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The Relationship of Pyrite Oxidation in Rockfill to Highly Acid Water at Corin Dam, A.C.T. Australia

by

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ABSTRACT

Study of a spring which appeared below Corin Dam as the reservoir filled led to the discovery that the water was highly acid. An integrated investigation by an engineering scientific team showed that the acidity was produced by the oxidation of pyrite in the rock-fill of the dam embankment. The oxidation was accelerated by the presence of abundant phosphate and nitrate, which stimulated activity of thiobacilli. It is considered that the formation of acid water by such processes may result from engineering construction activity more commonly than is generally recognised.

RESUME

L'étude d'une source qui apparut sous le barrage de Corin au cours de son remplissage fit découvrir que cette eau était fortement acide. Une expertise menée par une équipe d'ingénieurs spécialisés montra que cette acidité avait pour origine l'oxydation de la pyrite contenue dans le matériel utilisé pour l'enrochement du barrage. L'oxydation était accélérée par la présence d'abondants phosphates et nitrates qui stimulaient l'activité de thiobacilles. On considère que les techniques de construction peuvent engendrer par de tels processus la formation d'eau acide et cela beaucoup plus fréquemment qu'il n'est généralement admis.

INTRODUCTION

Corin Dam is the largest of three dams on the Cotter River that supply water to the Australian capital, Canberra. The dam was completed in 1968; it is 40 kilometres south-west of the capital.

Corin Dam is at latitude 35°32'S and an elevation of 900 metres above sea level. The climate is temperate; average mean daily temperatures range from 24° Celsius maximum and 11°C minimum in January to 8°C maximum and -0.5° minimum in July-August; the maximum diurnal temperature range exceeds 25°C. Average rainfall is 90 centimetres and, on average, this rainfall is fairly evenly distributed throughout the year; humidity generally is moderate to low.

The dam is 75 metres high, has a crest length of 278 metres, and contains 1.42 million cubic metres of placed fill. It is a conventional central earth-cored rock-fill dam (Figure 1). During construction waste earth and rock from excavations was placed against the downstream toe of the dam to RL 2930 (feet) for disposal and landscaping purposes. The spoil dump in this position was not part of the original design; it is shown in Figure 1.

Corin Dam was designed by, and built under the supervision of, the Commonwealth Department of Works. Engineering geology services were provided to the Department of Works by the Bureau of Mineral Resources, Geology and Geophysics.

Geological services included all aspects of preliminary and detailed feasibility studies, design investigations and construction services except the proving of and quality control for earth materials and some aspects of rock material testing. The construction services were continuous. Engineering geology services throughout all but the preliminary feasibility investigations were provided by Mr. E.J. Best, from whose unpublished completion report most of the relevant information on engineering geology was drawn for this paper (Best, 1967). Systematic geological investigations began in 1961, construction started in April, 1966, and the reservoir started to fill in May, 1968. By December, 1968, the reservoir was within 30 feet of full supply level; water spilled for the first time the following winter (July, 1969).

GENERAL GEOLOGY AND GEOMORPHOLOGY

The dam is situated in a north-trending youthful valley with a general V-shaped profile, exhibiting valley-in-valley structure; at the damsite the relief between the valley floor and the flanking ranges is from 600 to 900 metres.

