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Questa Baseline and Premining Ground-Water Quality Investigation 8.

Lake-Sediment Geochemical Record from 1960 to 2002, Eagle Rock and Fawn Lakes, Taos County, New Mexico

Scientific Investigations Report 2005-5006

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Prepared in cooperation with the New Mexico Environment Department

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Abstract

Geochemical studies of lake sediment from Eagle Rock Lake and upper Fawn Lake were conducted to evaluate the effect of mining at the Molycorp Questa porphyry molybdenum deposit located immediately north of the Red River. Two cores were taken, one from each lake near the outlet where the sediment was thinnest, and they were sampled at 1-cm intervals to provide geochemical data at less than 1-year resolution. Samples from the core intervals were digested and analyzed for 34 elements using ICP–AES (inductively coupled plasma–atomic emission spectrometry). The activity of ^{137}Cs has been used to establish the beginning of sedimentation in the two lakes. Correlation of the geochemistry of heavy-mineral suites in the cores from both Fawn and Eagle Rock Lakes has been used to develop a sedimentation model to date the intervals sampled. The core from upper Fawn Lake, located upstream of the deposit, provided an annual sedimentary record of the geochemical baseline for material being transported in the Red River, whereas the core from Eagle Rock Lake, located downstream of the deposit, provided an annual record of the effect of mining at the Questa mine on the sediment in the Red River. Abrupt changes in the concentrations of many lithophile and deposit-related metals occur in the middle of the Eagle Rock Lake core, which we correlate with the major flood-of-record recorded at the Questa gage at Eagle Rock Lake in 1979. Sediment from the Red River collected *at low flow* in 2002 is a poor match for the geochemical data from the sediment core in Eagle Rock Lake. The change in sediment geochemistry in Eagle Rock Lake in the post-1979 interval is dramatic and requires that a new source of sediment be identified that has substantially different geochemistry from that in the pre-1979 core interval. Loss of mill tailings from pipeline breaks are most likely responsible for some of the spikes in trace-element concentrations in the Eagle Rock Lake core. Enrichment of Al_2O_3, Cu, and Zn occurred as a result of chemical precipitation of these metals from ground water upstream in the Red River. Comparisons of the geochemistry of the post-1979 sediment core with both mine wastes and with premining sediment from the vicinity of the Questa mine indicate that both are possible sources for this new component of sediment. Existing data have not resolved this enigma.

Introduction

The Molycorp Questa mine, located in the Taos Range in north-central New Mexico, is currently producing molybdenite concentrate and is in the process of developing a mine-closure plan. This report is one of a series of reports designed to investigate the geochemical baseline and premining ground-water quality in the Red River basin, New Mexico, at the site. The main objective of these studies is to determine the premining ground-water quality at the Questa mine site. The Red River flows past the southern side of the Questa porphyry molybdenum deposit. Our study focused both on determining the geochemical signature in sediment transported by the Red River prior to open-pit mining as well as that transported today, and on determining the effect of recent mining activity on the sedimentary record in a core from Eagle Rock Lake. Upper Fawn Lake was sampled as a geochemical baseline site to document the temporal variation of metals supplied by erosion in part of the Red River valley, upstream of the Questa mine. Both lakes originated as borrow pits during road construction and paving of N. Mex. Highway 38. The borrow pit that became Eagle Rock Lake was created sometime after August, 1954, whereas the borrow pits that form Fawn Lakes were created in 1960–1961 (Miguel Gabalgon, New Mexico Highway Dept., oral commun., Sept. 2003; URS Corp., written commun., 2004). A portion of the water from the Red River flows through both Fawn Lakes and Eagle Rock Lake. Flow is regulated to about 2 cfs by head gates installed by the irrigation organization that owns the surface water rights in the Red River valley. The head gates serve as baffles that limit inflow and thus limit the amount of sediment deposited in the lakes during high flow. Fawn Lakes, located on the Red River upstream of the Questa mine (fig. 1), are two small lakes covering an area of about 1 hectare. The sediment in these lakes provides an annual record for the period from about 1960 to the present. Eagle Rock Lake, located downstream of the Questa mine (fig. 1), covers about 2 hectares and provides an annual sedimentary record of material transported away from the Questa mine site as well as from sites upstream. A comparison between the sedimentary records of the two lakes potentially provides a measure of the impact of development of the Questa mine, which began as an open-pit operation in 1965, as well as the mine-site geology prior to open-pit mining. Although there was mining activity upstream

