

Engineering Files

Berkeley, Dec. 1st, 1924.

Arthur P. Davis,
Chief Engineer,
East Bay Municipal Utilities District,
505 17th Street,
Oakland, California.

Dear Sir:

Under your guidance I have made a geological examination of certain alternative dam sites on the Mokelumne River and beg to advise you concerning them as follows:

The dam sites examined are known as Lancha Plana Nos. 1, 2, 3, and 4 the profiles of which have been determined, and the particular question put to me was: Are there geological conditions which make any one of these preferable to the others? Dam site No. 2, I was informed, is not satisfactory from an engineering point of view and has been rejected. Consideration was, therefore, limited to Nos. 1, 3 and 4. All the sites are situated in the narrow gorge of the Mokelumne River in a section a little more than a mile in length, No. 1 being at the upper end of this section and No. 4 at the lower end, with No. 3 in an intermediate position; and any one of the three may be utilized with equal effect as to the impounding of the waters of Mokelumne River in the proposed reservoir and raising the level in that reservoir so as to divert the waters to Jackson Creek. The choice of site depends on three factors: (1) The optimum of geological conditions. (2) The cost of construction of dam and supplementary structures. (3) The cost of properties which it may be necessary to acquire. At dam sites

Nos. 1 and 3 the third of these factors does not enter. No. 4 is below certain mining claims which would be flooded and which would therefore have to be bought if this site were finally chosen. The second factor determining the choice is a question for the engineers charged with the design of the dam, aqueduct, etc., and I shall not attempt to discuss it. The first factor, the suitability of site from a geological point of view is the same for sites Nos. 1, 3 and 4. The conditions at all three sites are equally good and leave little to be desired in the way of strength, security and reliability of foundations and abutments. The rocks at all three sites are sound, undecomposed, strong, impervious, metamorphic schists of the Bed-rock Complex of the Sierra Nevada. Originally these were sedimentary strata partly volcanic and partly detrital and the stratification is still very apparent. The schistosity which has been imposed upon the strata by reason of the metamorphism to which they have been subjected is parallel to the bedding. The strike of the beds and of the schistosity is transverse to the course of the river, and the dip is in all cases up stream at angles a little over 60° at sites Nos. 1 and 3 and 72° at site No. 4. At all three sites the rocks are splendidly exposed in the walls of the canon and there is almost no overburden to be removed to reach the firm rock. The excellence of these exposures removes all conjecture as to the nature and condition of the rocks; and the statements here made in regard to these matters are statements of observed facts and not merely opinions. There is no danger of landslides at or near any of the three sites. There are no active faults, and the seismic record of the region indicates that it is stable, and that the risk of damage from earthquakes is as small as could be found any-

where on the surface of the earth. The rock at all three sites is entirely solid and free from open spaces and there will be no appreciable seepage thru the rock. The joint systems which traverse the rock are non-persistent cracks which do not permit the transmission of water for more than short distances.

It would be difficult to find more satisfactory conditions for the foundation and abutments of a dam than those which are presented in this section of the canon of the Mokelumne River. At none of the sites are there any adverse conditions to be overcome. Since no discrimination can be made between the three sites under consideration on the basis of geological conditions, the choice of site must rest upon engineering considerations and costs.

You called my attention in the field to the fact that if dam site No. 1 is chosen a low supplementary dam, serving as a spillway, would be necessary on the lowest part of the crest of the ridge to the southeast of the main dam. This supplementary dam would have an excellent foundation of greenstone schist, and the water spilling over it would flow down a steep slope across the strike and dip of these rocks for a few hundred feet before encountering a belt of softer slates. The softness of the slates is largely a superficial character due to weathering. In my opinion the rocks both greenstone schist and slates are competent to withstand the erosive effect of the spill, and there is no danger of a rapid cutting back so as to undermine the spillway dam. The cutting effect of the running water free from detritus upon these rocks will be very slow, and, after the loose surface

material has been washed away, would be scarcely appreciable in a period of say 10 years. The rocks below the zone of weathering are just as competent to resist the action of the rapidly flowing clean water as would any concrete veneer that might be placed upon them to protect them.

I have the honor to be

Yours sincerely,

(Signed) Andrew C. Lawson.