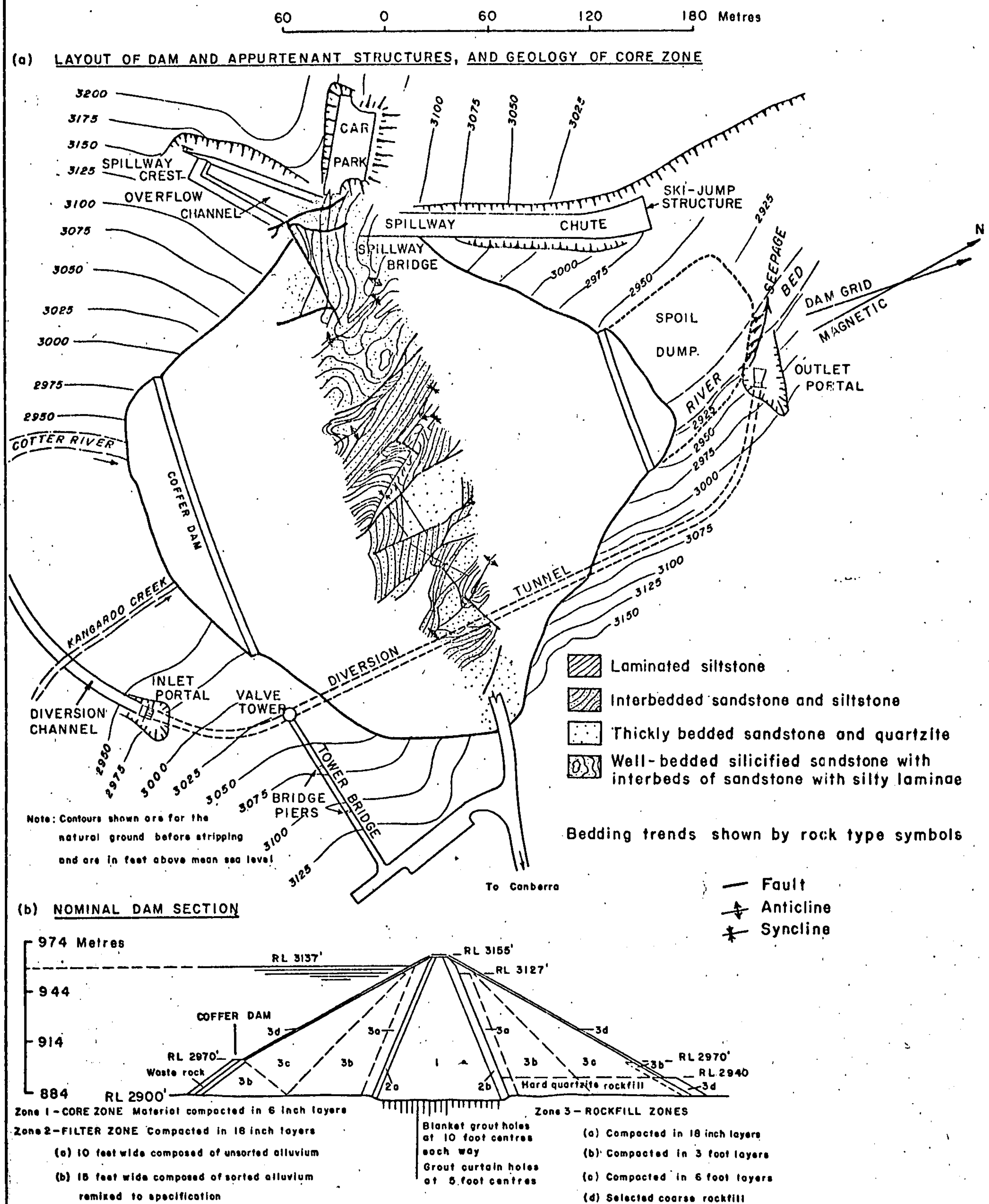
The terrain in which the dam is sited is of strongly folded and faulted Ordovician and Silurian rocks with intrusive Middle Palaeozoic granitic plutons within 2 kilometres, to both east and west; smaller quartz porphyry bodies occur within the reservoir. The course of the upper Cotter valley is controlled by a reverse fault which passes about 130 metres to the west of the western end of the dam crest; the fault dips steeply west.

The region has been subjected to erosion since late Palaeozoic time, since when crustal movements have been epeiric in character. The geomorphological history of the area has therefore been complex, with periods of strong warping and uplift and intervening periods of stillstand. The present relief in the area is due to late and post-Tertiary uplift and warping. Because of the complex geomorphological history, weathering is complex and varies greatly from place to place.

ENGINEERING GEOLOGY

The foundations and abutments of the dam consist of hard, generally strong, and slightly metamorphosed Ordovician sediments. The main rock types present are thick-bedded silicified quartz sandstone (quartzite in part), well bedded sandstone with silty laminae, thinly interbedded sandstone and siltstone, and laminated siltstone (see Figure 1). The siltstone is well cleaved in places. Unconfined

CORIN DAM — GENERAL ARRANGEMENT FIG I



BUREAU OF MINERAL RESOURCES: CANBERRA A.C.T. 155/A16/607 compression tests of typical slightly weathered to fresh foundation rock gave dry strength in the range 898 to 2130 kilograms per square centimetre. Pyrite is common in the foundation rocks but is not abundant: the percentage of pyrite is probably similar to that in the quarry (about 1%). The pyrite occurs as single cubic crystals, as clusters of crystals, and pods and irregular patches of disseminated pyrite. Sparse base metal sulphides are also present.