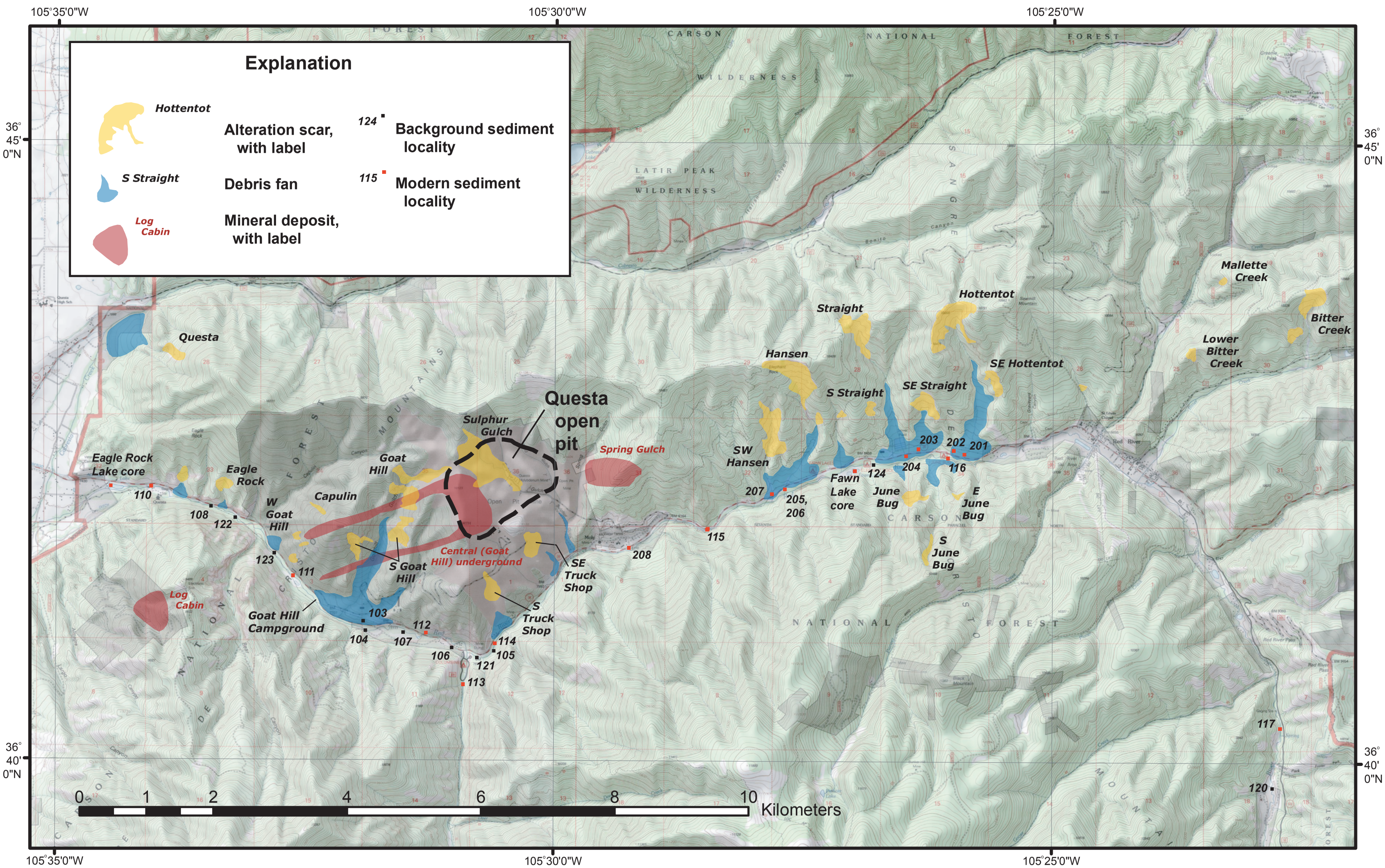

Figure 1. Topographic map of study area showing locations of altered areas (scars), debris fans, and mineral deposits (after Ludington and others, 2005) and sediment sample localities (tables 1–3). Outline of the open pit at the Questa mine is shown as a dashed line. Map projection is UTM, zone 13N; geographic coordinate system is North American datum 1927. One additional stream-sediment sample (not shown) was collected at the fish hatchery downstream from Questa near the confluence of the Red River with the Rio Grande. Sample localities of mill tailings spills and debris fans are not shown.

beginning in the 1860s, the effect of this previous mining activity on the geochemistry of sediment in the Red River from 1961 to 2002 is an integral component of the geochemical baseline recorded in the upper Fawn Lake core.