GEOLOGY OF PARDEE DAMSITEGEO. W. LOUDERBACK, GEOLOGIST.

The rocks of the gorge of the Mokelumne River in which the dam is located were originally a series of volcanic breccias, ash beds, lava flows, and terrigenous and mixed sediments which have been subjected to strong compression that has deformed them so that they now dip at high angles to the northeast, 55° to 84° , the sediments show the development of a slaty character, and the volcanic members have suffered to a greater or less degree changes in mineral composition sometimes called the greenstone type of alteration. The compression has also given rise to more or less of cleavage, well developed in the fine-grained terrigenous sediments, less well developed in the fine volcanic sediments, and still less developed in the coarser pyroclastic and massive volcanic layers. Throughout the area examined, this cleavage lies in the same planes as the stratification, and these planes are referred to in this report as the stratification-cleavage planes or surfaces.

The tilted layers strike from about 24° to 42° west of north, that is, obliquely across the river. As a result of this, any line drawn directly across the river, (at right angles to the stream course,) will in general not strike the same layer on the two banks, but any given layer will appear on the north bank farther up stream than on the south bank. As a further result, the layers do not run directly up the canyon sides, but obliquely, so that they are found farther west the farther they get from the river. This effect

is particularly marked to the south of the river, as is shown on the accompanying map. It is evident that the dam, which is to be placed transverse to the course of the river, will cross a number of layers obliquely, and many of these layers will pass out from under the dam on its east side and form part of the floor of the reservoir.

For the purpose of this report, the layers of rock have been roughly grouped into divisions which vary from their neighbors in lithologic characters and structural details, and therefore in engineering relationships. They are referred to here and on the accompanying map by numbers, sometimes with a letter attached to denote subdivisions.

DIVISION 1. Starting at a prominent outcrop on the south side of the river about 200 feet upstream from the dam location is a volcanic tuff carrying small lapilli usually less than one half inch in diameter. This originally fragmental rock is now well consolidated and indurated and up to about 250 feet above the river level yields prominent resistant rocky outcrops. It is tough and rather strong.

Fissures traverse the rocks of this division in various directions and separate it into rather large blocks.

(a) An important system of cracks follows the stratification-cleavage planes, striking $N32^{\circ}W$ and dipping $68^{\circ}-70^{\circ}$ NE. The width of the blocks at lower levels between these fissures varies usually from one to six feet, sometimes narrower. The number of

narrow blocks increases as the weathering increases, that is, as one goes higher on the canyon sides. For the higher parts of the canyon sides have been exposed to weathering longer than the lower ones. This is the reason that the prominent rocky exposures die out above the 450 foot contour.

(b) A cross fracturing occurs that strikes about $N 45^{\circ} W$ (somewhat variable), and dips on the average about $32^{\circ} SW$. This produces at the lower levels broad, flat, but usually not smooth separation planes that run for various distances: one face measured 15 feet down the dip, another 40 feet. Some of the cracks could be traced 50 feet or more. The dip varies from 20° to 40° .

(c) Another common direction of fracturing is $N 38-48^{\circ} E$ with approximately vertical dip. This produces more uneven faces than (b). The cracks lie a few inches to several feet apart.

(d) Other fissures are found, some of which are more or less prominent, but they do not fall into regular sets. For example, one $N 70^{\circ} E$, dip $55^{\circ} N$ was traced for 60 feet.

Near the western limit of Division 1 is a subdivision showing a coarse fragmental character, and carrying original volcanic blocks 3 to 5 inches in diameter, sometimes larger. This is indicated as 1A. It is followed to the west by a fine grained rock marked 1B. The structural relations of these subdivisions are similar to the main belt 1, but they are usually not quite so resistant to weathering. Subdivision 1A however often yields rather prominent resistant outcrops.

As they rise above the 500 foot contour all of the parts of Division 1 show practically the same weathering and jointage phenomena.

Division 1 (including 1A and 1B) crosses under the dam location diagonally, to the south of the river, and roughly between the 550 and the 500 foot contours. On the north side it is entirely east of the dam location.

