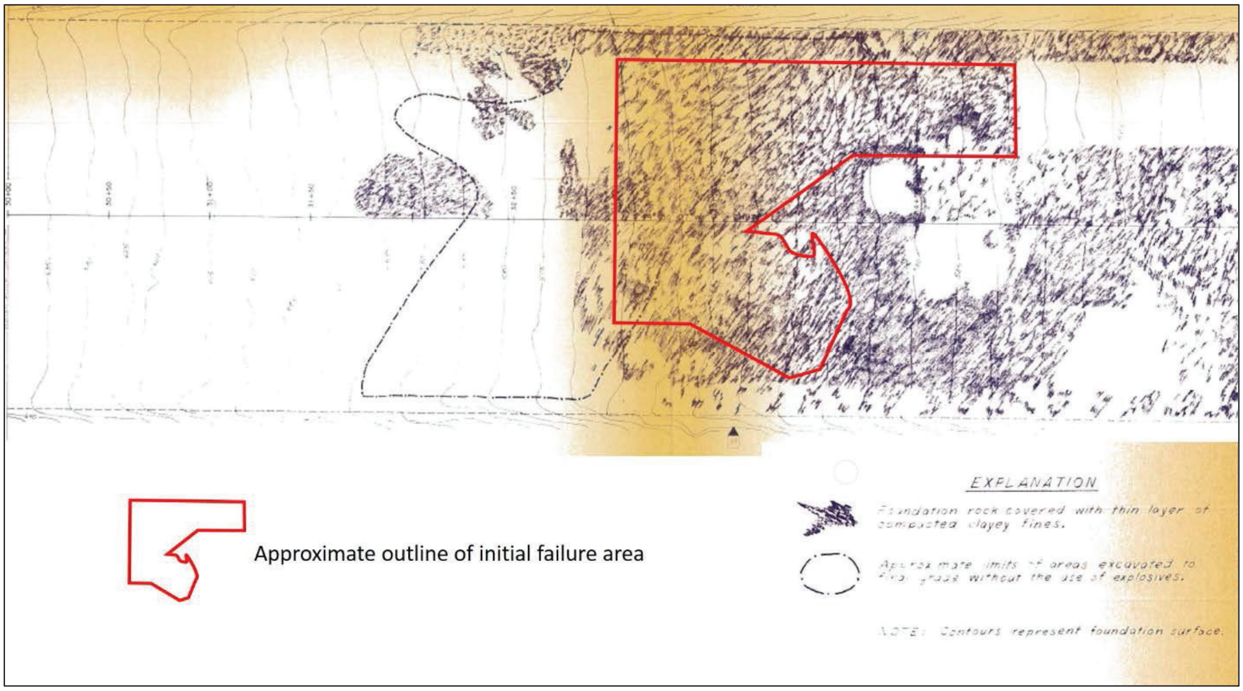


Figure C-12: Extents of Compacted Clayey Fines. Geologic mapping from Final Geologic Reportm [C-1]

Encountering strongly weathered rock was clearly never expected at the time of the 1964 Interim Geological Report. Although there are references in this report back to the early reports, there is no apparent connection made to the fact that these obvious changed foundation conditions were not covered under the project specifications.

Groundwater is noted as being encountered:

> "During excavation of the spillway chute, a few such springs were encountered (Plate 2), but none created a problem during construction, because the flows were very small (2 to 6 gpm). The chute slab underdrains should prove adequate to handle any future flow from these springs."

It is clear that the underdrain system was seen as necessary in response to potential groundwater and seepage past the grout curtain, and water injection during spilling was not being considered. Gravel-filled sonotube drain risers are shown in photographs (see Appendix A) as being installed in areas of overexcavation, but not commented upon in the text. Again, it is clear that the drains were mainly, or solely, included in the design to deal with potential seepage from the bedrock.

