DIRTY-WATER EVENTS AT ROCKY MOUNTAIN HOT SPRINGS

III. EVENTS TRIGGERED BY THE BORAH PEAK, IDAHO, EARTHQUAKE OF 28 OCTOBER 1983.

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CONTENTS

TABLES

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Abstract

Dirty-water events that lasted less than one day occurred at Miette Hot Springs and Radium Hot Springs after the Borah Peak, Idaho, earthquake of 28 October 1983. The events had only minor effects on the temperature and chemical composition of the spring waters. Sediment concentrations in collected water samples were about 6.0 g/ℓ at Miette (with 60 percent elemental sulfur), and 0.06 g/ℓ at Radium (with only 3 percent elemental sulfur).

INTRODUCTION

The first report in this series (van Everdingen 1983a) described a number of dirty-water events that occurred at Radium Hot Springs, Kootenay National Park (B.C.) and at Miette Hot Springs, Jasper National Park (Alberta), during the period 1959-1982. The report concluded that most of those events were caused either by earthquakes or by rapid infiltration of rainfall or snowmelt. The limited data available indicated that earthquakes had caused sediment contamination of the spring waters, with little or no change in spring-water temperatures. Rainfall-triggered events on the other hand were characterized not only by sediment contamination, but also by decreases in spring-water temperatures by as much as 34C°.

The second report in the series (van Everdingen 1983b) described some of the effects of the rainfall-triggered dirty-water event that occurred at Miette Hot Springs in early July 1982. During that event, spring-water temperatures decreased by 6.5 - 10.5 C°; dissolved-solids concentrations decreased by more than 50 percent; and changes occurred in the ionic and isotopic compositions of the spring water. The effects were interpreted as resulting from mixing of deep thermal water with cooler, less mineralized shallow water with different ionic and isotopic compositions. A sediment concentration of 7.5 g/ℓ, with 14% sand-size, 33% silt-size and 53% clay-size particles, was found in the water of the Miette swimming pool, supplied by discharge from springs No. 2 and 3. The sediment appeared to represent surficial materials, washed into the spring-water conduits, and small amounts of dissolution residues and secondary sulfur species (gypsum and native sulfur), dislodged from the conduit walls.

The present report describes dirty-water events that occurred at Miette Hot Springs and Radium Hot Springs on 28 October 1983, shortly after the Borah Peak, Idaho, earthquake struck at 08:06:06 MDT. Preliminary information on the earthquake (magnitude 6.9; epicentre at 44.05°N/113.89°W, about 744 km from Radium Hot Springs and 1043 km from Miette Hot Springs) was received by 10:00 MDT. When plotted on the graph of magnitude vs. epicentre distances for the hot springs (van Everdingen 1983, Fig. 7) the information suggested that dirty-water events would likely have been triggered at both hot-spring sites. Phone calls to both locations confirmed that dirty-water events were indeed underway.

SOURCES OF DATA

Information on spring-water temperatures, air temperatures and precipitation was supplied by Parks Canada staff at the two hot-spring sites; they also collected samples of sediment-contaminated water during the events. A misunderstanding regarding transportation arrangements unfortunately delayed the analyses of the samples from Radium Hot Springs by 10 days. Three of the samples from Miette Hot Springs turned out to be too small for complete major-ion analyses.

Water analyses were made by the Water Quality Branch Laboratory, Environment Canada, Calgary. Mineral analyses of the sediments, by X-ray diffraction and scanning electron microscope (SEM), were made at the Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary. Isotope analyses of water samples (for ^{2}H, ^{3}H and ^{18}O) were carried out in the Environmental Isotope Laboratory of the Department of Earth Sciences, University of Waterloo; isotope analyses of sulfur species (for ^{34}S and ^{18}O) were done in the Stable Isotope Laboratory of the Physics Department of the University of Calgary.

Information on the Borah Peak earthquake was provided by the National Earthquake Information Service in Denver, Colorado.

EFFECTS ON MIETTE HOT SPRINGS

Local Observations

At approximately 10 o'clock on the morning of 28 October 1983 it was noticed that blackish water was entering the Miette Aquacourt swimming pool. The springs were checked and found to be producing blackish-looking water. Small water samples were collected from the three springs between 10:30 and 11:00; around noon, larger samples were collected from spring No. 3 and from the swimming pool. The sediment contamination cleared up before the end of the day.

Precipitation appears not to have been a factor in this dirty-water event. Although 23 cm of snow (25 mm H_2O) fell on 26 October, only a minor fraction (4 cm) had melted by the 28th.

Water Temperatures

According to the available observations, the temperatures of springs No. 2 and 3 had dropped one degree by the afternoon of 28 October; the temperature of spring No. 1 had dropped the same amount by the morning of 29 October. No further changes were observed up to the end of November. As the temperature measurements are routinely rounded off to the nearest whole degree Celsius, the actual decreases in temperature may have ranged anywhere from zero to two degrees.

Flow Rates

It is not known whether the rate of discharge from any of the three springs varied during the event, because no arrangements exist at Miette Hot Springs for the measurement of discharge rates. No major changes were observed.