DIVISION 2. To the west of division 1 is a belt of thin-bedded rocks that were originally largely fine ash deposits, probably laid down under water and subjected to more or less current sorting. In certain streaks there is evident admixture of more or less terrigenous sedimentary detritus — earthy muds. The deposits of this division are well consolidated and show a more marked development of slaty cleavage. This is best developed in the original muds which are now definitely clay slates. The grain of the different layers varies, fine, very fine, and aphanitic layers alternating.

The more purely volcanic parts of this division commonly split off in thin layers parallel to the cleavage planes, and plates from 2 to 3 inches down to an inch or less in thickness are common. Some layers, more even grained, and without slaty streaks, give blocks a foot to a foot and a half across.

Four subdivisions may be recognized in a rough way:

2A. The easternmost part is largely of volcanic detritus and holds together fairly well.

2B. The next subdivision is chiefly of volcanic detritus, is better consolidated, is finer in grain, and breaks into coarser slabs.

2C. This subdivision is chiefly of volcanic detritus, but with admixtures or intercalations of earthy material as slaty streaks. It

is thinner bedded and breaks into thin plates, and in part shows a well developed slaty cleavage into thin sheets.

2D. Subdivision 2C grades into a fairly pure clay slate with cleavage into very thin layers well developed. There are occasional thin streaks or admixtures of volcanic detritus, but in minor proportion. In general this slate band is about 15 to 18 feet thick.

The slate band carries a number of quartz veins varying in thickness from a fraction of an inch up to six inches or more. The veins lie almost entirely in the stratification-cleavage planes and mostly in the upper (or eastern) part of the slate band.

A layer of gouge runs down through the slate band roughly parallel to the stratification, varying in width from an inch to several inches. It is usually soft and clayey and in part encloses an easily friable granular quartz streak that is evidently a crushed quartz vein. Pyrite is also found scattered through the slate.

This slate belt is a mechanically weak zone, and the fresh gouge indicates a movement of dislocation in comparatively recent time.

While the slate band is everywhere narrow, it is persistent and has been traced up the south side of the canyon to beyond the 575 foot contour. At the base of the slope south of the river it lies in the trench made for the cut off wall, and on its way across the river leaves the wall line diagonally, and passes into the floor of the reservoir. It strikes the north side of the river about 50 feet upstream from the cut off wall line. It then passes up the north side of the canyon and was traced up to the 550 contour. To the north of the river it is en-

tirely on the upstream side of the dam and from 30 to 150 feet away.

The better exposures show that the lower (or western) part of the slate band, near the contact with Division 3, has been broken and sheared, and about 5 to 7 feet from the contact is a line of clay gouge, now dry and rather hard.

On the south side of the canyon, the slate belt cuts obliquely across under the dam between the river and the 350 foot contour.

DIVISION 3. To the west of the slate is a massive fine granular rock of igneous origin that may have originally been a lava flow. Its exact nature could probably be determined by microscopic examination. It is fairly uniform in texture and composition.

The fractures in this massive greenstone are widely spaced and at irregularly varying angles. A definite series of fissures corresponds to the stratification-cleavage directions of the region, and at 25 feet from the slate contact (on 260 foot contour) was measured as N 32° W, dip 62° NE. Occasionally these fracture planes are well developed, but usually are not smooth and often not very flat (plane). They are irregularly spaced.

A fracture direction striking about N 28° E and dipping 10°-15° W gives occasionally broad surfaces along which the rock breaks off in ledges. A transverse fissure N 50° E with dip 76° NW gives rather even surfaces. Another direction with strike N 22° W and dip 20° W develops a number of smooth faces up to 30 or more feet across and showing

some movement of the blocks down the dip. Such a movement would carry the blocks down the canyon obliquely towards the river.

Other directions of fracture were observed, not falling into groups but irregularly oriented, and were not individually measured.

At lower levels in the canyon, the rock of Division 3 is broken by these various fractures into large irregularly polygonal blocks from a few inches to 10 or 15 or more feet across.