The following passage notes that the main consideration in foundation cleanup was bearing strength and groundwater seepage requirements, not erodibility:

> "The foundation underdrains beneath the chute lining slab consist of a network of six-inch perforated V.C.P. tile drains on a herringbone pattern, covered with select gravel backfill. In some areas these drains were placed on rock which had been thoroughly cleaned up, but in other areas only the loose material was removed from the foundation rock, leaving a

> layer of compacted clayey material on the rock beneath the drains (Photos 37 through 39, Plate 3). Removal of the compacted clayey material would not be necessary to satisfy foundation strength requirements for the chute lining. Also, removal of this material from 100 percent of the foundation would not be necessary to satisfy underdrain requirements. Therefore, the goal set by design engineers (removal of fines from 50 percent of the foundation) was a practical one, which would provide adequate relief of seepage pressures."

The IFT could find no other reference to the decision (by the design engineers or others) to relax the specifications and allow 50% fines to remain in the foundation, nor was it ascertained over what unit base area this estimation would be made.

A general statement near the beginning of the report states:

> "Foundation rock for the entire spillway is amphibolite, which contains numerous narrow shears and schistose zones. Fresh amphibolite is hard, dense, fine- to medium-grained, greenish gray to black, and generally massive, although a slight foliation (regional structure) is usually present."
>
> "Joint spacing, within each of the three major joint sets, ranges from a fraction of an inch to several feet, and averages about two feet."

This opening description, when read in isolation from the remainder of the report, describes very favorable foundation conditions, and this may be a major factor in the ensuing misinterpretations of bedrock conditions.

3.10 Foundation Conditions Documented After Construction

A major publication, "Bulletin 200," covering the execution of the entire project was published by DWR in 1974 [C-26]. However, there are very few passages pertaining to spillway chute conditions:

> "Rock at the site is moderately to strongly jointed and is transected by steeply dipping shears and schistose zones … The depth of weathering was found to be substantial and varied greatly from place to place …
>
> Except for a narrow strip immediately downstream from the weir, the terrain below the weir was not cleared of trees and other natural growth because emergency spillway use will be infrequent …
>
> Approximately 90% of the chute foundation required blasting to reach grade. The only extra excavation directed was removal of a few clay seams in the foundation and a few areas where slope failures occurred."

There is no mention of the changed conditions that were encountered during the service spillway chute excavation and the ensuing contractual and technical issues.

Of particular interest is the note that stripping of the terrain below the emergency weir was thought not to be required because of its infrequent use. Bulletin 200 states that the service spillway maximum discharge was chosen to limit Feather River flows to downstream levee channel capacity during the project design flood. The probability recurrence interval of this flood was given as approximately 450 years. Thus, the designer expected the likelihood of emergency spillway use to be in the order of 1:450 in any one year, or about a 20% chance over 100 years of project operation. This may have had implications in the assessment of failure modes as discussed in Appendix F3.

3.11 2002 Comments on Use of Emergency Spillway

The IFT was provided with no records of any geologic reviews or documentation from Bulletin #200 (1974) up until 2002. In August 2002, the Yuba County Water Agency produced "Technical Memorandum on Controlled Surcharge of Lake Oroville for Additional Flood Control" [C-27]. This memo was apparently not entered into the administrative record, but a cut-and-paste version of the memo, taken from a Yuba County Water Agency web page available at the time, was provided to the IFT. From the provided version:

> "The objective of this technical memorandum is to document the findings of studies under the Water Act of 2000 regarding the emergency operation of Lake Oroville for additional flood control."

The memorandum was focused on a proposed plan involving drawdown of the Thermalito Afterbay for supplemental flood control, and the memorandum included considerations of the emergency spillway weir. The memo provides comments on the impacts of using the emergency spillway as follows:

> "The discharge area below the emergency spillway is not armored and extensive erosion would take place if the emergency spillway were used. The spillway road and possible high voltage transmission towers would be impacted."
>
> "Because the area downstream from the emergency spillway crest is an unlined hillside, significant erosion of the hillside would occur."
>
> "EMERGENCY SPILLWAY IMPACTS: The hillside between the emergency spillway and the Feather River would be subject to severe erosion when water flows over the spillway. Depending on the rate of flow, the erodable area, as generally indicated by contours on Figure 1, could range from 50 to 70 acres. The amount of soil, rock, and debris that would fall into the Feather River could be very large, depending on the depth of erosion. There could be damages to downstream structures, including the Thermalito Diversion Dam and Powerplant, Fish Barrier Dam, and highway bridges. If there is river channel blockage below the spillway, there could be impacts on operation of Hyatt Powerplant. Additionally, erosion of 50 to 70 acres down to bare rock would have a significant adverse visual impact and effects on birds and wildlife that occupy the area."