Geologic Setting

The Questa mine lies along the southern margin of the Questa caldera, which is part of the late Oligocene Latir volcanic field in north-central New Mexico (Lipman, 1981). The Latir volcanic field consists primarily of mildly alkaline intermediate-composition lavas 1- to 2-km thick that overlie Proterozoic crystalline basement consisting of metasedimentary and metavolcanic rock that is intruded by numerous granitic plutons (Lipman, 1988; Lipman and Reed, 1989; Ross and others, 2002). Andesite and quartz latite flows predate caldera formation. Volcanism culminated in the eruption of the peralkaline Amalia Tuff (Lipman and others, 1986; Johnson and Lipman, 1988) and formation of the Questa caldera at about 25.7 Ma (Czamanske and others, 1990; Ross and others, 2002). Ludington and others (2005) provide the geologic framework of the Red River watershed pertinent to this study.

The Tertiary volcanic rock was subsequently intruded by a series of highly evolved, high-silica granites and subvolcanic porphyries (Johnson and others, 1989; Ross and others, 2002) that are the apparent sources of the hydrothermal fluids that formed the molybdenite deposits. The Bear Canyon and Sulfur Gulch stocks are associated with the molybdenum mineralization and are characterized by high concentrations of Y, Zr, and the rare earth elements (REE) and low concentrations of Ba and Sr (Johnson and others, 1989; Ludington and others, 2005). These granites and porphyries were emplaced after 24.6±0.1 Ma and appear along a N.75°E. trend that extends from the Bear Canyon stock at the western range front into the Red River intrusive complex northeast of the town of Red River. Mineralization in the Questa porphyry molybdenum system is dated at 24.1±0.2 Ma (Ross and others, 2002) and is comparable with other Climax-type, high-silica granitic stockwork molybdenite deposits (Carten and others, 1993). An elongate granitic batholith is inferred at depth, which served as the parent body to the high-level stocks that gave rise to the known mineral deposits. The Questa deposit contains molybdenum mineralization in quartz stockwork with minor galena, sphalerite, and chalcopyrite along with fluorite and carbonate minerals (Carpenter, 1968; Ross and others, 2002). Two ore bodies have been mined underground: Goat Hill (1983–2000) and D (2001–present). Both have quartz-molybdenite-bearing veins in molybdenite-bearing late-stage magmatic hydrothermal breccia (Ross and others, 2002). Carbonate and fluorite occur in both the magmatic hydrothermal breccia as well as in abundant carbonate and fluorite-bearing veins. Ross and others (2002) estimate that the volume of the magmatic hydrothermal breccia in the Goat Hill ore body was about 80 percent. Several generations of brecciation have been identified; fluorite occurs in the latest generation of hydrothermal breccias (primarily in zones D and E; table 3 and fig. 7 of Ross and others, 2002).

Hydrothermal alteration related to mineralization processes can be found along the entire length of the mineralized trend. The upper part of the Questa deposit has been oxidized, and the hydrothermal alteration assemblages are exposed at the surface. The alteration assemblages, as mapped by airborne visible–infrared imaging spectrometer (AVIRIS) (Livo and Clark, 2002), appear to be dependent upon the nature of the underlying mineralization and the amount of host rock cover over the mineralized porphyries. Alteration associated directly with the molybdenite mineralization is potassic, and includes assemblages containing hydrothermal biotite and orthoclase (Carpenter, 1968; Ross and others, 2002). Phyllic or quartz-sericite-pyrite (QSP) alteration overprints the potassic alteration and the known mineralized rock. Within the open pit at the Questa mine, the QSP mineral assemblage is characterized by the presence of sericite, kaolinite, goethite, and jarosite (Livo and Clark, 2002). At Questa, as at other Climax-type molybdenite systems, QSP alteration is peripheral to the underlying molybdenite-bearing rock. Distal to QSP alteration, both laterally and vertically, widespread propylitic alteration (epidote, chlorite, and calcite) is encountered. It is characterized in the AVIRIS image by combinations of epidote and epidote plus calcite (Livo and Clark, 2002).