The sediments are strongly, but irregularly, folded: bedding dips are generally greater than 45°. Six major faults affect the foundations, as shown in Figure 1. Only one fault proved to be of little engineering importance. In addition, the foundation rocks are dislocated by innumerable minor faults, and are generally closely jointed. The exploratory diamond drilling showed that fresh rock has a fracture density generally in the range of 10 to 30 fractures per metre of drill core, and greater in sheared and fault zones; weathered rock (see below) is, of course, more closely jointed and fractured. Joints in sandstone tend to be more open than those in siltstone.

Weathering is controlled almost entirely by fractures, the fresh rock material being almost impermeable. Seismic work and diamond drilling at the investigation stage showed that open joints and associated weathering extend from 15 to 45 metres vertically below the surface. Water loss at maximum pressure during water pressure tests of drill holes generally ranged from 3 to 30 litres per minute per metre of hole length. Weathering, particularly in the siltstone, had generally produced clay seams in fractured zones.

Rock for the dam embankment was obtained from a quarry about 1.5 kilometres from the dam. The quarry is in the same succession of rocks as the western part of the dam foundation. A representative stratigraphic section of the material quarried for fill, together with the estimated pyrite content for each rock type, is given below. The pyrite content was determined by a point count of grains in samples of each rock type, taken at 6-metre intervals, and should therefore be regarded as an indication only of pyrite content.

15 metres +	Interbedded sandstone and siltstone - 1 sample, 1.0% pyrite.
29.9 "	Thickly-bedded silicified sandstone (quartzite) - 5 samples, 0.50 - 1.42% (average 1.2%) pyrite.
19 " +	Well-bedded silicified sandstone (quartzite) - 3 samples, 0.42 - 0.05% (average 0.2%) pyrite.

The pyrite was most abundant in and near faults and commonly occurred as films along cleavage and joints; base metal sulphides were also present. An intrusive body of quartz porphyry forms the south-western limit of the quarry.

Filter zone materials were obtained from small deposits of river alluvium in the reservoir area.

Seventy percent of the core material used was weathered quartz porphyry from within the reservoir; the remainder was slope-wash material, largely derived from sediments, which overlay the weathered porphyry.

Foundation Treatment

Treatment of the foundations of the core and filter zones of the embankment followed, but was possibly more rigorous than, established practice. "Dental" treatment of defects in the surface of the foundation rock was most meticulous. The whole of the core zone was blanket-grouted to depths of either 4.5 or 7.5 metres, using a cement grout. A single-line grout curtain at centres of 1.5 to 3 metres generally extended into the lower-permeability zone located by the site investigation. Analysis of grout consumption showed that treatment had been conservative.

Groundwater Observation Holes

Two investigation drillholes were maintained, and one post-construction hole was drilled, as groundwater observation holes to give information on groundwater levels as the reservoir filled; the post-construction hole was designed specifically to monitor the possible movement of water along the Cotter Fault, which was not treated by grouting or other methods of sealing.

GROUNDWATER HYDROLOGY

The crystalline rocks of the catchment possess negligible intergranular permeability; the main storage and passage of groundwater occurs in zones of open-jointing and partial weathering. The permeable zones lie mainly at the base of the weathered mantle and around major faults.

The piezometric surface of the groundwater shows a regular pattern of major seasonal fluctuation: groundwater levels drop from about mid-October to mid-April and rise strongly from mid-April until about mid-October when the cycle begins again. The regular pattern of rise in winter and decline in summer is only interrupted in periods of serious drought; the interruption is most serious if it affects part of the recharge months between April and October. When severe drought conditions lead to failure of winter recharge the piezometric surface drops sharply and the normal groundwater flow pattern is distorted considerably. With the distortion of the flow pattern, the relationship between the bicarbonate waters, which are normal for the region, and sulphate-rich groundwater, derived from sulphide-bearing areas, is disturbed, and interaction takes place.