3.12 2005 Review of Geologic Conditions at Emergency Spillway

As part of the Oroville re-licensing process, a Motion to Intervene [C-28] was submitted to the FERC on October 17, 2005 by three environmental groups – Friends of the River, the Sierra Club and the South Yuba River Citizens League. One of the issues brought before the Commission in the Motion was directly based on the 2002 Yuba County memorandum, and cited the above quotations. On this basis, one of the requests to the FERC was:

> "Consistent with the Commission's responsibilities ... requiring relicensing applicants to demonstrate that existing structures are safe and adequate to fulfill their stated functions, [FERC should] issue a licensing order requiring the licensee to armor or otherwise reconstruct the ungated spillway and to make any other needed modifications so that the licensee can safely and confidently conduct required surcharge operations consistent with the Corps of Engineers Oroville Dam Reservoir Regulation Manual."

The November 27 edition of the Sacramento Bee newspaper carried a story covering claims made in the Motion to Intervene, including:

- The presence of a "design flaw" such that the emergency spillway "empties onto a bare dirt hillside"
- That "water flowing over the emergency spillway would wipe out two roads and two power lines built on the hillside below, and wash an estimated 70 acres of soil and rock downstream."

On November 29, the FERC requested an official response from DWR, which responded the same day (November 29) via a series of 17 emails [C-29]. It is clearly evident that the effort was rushed, with external pressure being applied to respond as quickly as possible. The IFT was not able to discern whether this pressure came directly from the FERC, or whether it came from DWR executives wishing to be seen as responding to the FERC without delay. Either way, the results are put into context in the first email to the FERC which states:

> "These emails are the result of about 2 hours of research by me and my staff …"

A later email (the same day) to the FERC states:

> "Good luck with your response to Washington. I hope I provided what was needed …"

Thus, it is evident that very little actual research, if any, was conducted. This was merely an exercise in document gathering. The emails included nine detailed borehole logs from 1962 (including core photos from one hole), summary geological profiles and foundation maps.

> "…it is the best we could do in this short time. If you zoom in, you will see the hole locations better. The holes on the hillside were drilled along a chute alignment that was not built. As you can see, the site was thoroughly explored. Next I will be emailing you several of the actual drill hole logs. They all show that the area of interest is composed of solid, essentially non-erodible bedrock with an insignificant layer of top soil that will erode."

However, as seen in Figure C-13, all of the detailed information in the following emails are from explorations in the crest area of the emergency spillway. Although reference is made to the borehole investigations downstream from the emergency spillway crest structure (along the original service spillway alignment), no detailed information whatsoever was provided for the area downstream of the overflow weir, neither any of the detailed borehole logs (as summarized in Table B-1 above) nor the geological sections prepared in 1962.

> "The attached drawing contains summary drill hole logs for some important drill holes. We could not find the actual drill hole logs, just this sheet."

Thus, the detailed geological descriptions that would have given critical information on strength and jointing (which would have indicated the likelihood of erodibility) downstream from the emergency weir were not accessed. However, the nine borehole logs that were accessed provided ample evidence of poor to very poor rock conditions. Even if one assumed that moderately weathered rock was non-erodable, six of the nine logs show worse than moderately weathered rock conditions. Two logs show strongly weathered rock to depths of 12 feet and 17 feet, and all six logs indicate moderately to strongly weathered, moderately weathered to soft, poor to fair conditions to depths ranging from 22 Feet to 44 feet.