Water Chemistry

Chemical analyses for the samples collected on 28 October 1983 are listed in Table 1. The first three samples collected allowed only incomplete major-ion analyses.

Comparison of the results in Table 1 with the background ranges based on the analyses of earlier samples (pre-1982, Table 1), suggests that some minor dilution was taking place. In the absence of chemical analyses for the days immediately preceding the event it is impossible to determine whether the minor dilution was caused by the dirty-water event or not.

In the last two samples, values for bicarbonate, sulfate and chloride concentrations actually exceed the background ranges.

Isotopic Composition of the Water

Results of isotope analyses of the first three samples collected are also listed in Table 1. Comparison with the background data for pre-1982 samples in Table 1 suggests that the thermal water was slightly diluted with water having somewhat less negative $\delta^{2}H$ and $\delta^{18}O$ values and a small ^{3}H content.

Sediment Content

Sediment concentration in two samples totalling 1.6 ℓ was approximately 6.0 g/ℓ, only slightly less than the concentration of 7.5 g/ℓ found in the dirty-water sample collected from the swimming pool during the July 1982 dirty-water event. The sediment consisted primarily of yellowish-grey aggregates, and a small proportion of silt-sized and clay-sized mineral particles.

X-ray diffraction analysis indicated 60 percent native sulfur, with the remainder consisting of quartz, mixed-layer clays and dolomite (Table 2). These results were supported by a number of SEM spot analyses. Gypsum was found to be present in minor amounts.

Comparison of the sediment from this earthquake-triggered event with the sediment from the rainfall-triggered event of July 1982 shows that the earlier samples "missed" much of the algal/bacterial sulfur aggregates and clay minerals. It can be presumed that these lighter components had been washed away before the 1982 samples were collected.

Results of isotope analyses of the two sulfur species identified in the sediment are given in the notes accompanying Table 2. They indicate that both the sulfur and the gypsum are secondary minerals, produced by oxidation of HS^- from the spring water (c.f. van Everdingen 1983b, p. 11). These secondary minerals probably represent deposits removed from the walls of only partially water-filled spring-water channels.

EFFECTS ON RADIUM HOT SPRINGS

Local Observations

At approximately 10 o'clock on the morning of 28 October 1983 it was discovered that the water in the Radium Hot Springs hot pool had turned "murky". Water from the combined spring source was also found to be dirty. By 12:30 the source appeared to have cleared, but by 13:00 the springs were again producing dirty water. By 19:30 the spring water was finally clean again. Samples of the dirty water produced by the springs were collected at 10:30, 11:30, 12:00 and 14:30. A further sample was collected by the writer on 5 November.

Precipitation was not a factor in the dirty-water event. No precipitation was recorded in the 48-hour period preceding the event; only 2.6 mm of rain fell during the three days before that.

Water Temperatures

According to the available observations, the temperature of the combined spring flow remained constant at 45°C. A measurement by the writer on 5 November indicated the same temperature.

Flow Rate

No change was recorded in the combined discharge from the springs.

Water Chemistry

Chemical analyses for the samples collected on 28 October and 5 November are presented in Table 3.

Comparison of these results with the background ranges based on the analyses of earlier samples (pre-1982, Table 3), shows that the concentrations of most of the ions were less than 15 percent below the earlier recorded maxima. Concentrations were somewhat higher in the 5 November sample. In the absence of any chemical analysis for the period immediately preceding the event, it is impossible to determine whether the minor dilution was related to the dirty-water event or not.

Isotopic Composition of the Water

Results of isotope analyses of the water samples are also presented in Table 3. It appears that during the early stage of the event the thermal water was being diluted with a small percentage of water with somewhat less negative δ^2H and $\delta^{18}O$ values and a small ^3H content.

Sediment Content

Sediment concentration in the four samples taken on 28 October 1983 (at total of about 16 litres) was approximately 0.06 g/ℓ. The only particles larger than 0.05 mm were blue paint flakes (probably from the swimming-pool walls).

The results of X-ray diffraction analysis of the sediment are listed in Table 2. The results were supported by a number of SEM spot analyses. Quartz, mixed-layer clays and dolomite are the major constituents; only small percentages of gypsum and sulfur are present. Because of the small size of the sample, it was impossible to perform isotope analyses on the sulfur species.

DISCUSSION AND CONCLUSIONS

The earthquake-triggered dirty-water events of 28 October 1983 at Miette and Radium Hot Springs had little effect on the discharge rates of the springs, on the water temperatures, or on the chemical and isotopic compositions of the spring waters.

The sediment concentration in the dirty water produced by the Miette Hot Springs was 100 times that in the water produced by the Radium Hot Springs. This contrast may be caused by several factors. First of all, the spring system at Miette appears to be more accessible to sediment input from the surface (see van Everdingen 1983 b). Secondly, a major proportion of the sediment discharged by the Miette Hot Springs consisted of secondary sulfur species, produced through oxidation of the HS^- content of the spring water. The Radium Hot Springs water has a much lower $SO_4{}^{2-}$ content and it contains no HS^-; hence the production of secondary sulfur species is minimal. Finally, differences in the rock types traversed by the water of the two spring systems will result in differences in the type and quantity of residues left by subsurface dissolution.