On the south side of the river and just west of the slate belt, this massive greenstone shows a bulge to the east between the river and the 290 foot contour that has pinched somewhat the slate belt and caused it to mold itself over the top of the bulge and overthicken to 25 or more feet and show a certain amount of distortion. The greenstone in the "bulge" area has been transversely fractured and the fractures have been filled with quartz veins. Many of these veins run back from the slate contact, branch irregularly and join other veins or die out. They are mostly narrow but occasionally reach 4 or 5 inches in thickness, and one intersection shows 10 inches of quartz. The veins stop short at the slate contact and do not enter the slate. Strangely enough the part of the slate belt near the contact carries almost no vein quartz. Within the massive greenstone most of the veining is within ten feet of the slate contact although some of the larger veins run out 25 or 30 feet.

The described phenomena of the bulging, fracturing and veining of the massive greenstone, and the bending, pinching, and swelling of the slate, evidently means local mechanical deformation. It probably

took place when the region suffered its original folding deformation that turned the beds into their present high dips. The complete healing of the greenstone fractures with quartz and the absence of reopening phenomena, indicates a relative antiquity. The movement indicated by the gouge in the slate band is much later and unrelated.

The rocks of Division 3 are exposed along the river on its south side for about 150 feet and at this elevation will be entirely covered by the dam. Going up the south side of the canyon above the bulge and belt rapidly narrows and passes out from under the dam between about the 270 and the 340 foot contours.

North of the river. To the north of the river, Division 3 is the chief belt underlying the dam. Very striking are certain broadly developed fracture planes giving rise to broad, rather smooth surfaces, some of which have recently been cleaned off and exposed. They are best developed in the first 200 feet above the river, as above that the rock becomes more platy and appears less massive, due to the action of weathering in developing a larger number of cracks and fissures along the stratification-cleavage planes. One of the striking cross fracture surfaces strikes $N 38^{\circ} E$ and dips $39^{\circ} SE$, and gives a slope of the fracture plane towards the river. Other similar planes occur at somewhat different attitudes. As noted south of the river, there are indications that movement has taken place on these fracture planes, but the slopes involved on the north side are steeper and longer than those on the south.

As mentioned above, some of these faces have already been stripped but at the time of my visit there was still a large mass of

material just along and to the east of the eastern line of the dam, and extending between the 260 and the 450 foot contours (limits not accurately determined) which lay over such a face. It represents material that has previously moved, and is disturbed and broken in such a way that it has the character of "unconsolidated" material, and under favorable conditions might move or slide in part or as a whole. Two factors that would tend to start movement are: (1) thorough wetting of the old movement plane or planes, (2) removal of support by cutting into lower part. At present the planes seem rather dry; the rains of this winter have apparently not penetrated to any great extent. It will apparently be necessary to cut into the lower part of the slide material in constructing the dam. It may be that the dry condition of the movement planes will frictionally hold the material even if part is cut away. The result may depend on the rainfall during the next month or two.

DIVISION 4. To the west of Division 3, south of the river, the rocks become more distinctly bedded again and break up into thinner layers along the stratification-slaty cleavage. Not, however, to the extent of Division 2. The belt is moderately massive and breaks into fairly large blocks along cross fractures, such as one N 60° E with dip 66° NW, and others N 75° E with dips of 27° more or less. This division underlies the toe of the dam from about the 270 contour south of the river to the 320 foot contour north of the river.

DIVISION 5. West of belt 4 the rocks again become more massive. As this division is entirely west of the dam no further description is given.

DIVISION 6: The upper part of the dam south of the river will lie on a formation that was not studied along the river. It lies east of Division 1 and cuts diagonally across the dam line. It will underlie the dam above contour 450. It is a volcanic sequence, moderately massive, and shows the dominant fracturing in the stratification-cleavage plane, which in the cut near the south end of the dam location strikes $N 30^{\circ} W$ and dips $61^{\circ} NE$. Where crossed by the dam it is at a high altitude and has suffered more from weathering than the formations lower down.

GEORGE D. LOUDERBACK (Signed)

NOTE. In the accompanying map the tracing of the lines up the sides was not done in any detail on account of limited time. They are believed to be approximately correct. The topography represented on the map was considerably altered on the ground by the extensive excavations that have been made and the stripping of part of the dam site. Locations were therefore difficult to make, and the plotting of the geology has been done to represent as nearly as could be estimated the conditions as they were before the recent topographic changes.