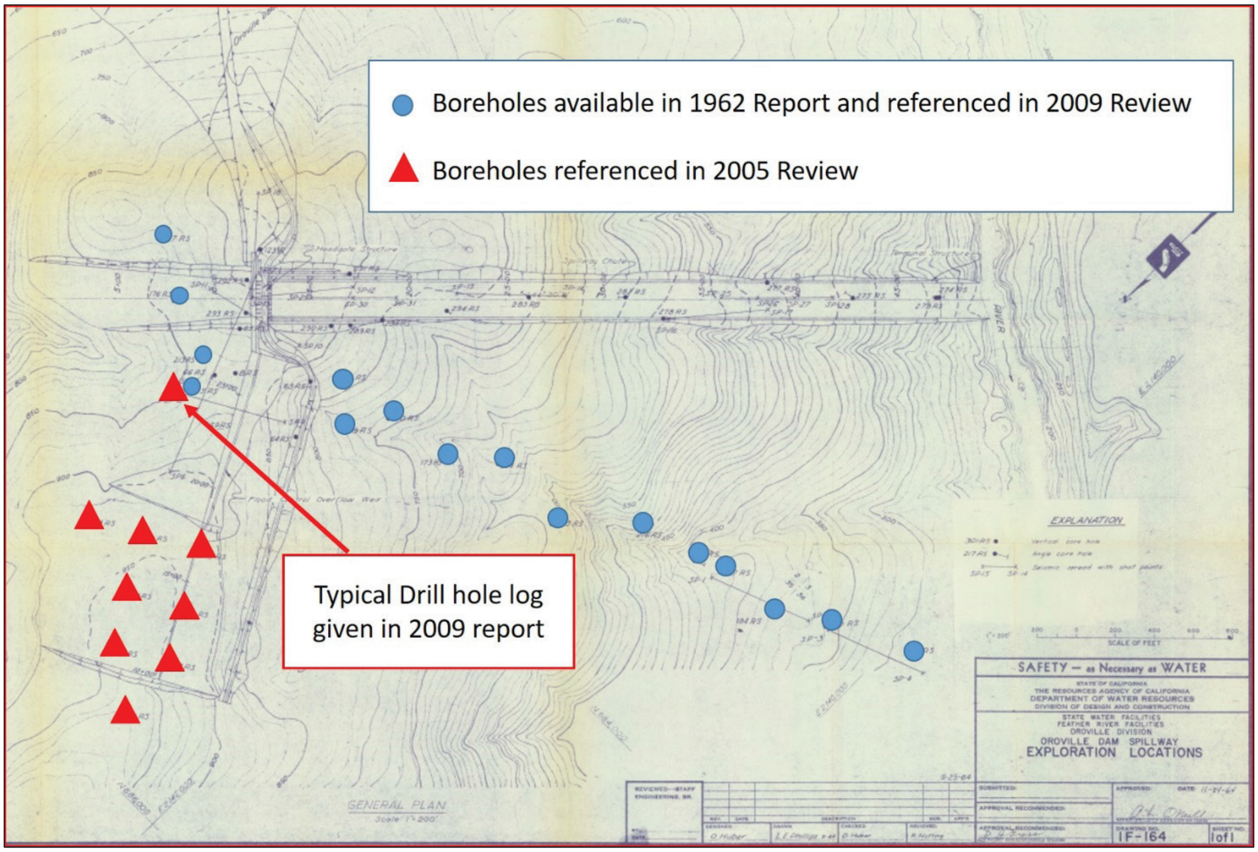


Figure C-13: Borehole Logs Available for Review

The email train includes a summary memorandum [C-30] from the Project Geology Section to the Civil Maintenance Branch of DWR. It is stated in the memorandum that:

> “The Emergency Spillway does not empty onto a bare dirt hillside. Instead, it empties onto a hillside composed of solid amphibolite bedrock extending from the spillway crest down to the Feather River. *Where the rock is fresh, it is hard, dense, fine- to medium-grained, greenish-gray to black and generally massive.* Even though this rock contains numerous narrow shears and schistose zones, variable weathering, joints and fractures, it is considered an excellent and competent spillway rock.” (italics added for emphasis)

The sentence in italics is a direct quote from the 1960s Interim geological reports, and remains true, but irrelevant and misleading when taken out of context. The IFT could find no basis for the remainder of the claim that *solid* amphibolite extended "from the spillway crest down to the Feather River." Since no information covering the area from the crest to the river was included in the emails, the IFT assumes that this information was never accessed in the time available, and that no work was done as a check against this claim.