Meyer and Leonardson (1990) identified additional areas of hydrothermal alteration exposed upstream from the Questa deposit (fig. 1). These areas have also been mapped by AVIRIS (Livo and Clark, 2002) and are discussed in detail by Ludington and others (2005). These altered areas are subject to rapid erosion of hydrothermally altered rock along the N.75°E. trend above the inferred batholith. Steep barren drainages are formed by mass wasting and rapid erosion of the highly altered rock and are the result of landslides, slumps, rock falls, and fluvial processes. In the AVIRIS images, the erosional scars are surrounded by propylitic mineral assemblages, but within the scars, QSP alteration assemblages contain kaolinite, sericite, jarosite, and goethite (Livo and Clark, 2002). Although supergene alteration minerals like kaolinite and gypsum are commonly observed, exposures of bedrock usually exhibit primary alteration assemblages, most commonly QSP. A large proportion of the erosion that occurs in these altered areas takes place during intense summer thunderstorms as well as during the spring snowmelt. At these times, large amounts of sediment-laden water runs off the base of the scars and has formed large debris aprons at their base. These debris aprons consist of poorly sorted material, rich in pyrite and other weathering products, that range in size from large blocks with dimensions of tens of meters, down to silt- and clay-size material. The aprons generally reach the banks of the Red River, and much of this altered material enters the river during periods of high runoff. Large-scale mass wasting from these altered areas has been suggested as a source of metals in sediment in the Red River. These altered areas and their geochemistry are discussed in detail in Ludington and others (2005). Three of these altered areas, the Hottentot and Straight Creek drainages on the north and June Bug on the south, are upstream of Fawn Lakes (fig. 1). Thus, the sediment contributed by these altered areas is included in the geochemical baseline core from upper Fawn Lake.

History of Mining

Recorded mining began in the Red River mining district in the late 1800s (Schilling, 1960). The earliest claims were based on the discovery of placer gold in Quaternary gravel and sediment, but lode claims were also staked in both Tertiary and Precambrian rock for gold, copper, lead, and zinc (Jackson and others, 2003; McLemore, 2001). The town of Red River was established around 1895 in response to the discovery of the first lode gold claims in the area, but the town experienced its last true 'boom' in 1904 (Schilling, 1960; Pearson, 1986). The first claims on what is now the Molycorp property were filed by the Western Molybdenum Corporation in 1916; the R&S Molybdenum Corporation established claims in 1918, and both companies were bought in 1920 by the Molybdenum Corporation of America, now known as Molycorp (Schilling, 1960). Between 1919 and 1958, operators produced 18.4 million pounds of molybdenite (MoS_2) using selective underground stope mining methods to recover high-grade (~4 percent MoS_2) molybdenite ore from veins in the upper portion of the Questa ore body (Ross and others, 2002, table 2; Schilling, 1960).

Open-pit mining began at Questa in 1965 (table 2 of Ross and others, 2002). From 1965–1983, an estimated 81 Mt (million tons) of ore was removed, averaging 0.191 percent MoS_2. Initial production was 10,000 tons/day with a mill capacity of 15,000 tons/day (Carpenter, 1968). A total of 350 Mt of subeconomic Mo-mineralized and unmineralized overburden was removed from the open pit during the stripping and production of this ore (D.C. Jacobs, Unocal, written commun., 2003). From 1983 through 1991 and from late 1996 to 2000, the Goat Hill ore body, south and west of the open pit, was mined using underground block- and front-cave methods. A total of 21 Mt of ore, averaging 0.318 percent MoS_2, was removed and processed during this period. In 2001, Molycorp began production from the D ore body using a gravity-block-caving mining method. This orebody is expected to average around 0.338 percent MoS_2 (B.M. Walker, Molycorp, written commun., 2004).

Previous Geochemical Studies

The general area on either side of the Questa deposit was studied and mapped during the U.S. Geological Survey (USGS) wilderness assessment studies in the early 1980s. The Red River generally follows the southern margin of the Questa caldera. Volcanic rock of the caldera is in fault contact with Precambrian rock, which is exposed on the south side of the Red River. Tributary streams draining north from this Precambrian terrane, with the exception of Columbine Creek, are in Precambrian rock and have no base-metal anomalies in stream sediment (Sutley and others, 1983). The Questa deposit lies in the caldera on the north side of the Red River (fig. 1). Stream-sediment samples taken from tributaries draining the north side of Cabresto Creek—drainage north of the Questa block—also had no base-metal geochemical anomalies indicative of a Climax-type porphyry molybdenum deposit. No data were collected from the area between the town of Red River and Cabresto Creek during the USGS wilderness assessment studies.