The salinity of the groundwater is generally low (150 to 500 parts per million total dissolved solids) and the pH close to neutral (6.8 to 8.1) see Table 1, Analysis 7). In some areas near Canberra where sulphide mineralization is noticeable, the pH is often about 5.0 (Table 1, Analysis 8).

The filling of the Corin Dam reservoir coincided with the end of the most severe drought on record. The distortion of the groundwater flow pattern to which the environs of the dam were subjected by the filling of the reservoir was therefore superimposed on an abnormal groundwater situation. For this reason departures from normal groundwater chemistry in the chemistry of the spoil spring waters were not amenable to simple interpretation.

INVESTIGATION OF POSSIBLE LEAKAGE

In June, 1968, when the reservoir was at R.L. 3007 (feet) - about 28 metres deep - a small spring appeared at the eastern edge of the spoil dump placed at the toe of the dam; it discharged into the old course of the river about 15 metres downstream from the outlet portal of the reservoir outlet tunnel. The flow was estimated to be roughly 0.005 cubic metres per second.

Although the flow was small, it was necessary to know whether the water, in fact, came directly from the reservoir and, if it did, which of the following it was passing through: a dam abutment, the dam foundations, the embankment, or at the interface of embankment materials and the dam foundations. Because of the masking effect of the spoil dump and the lack of internal instrumentation in the embankment and foundations, it was not possible to determine directly the source and path of the water forming the spring (which became known as the spoil spring). Documentation of the spring was initiated in mid-June, 1968, by the Department of Works and the Bureau of Mineral Resources. By November, 1968, the yield from the spoil spring had increased to an estimated 0.025 cubic metres per second. Increase in flow was roughly proportional to the rise in head of the reservoir, but leakage of water from the spoil dump increased temporarily after sustained heavy rain; as the reservoir level rose water also began to enter the concrete-lined outlet tunnel at a number of points, both upstream and downstream of the grout curtain under the core of the dam. At an early stage of the investigation the water from the spoil spring was found to have a high electrical conductivity and to be highly acid (pH 4.2 in November, 1968). It therefore became necessary to consider whether such waters, if in contact with either the earth core of the dam embankment or with the cement grout and concrete treatment of the foundations, might not cause unacceptable deterioration. The chemistry of the waters emerging from the spoil dump and the outlet tunnel (and later from a spring about 200 metres downstream from the dam, near the Cotter Fault which could reasonably be considered to provide the leakage path) became the main tool in studying and evaluating the origin, and likely effect on the dam structure, of the spoil spring water. Other techniques used, or attempted, by the investigators (not all successfully) were: gauging flows of emerging waters; surveys of the dam embankment for settlement; water temperature measurements; resistivity survey of the spoil dump; tracing of water movement below the spoil dump by sensitive microphones. The chemical work was supplemented by bacteriological studies.

The integrated investigation was carried out by geochemists, engineers, geologists, surveyors and geophysicists of the Bureau of Mineral Resources and the Department of Works. Outside assistance was obtained in some of the survey and bacteriological work.

Close observations were maintained until April, 1969, when a review by the authorities concerned and consultants led to the conclusion that, although concrete was undoubtedly being attacked, there was no threat to the dam embankment (as evidenced by a very satisfactory settlement curve) or associated concrete works. Periodic observations and tests are being maintained.

CHEMISTRY AND GEOBIOLOGY

Systematic sampling, with selected chemical analysis, measurement of acidity and electrical conductivity, and periodic water temperature measurements, was carried out at the spoil spring, four fixed leakage points in the outlet tunnel, groundwater observation holes, the reservoir, and later the spring near the Cotter Fault. Some 49 other leaks in the outlet tunnel were tested at least once. Conductivity and acidity were determined by instrument in the field to avoid losses of dissolved gases. These instruments proved to be of great value. Some representative analyses are given in Table 1.