In the ensuing back-and-forth email communication [C-29], DWR notes to FERC:

> "You probably recall that we all discussed this exact issue during the PFMA last year, and my recollection is that we dismissed it. I remember we said that a lot of debris would get washed into the river, but I think we concluded that there would be no structural damage …"

The memorandum [C-30] concludes:

> "Based on the information presented in this Office Memo, as obtained from the reports in the Project Geology files, it is my belief that Emergency Spillway at Oroville Dam is a safe and stable structure founded on bedrock that will not erode."

Although a reasonable statement for the overflow weir itself, where significant excavation had been made to expose an acceptable foundation surface, it has no relevance in regard to the downstream conditions, where no such excavations had been made to remove areas of unprotected, highly erodible, weathered and jointed rock to significant depths. The major inconsistency between the conditions shown on the nine borehole logs and the sweeping generalization of acceptable rock conditions downstream from the emergency overflow weir was not recognized by either the author, or the FERC recipient of the memorandum.

This memorandum, based on work performed within one day, apparently without DWR peer review, and obviously not critically reviewed by FERC, is referenced in all future project reviews, apparently forming the basis of the ongoing overall misrepresentation of the bedrock conditions at the Oroville Dam spillways from that time forward.

3.13 2006 State Water Contractors Review

The Metropolitan Water District of Southern California was working in concert with the State Water Contractors on the Oroville FERC relicensing, and subsequently reviewed the 2005 Motion to Intervene. The results of the review were provide to the FERC on May 26, 2006 [C-31]. The issue regarding impacts of emergency spillway usage are covered in the following:

> "… Sutter County/Yuba City have not offered any evidence to cast doubt on the integrity of the hillside downstream of the emergency spillway …"
>
> "Friends of the River cites an August 2002 Yuba County Water Agency Technical Memorandum … but the cited memo is nowhere to be found in the record of this proceeding. The Commission should either seek to have the YCWA memo included in the record or to consider the information as anecdotal and without technical merit."

Apparently, the latter approach was adopted, and the potential for erosion was ignored.

The IFT was approached by the registered civil engineer who in his capacity at the time, was asked to review the Motion to Intervene. He informed the IFT that the purpose of the review was to:

> "…determine whether it included new technical analyses that would lead one to doubt the decisions that drove the design of the Oroville Facilities….. In drafting the SWC/Metropolitan response to FOR's filing, I relied on the assumption that the dam designers used appropriate safety factors in their design and that geologists that oversaw the construction competently inspected the dam foundation preparation to assure that it supported the assumptions used in designing the weirs."

Thus, as with the 2005 DWR review, there was no actual technical questioning by the SWC of the geologic conditions downstream from the emergency spillway weir.

3.14 2009 Emergency Spillway Erosion Study

Another review of the conditions downstream of the emergency spillway was undertaken in 2009. This was in response to a concern raised by the FERC in their comments on the Seventh Independent Consultants' Safety Inspection Report. This report had recommended evaluating the effects of deposition of eroded material from the use of the Oroville emergency spillway on the downstream Thermalito Diversion Dam reservoir.

The result is a memorandum from DWR Engineering (Dams and Canals Section) to DWR Operations and Maintenance, dated April 21, 2009 [C-32]. This work estimated the volume of erosion that could be expected downstream along the emergency spillway, and references both the 2005 memo and the original 1962 investigations. However, the work apparently started with the premise of the 2005 memo that the foundation was considered "an excellent and competent spillway rock," and that "only soil and decomposed rock" is erodible. The 2009 Report includes this statement:

> "That memo (DWR 2005) also describes from an engineering geology point of view that there is 'an insignificant amount of top soil' overlying the bedrock. In that context, 'insignificant' means that even if the reservoir water were to flow over the Emergency Spillway, the water would very quickly encounter solid bedrock on the downstream side of the spillway, and as the thin mantle of soil would be eroded away, the rock would remain very resistant to erosion. Typical drilling logs and core samples are shown in Figure 5 and Figure 6."

Interestingly, the one typical log from downstream along the alignment given in the report (173RS) is referenced as coming from the 2005 report, however this is an apparent error – it does not appear in the copies of the 2005 report available to the IFT. That particular borehole log is from the 1962 report, which was obviously researched to a greater extent than in 2005: the 2009 report accurately quotes from the original 1962 text, and also accurately summarizes borehole information in a table documenting depths of "soil and decomposed rock" and depths of "strongly and/or moderately weathered rock," up to 36.5 feet, which is in direct contradiction to the statement quoted above.