In 1976, the National Uranium Resource Evaluation (NURE) project sampled sediment in surface streams in the vicinity of the Questa mine. Sediment was sampled in tributaries on both sides of the Red River and analyzed by inductively coupled plasma–atomic emission spectroscopy (ICP–AES) at Oak Ridge National Laboratory (NURE, 1981). These data provide a 1976 geochemical baseline during the period when the open pit was in operation (fig. 1).

Allen and others (New Mexico Office of the Natural Resource Trustee, written commun., 1999) conducted a study of the sediment geochemistry in the Red River and in the two lakes discussed here. They sampled sediment from cores in each of the two lakes and from seven localities along the Red River between the towns of Red River and Questa. Lake cores were taken near the inlet and outlet of the lakes (fig. 2). Samples were collected and dried. Following digestion, samples were analyzed for Al, Fe, Mn, Co, Cu, Mo, Ni, and Zn by atomic absorption. There was no absolute age control on these cores. The layers in the delta phase of the lakes were counted and related to annual snowmelt-runoff events to estimate the year that the layers were deposited. Concentration data were reported from 11 intervals from Eagle Rock Lake core ERL-C1 (1.6-m depth), for 12 intervals from Eagle Rock Lake core ERL-C2 (0.7-m depth), and from 11 intervals from the upper Fawn Lake core UFL-C2 (1.4-m depth). Allen and others (unpub. data, 1999) reported several aluminum-rich layers in the cores that formed subsequent to about 1980 in the Eagle Rock Lake cores. In March 2000, Molycorp initiated a study of the sediment in the two lakes to investigate further the chemistry of these aluminum-rich precipitates and evaluate the stratigraphy of the lake sediment (URS Corp., written commun., 2004). In their report, three cores were taken from the two lakes (fig.2, SED-1–SED-3) to duplicate the results of Allen and others (unpub. data, 1999), to work out the stratigraphy in more detail, and to select intervals to be analyzed for a number of metals using a partial digestion procedure.

Jackson and others (2003) have recently completed a water and stream-sediment study of the Red River watershed upstream of Hansen Creek (fig. 1). They collected 16 samples from locations immediately downstream of the major tributary confluences. Analyses of water and the <63-μm fraction of the stream-sediment samples showed significant increases in conductivity and in analyte concentrations in water for Na, Mg, Si, SO_4, and F and a decrease in pH downstream from the confluence with Mallette Creek near the town of Red River (fig. 1). Their sediment data showed significant increases in S, As, Cu, and Zn downstream from Mallette Creek that were attributed to Tertiary acid-sulfate alteration. Strong correlations between the Fe, Ti, and V data were attributed to the presence of magnetite that was found in heavy-mineral concentrates.