Salient features of the waters observed in the course of the investigation include:

(a) Water from leaks in the outlet tunnel, and emerging from the tunnel in streamline flow, at an early stage covered the stream bed below the dam with a layer of calcium carbonate, derived by leaching from the newly placed concrete. When the spoil spring started to flow it displaced the water from the outlet tunnel to one side allowing the acid spring water to cover the carbonate deposits, which reacted to form a white encrustation of hydrated alumina with minor gypsum. In the early stages of the investigation this aluminous deposit covered the river bed for at least 500 metres downstream. It was later flushed out during testing of the outlet valve. Subsequently a rich growth of green algae developed in the bed of the river. Various encrustations and growths also appeared at leakage points in the tunnel, and these were studied chemically and by other means. The studies showed that the acid waters were attacking the concrete lining of the tunnel.

Table 1 - Analysis of water samples from Corin Dam

	1	2	3	4	5	6	7	8
Source	Quarry Drainage	Reservoir	Spring	Spring	Spring	Outlet Tunnel	Bore Canberra	Bore Williamsdale
Date	Nov. 28.'68	Nov. 28-'68	March 14-'69	Feb. 13-'69	April 16-'69	Nov. 28-'68		
pH	2.9	6.5	3.7	3.3	2.8	4.4	8.1	5.5
Sp.Cond.	1510	30	640	2020	3900	200	216	-
Ca	34	3	20	71	28	6	29	28
Mg	62	1	39	87	190	12	7	22
Na	-	2	5	5	-	3	1	69
Cl	9	1	3	5	5	2	3	30
SO4	1300	4	393	1330	1540	172	6	96
HCO_3	nil	7	nil	nil	nil	nil	160	190
Fe	21	0.3	0.3	19	312	0.3		
Al	82	nil	-	80	135	8		
Mn	14	0.1	15	51	85	2.6		
Zn	2.8	0.02	0.7	4.7	12.5	0.4		
Cu	0.9	0.1		1.4	4.5	0.1		
Ni	0.7	0.1			3.6	0.1		

(b) There is a striking correlation between heavy and sustained rainfall and the character of the water emerging from the spoil dump, as is shown by Figure 2. Following a period of rainfall of sufficient time and intensity to saturate the rock-fill completely the spring water has shown a sharp rise in conductivity, iron has appeared and the pH has fallen to 2.8 - 3.3. Analyses 4 and 5 of Table 1 present the water composition on two such occasions when the total rainfalls were 11 cm. over 4 days and 15.8 over 2 days respectively. After the rain ceased on each occasion conductivity fell exponentially over a period of 20-30 days to a steady base level of about 600 micromho/cm and a composition represented by analysis 3, Table 1. Light rainfall does not produce significant changes in the composition of the spoil spring.