The IFT learned through interviews that the DOE was given about 200 hours for this study, with 20 hours allotted to the DOE Project Geology group to look up old reports and to give an opinion on what was erodible. Thus, there was adequate time to properly access the downstream information that was overlooked in 2005. However, the stark disparity between the 1962 information and the basis of the 2005 claim was not recognized, nor apparently reviewed. By quantifying the amount of expected erosion upon use of the emergency spillway, this memorandum effectively sealed the impression that only an average of 4 feet of “soil and decomposed rock” will be erodible and wash into the Feather River if the emergency spillway operates, and this impression is apparently carried forward in later PFMAs and various project reviews without question.

3.15 IFT Findings in Subsequent Interviews

The IFT had the opportunity to interview a number of persons involved at the time of the 2005 and 2009 reviews of spillway foundation conditions. The individuals involved with this work are “2nd generation” geologists at DWR, without having had direct involvement with any of the original investigations and design. A number of relevant facts and opinions emerged:

2009 Erosion Study [C-32]:

- The principal DOE author of the 2009 Erosion Study depended on all of the previous descriptions and did not question the data in the borehole logs.
- DOE was specifically tasked to look at only the erosion potential of the soil and completely weathered rock. There was never any discussion whether or not strongly weathered rock would erode. There was also no inclination to do additional investigation due to workload and time constraints.
- O&M had a preconceived notion that only this material would erode, based on the 2005 Review by DOE (the same group, but not the same individuals tasked with the 2009 study). O&M commented that they relied on DOE, and would not “go back and second-guess” the DOE Project Geology group.
- The 2009 study was not peer reviewed in detail.

2005 Review [C-30]:

- There was no time available to do any assessment or evaluation during the preparation of the 2005 memo: it was essentially an exercise of gathering the series of borehole logs and plans, and writing the memo. From various interviews, it was apparent that there was a great reliance on previous recollections and impressions. The DOE Project Geology group agreed to answer the FERC request within a few hours “because there was a longstanding level of confidence in the rock …”
- Prior to the 2005 review, no one in the Project Geology group had looked at any geologic details. Impressions had been made on geology staff by those who had been there. They had “heard all the stories” from those who had been involved, and had previously relied on these. The following represents this “oral history”:
    - The general impression from the original exploratory trenches by bulldozer in the 1950s was that the rock was good quality, sound and firm. In hindsight, interviewees admitted that these trenches would have only been on the order of 3-5 ft. depth, so this interpretation does not seem credible. However, this was the impression at the time.

  - Following the trenches, a number of seismic refraction surveys were run, showing relatively high velocities in the upper velocity layer which seemed to confirm the initial impressions (however, this is not borne out in review of the 1964 Interim Geology report).
  - Results from the borings were seen as representing localized conditions, not as a fatal flaw.
    - These first three points above, based on oral history, are in contrast to the 1964 Report, which as previously noted, clearly states "Since drill hole data are more reliable than seismic data, 'Depth to Sound Rock' as presented in this report is based primarily on drill hole data."
  - There may have been bias, because all the boreholes were located along a topographic low, with the assumption that rock conditions would be somewhat worse along this alignment than an average across the entire width of the emergency spillway chute.
- There was not believed to be any reason to question, or check this mindset. Collective thinking was that the rock was overall good quality, and that there just was not enough poor quality rock to be a problem.
- Bill Akers (signator to the Final Construction Geology report) moved into DSOD in his later career and was active until 1984; he was highly respected and had a large influence. He never raised any concerns regarding potential erosion.
  - The IFT can find no evidence that Mr. Akers was involved with either the 1962 or 1964 investigations, nor was he a member of the on-site geology team during construction. Although stationed in Sacramento, one assumed he would have been aware of the major issues and construction claim involved with the service spillway, but would have been on the side arguing that the foundation conditions were fully acceptable. One long-retired employee who knew Mr. Akers remembers much discussion regarding the required foundation cleanup, but not the details. He noted that Mr. Akers used to boast that DWR had as many geologists in the 1960s as the Corps and Bureau combined.
- There was agreement that the relevant issue with respect to erodibility is not necessarily only the degree of weathering, it is joint spacing and condition. The significance of the jointing was not recognized – although simple in hindsight, it is not necessarily apparent in the reports, only the borehole logs.
  - The full descriptions are only prominent in the detailed borehole logs, and as these were never reviewed by any "2nd Generation" geologist in any detail, the significance of the jointing and other rock mass properties was missed.
- When asked directly by the IFT, no opinion was given as to why any geologist would interpret strongly weathered, strongly fractured, very soft or soft rock with open jointing as being non-erodible.