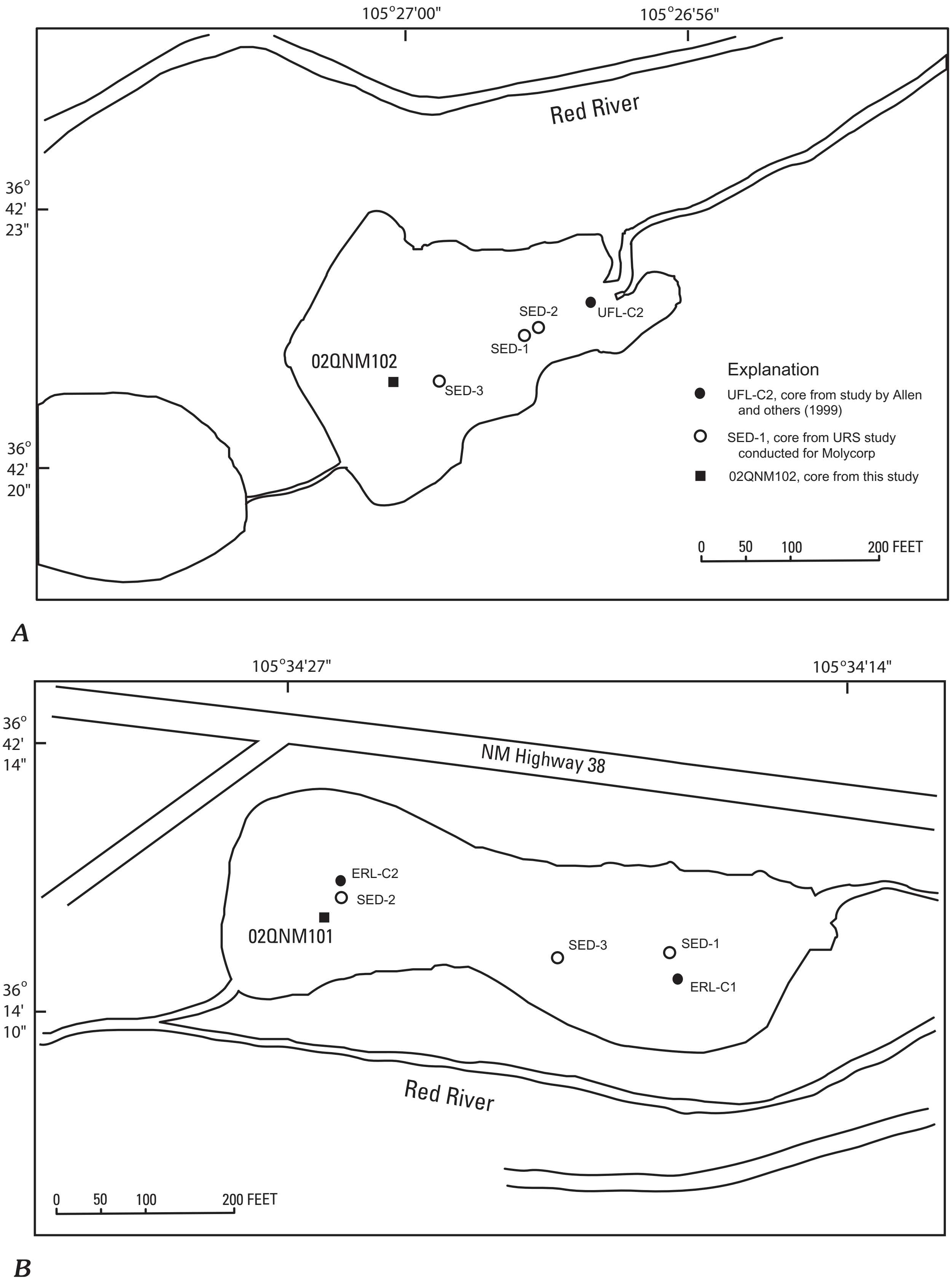

Figure 2. Maps of (A) Fawn Lakes and (B) Eagle Rock Lake showing location of the core sites. Also shown are localities of cores taken by Allen and others (unpub. data, 1999) and by URS (unpub. data, 2004) for Molycorp.

Methods

Sampling Plan

We used a pontoon boat to sample lake sediment from upper Fawn and Eagle Rock Lakes on consecutive days, June 19 and 20, 2002 (fig. 3). We anchored the boat in the deepest part of each lake, away from the inlet, to collect accumulations of largely very fine-grained, suspended sediment rather than detrital material to minimize the effects of storm deposits on the thickness of individual strata in the cores. We sampled the lake sediment by driving a 7.6-cm-diameter polycarbonate coring tube into the sediment and then extracted it using a hoist attached to the A-frame on the boat (fig. 3). The cores were driven to resistate; coarse angular monolithic rock fragments were recovered in the basal 1-cm section from each core. We recovered the entire lake-sediment stratigraphy from both lakes (53-cm core from upper Fawn Lake and 55-cm core from Eagle Rock Lake; fig. 4). Little evidence of any discernable stratification was visible in the lake cores. The upper few centimeters of sediment in each core were light tan, but in both cores, sediment color quickly changed to black. All material was silt and clay size. The core samples were sectioned at approximately 1-cm intervals immediately upon collection, placed in plastic bags, sealed, and shipped to the USGS geochronological laboratory at St. Petersburg, Fla., for radioisotope determinations. To evaluate the source of sediment in the lake cores, we sampled modern stream sediment from the active alluvium of the Red River and premining sediment from preserved terraces along the course of the river to determine the modern and premining geochemical baseline. Sampling methods for the premining baseline sampling have been previously described in Church and others (2000). We also sampled sediment from six creeks draining the altered areas upstream of the Questa mine (fig. 1) to determine the type of sediment material being supplied by the barren scar areas to the Red River, and we collected composite samples of ten terrace fans in the study area to evaluate spatial variability.