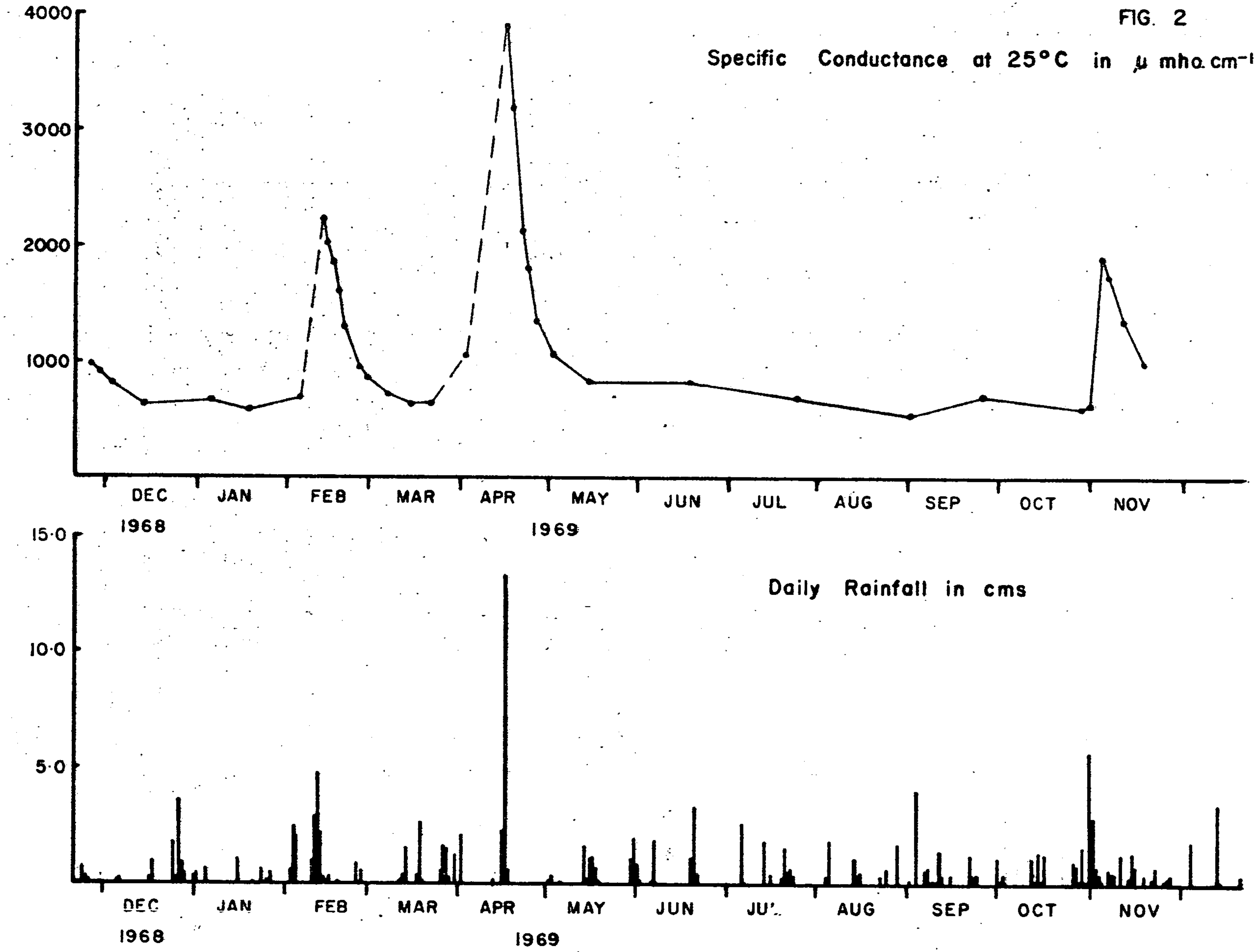


FIG. 2

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(c) Micro-biological studies of water from the spoil spring have shown that thiobacillus, presumably Th. ferro-oxidans and Th. thio-oxidans, occur abundantly.

(d) Waters emerging into the tunnel through leaks in the wall display a remarkable diversity. Five basic types of water have been recognized: almost unmodified reservoir water, three types of groundwater (bicarbonate water typical of the normal local groundwater, ephemeral shallow groundwater little modified from rainwater, and sulphate-bearing groundwater) and sulphate water similar to that collected in the rock quarry and emerging from the spoil spring. Water temperature measurements, though not conclusive, are consistent with the interpretation of origins given here.

(e) The sulphate water referred to in (d) leaks into the outlet tunnel upstream of the dam axis--line and grout treatment. Its chemical composition is presented as analysis 6, Table 1. Although less saline than the quarry and spoil spring waters, this water is clearly carrying sulphide oxidation products. As the leak occurs upstream of the core and grout curtain the acid oxidation product must be derived from the upstream side of the rock pile. This is further supported by values of 1 ppm P_2O_5 and 5 ppm NO_3 in the leakage water (see below).

(f) Analysis of emerging waters showed the presence of abundant phosphate in some, but not all, the water. Phosphate was first found associated with thick ferruginous deposits formed at certain leakage points in the outlet tunnel. Values ranged from 0.8% to 9.7% P_2O_5. Further analyses showed from 2 to 5 ppm P_2O_5 in the water from the spoil spring. The water leaking into the outlet tunnel associated with the ferruginous deposits does not contain phosphate ions as these have been removed by iron oxide in the wall deposits. Apatite is commonly associated with sulphide mineralization and occurs with chlorite in quartz porphyry near the dam site. Under the acid conditions resulting from pyrite oxidation (see below) apatite is converted to the very soluble monocalcium phosphate and it is suggested that this is responsible for the high phosphate level in the leakage and natural ground waters.