During its investigation, the IFT found that there still seems to be a reluctance to believe the rock condition was misinterpreted or misrepresented, and there is an apparent willingness to defend the geological interpretation. A number of interviewees were quick to note that the rock held up well to erosion where confined, and that blocks did not necessarily erode until they toppled and shattered. Others expressed disbelief in the possibility of the severity of erosion until they had actually seen it occur, and one opined that “nothing” could have withstood the flow.

4.0 SUMMARY

The misconceptions regarding the erodibility of the bedrock along the two spillway alignments are central to the development of the Oroville incident. It is now clearly evident that actual bedrock conditions, and the implications of those conditions, were well documented prior to and during construction, but there was no post-construction recognition of the weathering potential of the rock types present at Oroville. Detailed and accurate information was not properly accessed in subsequent years; rather, inaccurate and incomplete summaries of information were passed on through generations of DWR personnel.

There is reasonably common knowledge in current geological practice that foundations involving the rock types present at Oroville (amphibolite, greenstone, ophiolite) might point toward a particular susceptibility for pronounced weathering, and that the weathered by-products would be vulnerable to erosion. Since the 1980s at least, based simply on regional geological mapping, a qualified engineering geologist should have been able to recognize this potential. However, there apparently was never any attempt to have a new look at the data in order to make that interpretation.

The earliest geological site investigation reports from 1948 clearly recognized this issue, and actually proposed a solution for the emergency spillway that is now being utilized in the remediation works – a deep cutoff to fresh rock. More detailed investigations, reported in 1962, properly and fully described the typical deep weathering pattern in bedrock, and clearly recognized its very irregular pattern, noting that “weathered rock will of course be subject to relatively accelerated erosion; where this is critical, the rock should be protected.” The descriptions in the borehole logs are detailed and very precise, and even a cursory inspection of these logs clearly indicates the significant depths of strongly weathered, strongly fractured, soft rock with open jointing, covering a range in quality that was described as “poor to fair” rock conditions. The IFT believes that any even relatively unexperienced geologist or geotechnical engineer today would consider these “poor to fair” conditions as being very erodible, as did the first geologists onsite in 1948. However, this detail is lost in the summary logs and sections reproduced in later reports.

The same degree of care and professionalism is evident in the production of the borehole logs, and geological descriptions during further investigations in 1964. However, there appears to have been a major change in opinion regarding the geotechnical acceptability of moderately weathered rock. The 1964 updated conceptual service spillway chute profile shows a large portion of the chute founded on moderately weathered rock, which was now considered to be an adequate foundation for most of the structures, although it “may require some special treatment.” The required special treatment was not defined in the report.

Comments made in 1962 on potential scour were not carried forward to the 1964 report. However, from comments in the 1964 report, the geologists were certainly aware of scouring as a failure mode. It is likely that the geologists were relying on the spillway chute designers to provide adequate protection for the poor foundation, while the designers were relying on the geology to provide a good, solid foundation, as was indicated in IFT interviews.

The 1964 report also recommends an underdrain system to be built upon the invert. Evidence suggests to the IFT that the purpose of the drains was mainly, or solely, to deal with potential seepage from the bedrock. Thus, the same report that very professionally describes the poor to very poor geological conditions at the proposed invert elevation of the service spillway, fails to connect the geological descriptions with the potential for scour of the rippable rock due to flow in the underdrains. Regardless, it is evident that prior to construction, there was never any intention of founding the slabs or placing the underdrains on a strongly weathered rock foundation.