At the laboratory, the lake-sediment samples were air dried and split prior to geochemical analysis. Fan and stream-sediment samples were sieved to minus 80 mesh and ground prior to analysis.

Figure 3. Photograph of the USGS pontoon boat used to core sediment in upper Fawn and Eagle Rock Lakes. Anchors were deployed from each corner and the core driven through an opening in the deck. Core was then pulled using a hoist attached to the A-frame tower. Core was sectioned on site. The samples were placed in plastic bags and shipped to a geochronology laboratory for processing. Photograph taken at Eagle Rock Lake dam, June 19, 2002, by Philip Verplanck. Stan Church (right) and David Fey (left) are on the boat deck.

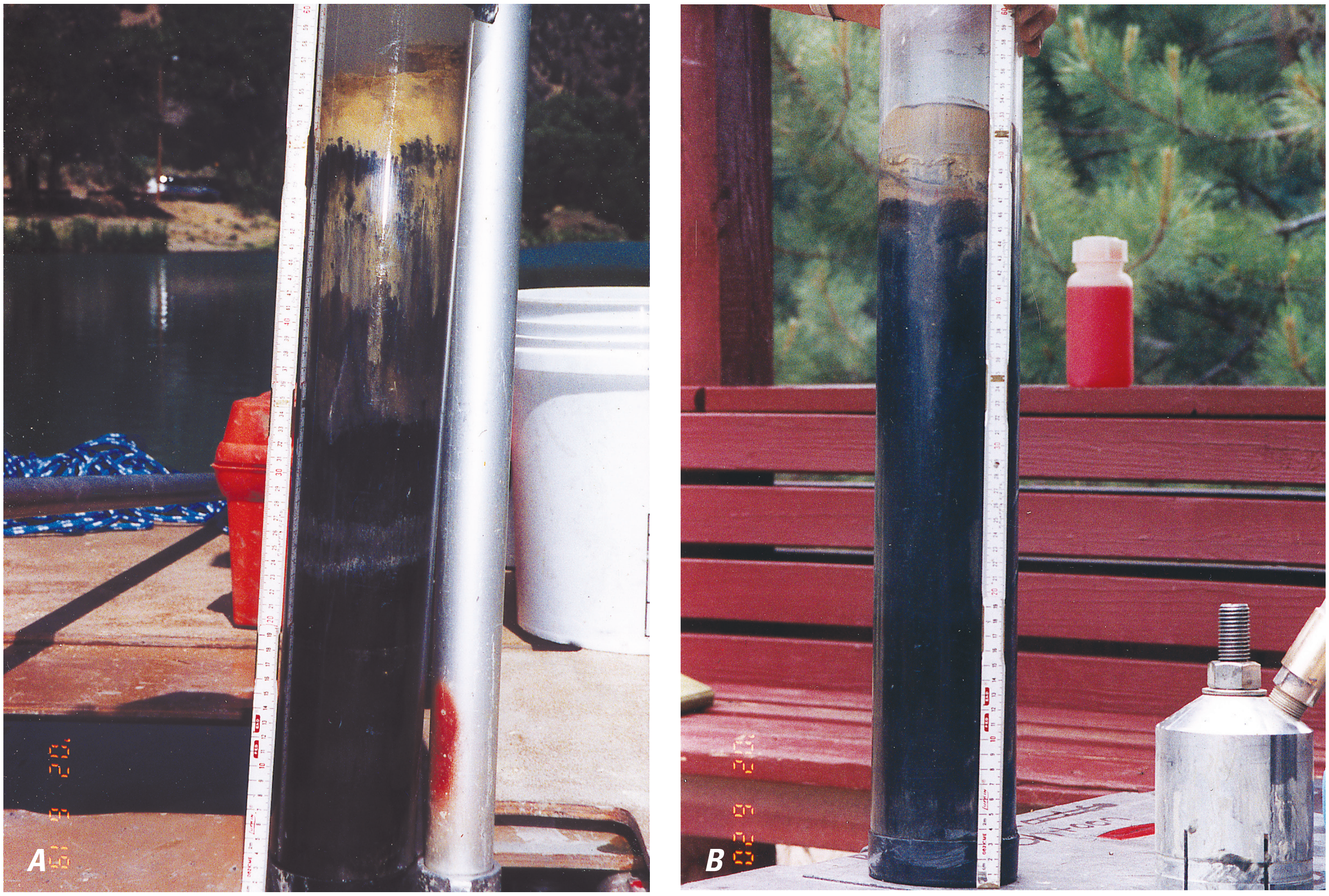

Figure 4. Photographs of cores (A) from Eagle Rock Lake (sample taken on June 19, 2002) and (B) upper Fawn Lake (sample taken on June 20, 2002).