(g) The spectacular rich green growth of algae at the spoil spring suggested an abundance of nitrogen. Chemical analysis of the spoil spring water gave a value of 18 ppm NO_3. Natural groundwater which had not been in contact with quarried rock and which leaks into the outlet tunnel close to the spoil spring did not contain nitrate. As a natural source of nitrate which could give rise to a water carrying 18 ppm of NO_3 is not evident and as it has been found only in water associated with quarried materials, the nitrate is considered to be probably derived from the retention of explosive and explosion products in the quarried rock. The explosive used was ammonium nitrate, quilox and diesel oil at the rate of 0.45 kilograms per cubic metre of rock broken.

Interpretation and Discussion

The high acidity and salinity of the waters emerging from the spoil spring are undoubtedly due to the oxidation of naturally occurring pyrite (FeS_2): this is borne out by the presence of roughly 1% FeS_2 in both the rock-fill and the foundations of the embankment and the evidence in the field of oxidation of the pyrite (particularly in the quarry).

The oxidative decomposition of sulphide minerals has been studied extensively in recent times, mainly in relation to the recovery of metals by the dump leaching process. The scheme suggested by Temple and Delchamps (1953) is now generally accepted. The first reaction is purely chemical and involves the oxidation of pyrite to ferrous sulphate thus:

$$FeS_2 + H_2O + 7\,(O) \longrightarrow FeSO_4 + H_2SO_4 \qquad (1)$$

Further chemical oxidation of the ferrous sulphate is extremely slow under conditions where sulphides occur naturally. The second stage oxidation and further decomposition of pyrite is readily brought about by thiobacilli, in particular Th. ferro-oxidans and Th. thio-oxidans, according to the following reactions:

$$2\,FeSO_4 + (O) + H_2SO_4 \longrightarrow Fe_2(SO_4)_3 + H_2O \text{ (Th. ferro-oxidans)} \qquad (2)$$

The ferric sulphate formed is chemically reduced by pyrite:

$$Fe_2(SO_4)_3 + FeS_2 \longrightarrow 3FeSO_4 + 2S \qquad (3)$$

The sulphur generally is converted by Th. thio-oxidans to sulphuric acid according to the reaction:

$$S + 3(O) + H_2O \longrightarrow H_2SO_4 \text{ (Th. thio-oxidans)} \qquad (4)$$

A more detailed account of the oxidation of pyrite and other metallic sulphides will be found in Sokolova and Karavaiko (1968), Kuznetsov, Ivanov and Lyalikova (1963) and Blanchard (1968).

With an abundance of phosphorus and nitrogen, biological growth is greatly accelerated, resulting in an increase in the rate of decomposition of the pyrite directly by reaction (2) and indirectly through the sulphuric acid formed by reaction (4). A sample of pyritic shale from the dam placed in distilled water with free access to the air showed no evidence of pyrite oxidation.

The composition of the oxidation products as seen in the emergent spring water and quarry drainage is modified from those indicated above by secondary reaction with the country rock which, in the case of Corin Dam, gives high values for magnesium and aluminium relative to the dam water.

There is little doubt that pyrite oxidation was active in the quarry prior to development. Oxidation products, both primary and secondary such as ferrous, ferric, aluminium and magnesium sulphates, moving with the groundwater appear as efflorescent deposits on the quarry face. Also, the natural groundwater drainage and water used in the quarrying operations, in addition to being acid, developed the deep red coloration of ferric oxide sol. Both features were evident when the quarry was inspected in November, 1968. A partial analysis of the water draining away from the quarry is given in Table 1.

From a study of the fluctuation of the rate of discharge and of the chemistry of the spoil spring water with rainfall, it appears that the spoil spring derives its water from at least two sources: rainfall on the downstream side of the dam and nearby valley slopes that drain into the spoil dump area, and a leak through or beneath the dam embankment. The base flow of the spring indicates that the leak is of the order of 0.025 cubic metres/second, and the stability of flow since the reservoir filled, the chemistry of the water and the scant settlement of the dam embankment indicate that the leak is through the foundations rather than the embankment. The very high acidity of the spring water after heavy rain demonstrates that the main source of acid is the downstream rock-fill section of the dam.

Further, the high acidity of the base flows during the course of the investigation shows that the water leaking from the dam is strongly acid and it is inferred that some, or all, of the acidity derives from the oxidation of pyritic rock-fill in the upstream section of the dam. This is borne out by the presence of acid water in the outlet tunnel ("e" above). The waters from the upstream and downstream sections of the dam, embankment mix in a bedrock depression below the spoil dam.