The 1964 report states "… most of the non-rippable rock will be adequate for this structure," inferring that the moderately weathered rock would be non-rippable. Likely based on this assumption, specifications for the spillway chute excavation did not explicitly cover the conditions in which moderately or strongly weathered rock could be easily removed without heavy-duty power excavating equipment beyond the excavation limit lines. A 1965 design review pointed out that "backfill concrete will probably be required for the purpose of filling deeply weathered pockets," but fails to recognize that the specifications do not adequately cover the situation of rippable rock below the grade line of the excavation.

There was a major claim by the Contractor during construction related to the change to the drain design and over-excavation required. DWR clearly documents that they originally took the position that any excavation with heavy power equipment beyond the minimum excavation limit lines would not be payable. However, it was later agreed that payment was due for all shear-zone excavation and the concrete backfill costs for material so excavated by heavy duty power equipment. This is likely one reason why the shear zones were carefully mapped and individually numbered. However, the agreement did *not* include areas of highly weathered rock.

It is clear that portraying foundation conditions at invert level as being acceptable was central to DWR's defense against the Contractor's claim of poor rock conditions. It remains speculation as to whether a DWR organizational reluctance to acknowledge out-of-specification foundation conditions, and instead to consider the encountered rock conditions as being acceptable, became entrenched as part of oral organizational history. The final construction reports simply state "In the chute, there was very little extra excavation directed." The report also either did not recognize, or chose not to comment, on the fact that the anchor tests were not conducted in the worst foundation as stated, but rather the "worst foundation available" at the time of the tests, prior to exposing the moderately to highly weathered areas.

The detailed borehole logs containing the accurate descriptions of the moderately to highly weathered bedrock are given in the 1962 and 1964 Interim Geological reports, but are omitted from the Final Geological Report. The opening description of the Final Geological Report, when read in isolation from the remainder of the report, describes very favorable foundation conditions, and this depiction may be a major factor in the ensuing misinterpretations of bedrock conditions.

In the early to mid-2000s, as part of the Oroville Dam re-licensing process, external groups questioned the safety of the emergency spillway due to the potential for bedrock erosion, based on the original records and reports. DWR was requested by the FERC to investigate this, and a very brief review was undertaken. It was essentially an exercise of pulling together a series of borehole logs and plans, and writing a short cover memorandum. However, all of the detailed information that was supplied to the FERC was from the crest area of the emergency spillway, apparently in support of the claim of acceptable foundation conditions for that structure. Six of the nine borehole logs showed significant depths (22 to 44 ft) of poor to fair rock, moderately to strongly weathered, moderately hard to soft rock conditions. No detailed information whatsoever was provided for the area downstream of the overflow weir. Regardless, the position is taken in a 2005 DWR memorandum that solid amphibolite extended "from the spillway crest down to the Feather River." It seems apparent that there was a great reliance on the recollections and impressions from previous generations of DWR geologists. The major inconsistency between the borehole logs as presented and the claims made in the memorandum was not recognized by either DWR or FERC. To the IFTs knowledge, no work was ever been done, either internally or externally, as a check against these claims.

A study was undertaken in 2009 to quantify the expected erosion upon use of the emergency spillway, specifically to look at the erosion potential of the soil and completely weathered rock. Although the actual detailed geological descriptions were accessed for this work, the stark disparity between these descriptions and the basis of the 2005 claim was not recognized. Neither the 2005 nor the 2009 work was apparently peer reviewed in detail. By quantifying the amount of expected erosion upon use of the emergency spillway, the 2009 work effectively sealed the impression that only an average of 4 feet of "soil and decomposed rock" would be erodible and wash into the Feather River during activation of the emergency spillway, and this impression is apparently carried forward in later PFMAs and various project reviews without question.

Had the recognition of the weathering potential of the rock types present at Oroville been made at any time post-construction, it should have led to (1) questioning if such conditions had been properly recognized and managed during design and construction (e.g. making appropriate adjustments in excavation depths, anchor lengths, or other measures); (2) questioning the erodibility of the foundations, particularly if there is knowledge that weathered materials had been left in place; and (3) questioning whether the slab design was suitable for as-built foundation, given the presence of weak and erodible foundation materials.

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