The observations described in this report confirm the conclusions of the first report in this series (van Everdingen 1983a) regarding the character of earthquake-triggered dirty-water events.

ACKNOWLEDGEMENTS

Parks Canada staff at Miette and Radium collected the water and sediment samples and made the temperature measurements during the events described in this report. Mineral analyses were performed by J. Wong and A. G. Heinrich, Institute of Sedimentary and Petroleum Geology (GSC), Calgary. R. Drimmie and D. Palmer, University of Waterloo, performed the ^{2}H, ^{3}H and ^{18}O analyses; H. R. Krouse and M. A. Shakur of the University of Calgary provided isotope analyses of the sulfur species collected at Miette.

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Table 1. Physical, chemical and isotope data for Miette Hot Springs for 28 October 1983, and for pre-1982 samples.

Source and time of samples	Ranges for pre-1982 samples, springs 1, 2 and 3	Spring No. 1 11:00	Spring No. 2 10:30	Spring No. 3 10:30	Spring No. 3 12:00	Swimming pool (1)
Temperature, °C	44.4 - 53.9	48	54	51	51	43
Conductivity, μS/cm	1720 - 2086	2160	2230	2180	2120	2170
pH, units	6.7 - 6.9	6.7	6.8	6.8	7.1	7.2
Constituents, mg/ℓ:						
Ca	330 - 423	348	366	338	397	420
Mg	54.5 - 76.0	64	66	63	66	60
Na	8.0 - 12.2	*	*	*	10	13
K	12.0 - 17.1	*	*	*	15	16
HCO_3	116 - 148	*	*	*	122	183
SO_4	840 - 1178	1180	1200	1120	1210	1290
Cl	3.0 - 5.6	*	*	*	4.4	6.3
F	2.3 - 4.6	*	*	*	3.6	3.6
SiO_2	39.0 - 72.0	*	*	*	54	61
Sum	1456 - 1865	*	*	*	1882	2053
Stable isotope abundances:	Ranges for 1980 samples, springs 1 and 3					
δ^2H, °/oo SMOW	-169	-161 (2)	-166	-158	-	-
$\delta^{18}O$, °/oo SMOW	-21.5 to - 21.4	-21.2	-21.3	-21.0	-	-
^3H, tritium units	0	13	6	5	-	-

* Insufficient sample

(1) Water derived from springs No. 2 and No. 3.

(2) Average of 2 values: -160 and -162 °/oo SMOW.

Table 2. Mineral composition of sediments produced by Miette and Radium Hot Springs on 28 October 1983 (1).

Mineral	Miette Hot Springs	Radium Hot Springs
Dolomite	2	17
Calcite	-	2
Gypsum	Present (2)	5 (4)
Sulfur	60 (3)	3 (4)
Quartz	25	43
Mixed-layer clays	13	19
Kaolinite	-	4
Illite	-	4
Feldspars	-	3

(1) From X-ray diffraction analysis, in %.

(2) $\delta^{34}S$ (gypsum) = -13.1 $^{\circ}/_{\circ\circ}$ CDT.

(3) $\delta^{34}S$ (sulfur) = -12.2 and -12.0 $^{\circ}/_{\circ\circ}$ CDT.

(4) Sample too small for isotope analysis.

Table 3. Physical, chemical and isotope data for Radium Hot Springs for 28 October 1983, and for pre-1982 samples.

Source and time of samples	Ranges for pre-1982 samples	Springs, 10:30	Springs, 11:30	Springs 12:00	Springs 14:30	Nov. 5, 1983 12:30
Temperature, °C	35.3 - 46.5	45	45	45	45	45.0
Conductivity, µS/cm	766 - 980	884 (1)	881 (1)	886 (1)	875 (1)	932
pH, units	6.8 - 7.0	7.4 (1)	7.5 (1)	7.5 (1)	7.8 (1)	6.9
Constituents, mg/ℓ:						
Ca	109 - 150	136	137	138	134	143
Mg	22.2 - 36.3	32.9	32.8	32.8	33.0	33.9
Na	9.4 - 16.0	17	14	14	14	15
K	2.1 - 3.3	3.3	2.8	2.8	2.7	2.8
HCO_3	206 - 221	213.3	213.3	207	207	207
SO_4	230 - 356	310	304	304	306	336
Cl	6.9 - 12.6	12	12	12	11	11
F	0.3 - 0.8	0.33	0.37	0.37	0.37	0.41
SiO_2	27.0 - 54.0	36	36	36	37	40
Sum	629 - 807.5	760.8	752.3	747.0	745.1	789.1
Stable isotope abundances:						
δ^{2}H, $^{\circ}/_{\circ\circ}$ SMOW		-151	-150	-153	-151	-151
δ^{18}, $^{\circ}/_{\circ\circ}$ SMOW		-19.1	-19.4	-19.4	-19.5	-19.5
^{3}H, tritium units		4	7	0	0	0

(1) pH values may have increased and conductivities decreased, due to 10-day delay between collection and analysis.