Whether oxidation of sulphides is still continuing in the submerged upstream side of the dam has not been definitely established. Most species of Thiobacillus are strict aerobes; however, Th. denitrificans is a facultative anaerobe capable of oxidizing sulphur and sulphides, utilizing nitrate as source of oxygen (Sokolova and Karavaiko, 1968), so that continuing oxidation is possible. On the other hand conductivity of the water leaking into the tunnel ("e" above) has fallen over a period of 15 months from 200 to 60 micromho/cm. This suggests gradual leaching of a reservoir of oxidation products imprisoned in the upstream rock pile with little or no replenishment by biological oxidation. If this is so, chemical attack on the cement of the curtain and blanket grout and on the concrete of the foundation treatment and the outlet tunnel (if any of these are exposed to the acid water leaking below the dam) should decline significantly in the next few years.

The close correlation between heavy rainfall and spoil spring flow and chemistry indicates that the site of the oxidation in the downstream rock-fill of the embankment must be deep within the fill, in the fine fractions where permanently moist conditions required for the growth of the thiobaccilli may be maintained. Some superficial oxidation undoubtedly occurred immediately after construction. However, pyrite now exposed at the surface does not show signs of active weathering. Oxidation products of pyrite are slowly washed down by rain water to the base of the rock pile, where they are picked up and flushed out by water leaking through the dam. As this is a comparatively slow process in which the occasional light rainfall maintains the downward leaching there is time for partial neutralization of the acidity with removal of all the iron by hydrolysis. With heavy rainfall the rock pile becomes saturated and water flows freely, causing rapid flushing of the accumulated salts. The leaching waters then become more concentrated, with a simultaneous increase in acidity which represses hydrolysis so that iron appears in the effluent water.

It has not been possible to make a reliable estimate of the rate of sulphide oxidation because of the dependence of leaching on rainfall, and accurate gauging of the flow of water from the spoil spring could not be arranged. Based on an estimated 0.025 cubic metres/second minimum steady state flow the rate of oxidation is 500 Kg FeS_2 per day. Approximate integration over a period of 30 days following heavy rainfall on the 13th February, 1969, and 16th April, 1969, give values of 1300 and 2000 Kg FeS_2 per day respectively for the rate of pyrite oxidation, assuming that all the sulphur in the pyrite appears in the effluent water as sulphate.

The minimum flow condition obviously does not remove all the products of pyrite oxidation as the leaching rainwater does not penetrate sufficiently deeply into the rock pile. As the average rainfall intensity increases from 0.2 through 2.8 to 7.9 cm per day the average rate of pyrite removal increases from 500 through 1300 to 2000 Kg FeS_2 per day respectively. The deeper penetration by leaching rain water obtained under the higher rainfall intensity removes oxidation products that have been accumulating throughout the rock pile, resulting in higher values for the apparent oxidation rate. The whole system is a dynamic one in which the rock pile acts as a reservoir of acid salts and a buffer between rainfall and spring flow and composition.

CONCLUSIONS

The technical literature appears to contain few references to the production of such highly acid waters from pyritic rock in a dam embankment as has occurred in Corin Dam. The authors consider that the environment at Corin Dam is by no means unusual and suggest that the formation of acid waters from pyritic rock in quarries, dam embankments, and other engineering structures may be more common than has been recognized. The process at Corin Dam may have been more vigorous than is normally the case because the abundant phosphorus present would have accelerated the bacterial action.

The role of Thiobacillus, and the possible role of ammonium nitrate, in accelerating acid formation suggests the need for additional test procedures to predict accurately the performance of pyritic rock in engineering works. Periodic inspections of quarries and testing of quarry waters during construction operations should permit accelerated pyrite oxidation to be recognized and remedial action to be taken.

The level of nitrate in the spoil spring water is in excess of the acceptable level for water for town supplies. No problem is created in the Cotter River because of dilution by other water but, under other circumstances, a small water supply could be seriously affected by the process at work in the fill of Corin Dam.

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The paper is presented with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics, and the Director, Commonwealth Department of Works, Canberra, A.C.T.

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