Analytical Methods

The lake-sediment samples were analyzed for loss on ignition (LOI) to remove organic material by heating in a muffle furnace at 450ºC for 6 hours. Selected samples were counted using a Canberra intrinsic germanium detector to determine the depth of the maximum ^{137}Cs activity. Peak activity was assigned a date of 1963, which corresponds to the maximum fallout activity from atmospheric nuclear testing. The sample descriptions and the radioisotope results are in tables 1 and 2. Stream-sediment, lake-sediment, mill tailings, and terrace-composite samples collected for this study were analyzed using ICP–AES methods following a mixed acid total digestion (HCl, HNO_3, HF, and $HClO_4$; Briggs, 1996). Samples were submitted blind and were randomized prior to analysis. Statistical data for results from replicate analyses of these standards are documented in Fey and others (1999). Geochemical data are in tables 1–3.

Samples of the magmatic hydrothermal breccia from the D ore body were supplied by Meghan Jackson (Molycorp, 2003) for analysis. Three of the samples, selected on the basis of variations in grain size, were disaggregated and separated into discrete phases—a light green phase (fluorite) and a white phase (carbonate)—for analysis. Samples were hand-ground with an agate mortar and pestle. The samples were digested in hot HNO_3 and the soluble phase dissolved for analysis. The residues were digested using mixed-acid total digestion (HCl, HNO_3, HF, and $HClO_4$; Briggs, 1996), although additional $HClO_4$ was added to insure that insoluble REE fluoride minerals did not form.

Stream Flow Recorded at the Questa Gage

Daily stream-flow measurements of surface-water discharge have been recorded at the gage at Questa, New Mexico (08265000) for 80 years (beginning in Oct., 1924). The stream gage is immediately upstream from Eagle Rock Lake (fig. 1) (sample site 110). Data show that the flood-of-record occurred in 1979 (fig. 5). Runoff exceeded 300 cfs (ft^3/s) for 44 days and had an average peak daily flow of 557 cfs on June 9, 1979. Daily stream-flow data (1960 to Sept. 30, 2002), where greater than 300 cfs, are in table 4 (http://nm.waterdata.usgs.gov/nwis). Periods of peak stream flow correlate well with changes in the geochemistry of the core from Eagle Rock Lake.

Results and Discussion

Lake Sediment Chronology

^{137}Cs is a thermonuclear byproduct released by atmospheric nuclear testing. The U.S. atmospheric nuclear testing program began in the 1950s and was terminated in 1965. ^{137}Cs reached its maximum activity between 1962 and 1964 (90 percent of the ^{137}Cs was released between 1962 and1964; http://www.eml.doe.gov). ^{137}Cs is swept out of the atmosphere by rain and captured on clay minerals in the soil, ultimately ending up in lakes and oceans. Thus, radioactive decay of ^{137}Cs with a half-life of 30.3 years is ideal for dating of sediment in reservoirs where the sediment accumulation rate is low. The ^{137}Cs data from both lake cores indicates that the ^{137}Cs peak is only a few centimeters above the bottom of the core at depths of 49 and 50 cm below the sediment interface (fig. 6). Given that both lakes were constructed prior to peak ^{137}Cs activity (URS Corp., written commun., 2004), this setting is ideal for application of the ^{137}Cs dating method. The ^{137}Cs ages were calculated assuming that the depth at maximum ^{137}Cs activity occurred at the peak of atmospheric nuclear testing activity in 1963 ± 2 years. Counting statistics for peak ^{137}Cs activity are about ±7 percent and the sampling error is less than the sampling interval. Thus, the Eagle Rock Lake core contains a record of sedimentation

Table 1. Analytical, statistical, and descriptive data from the core from Eagle Rock Lake, lower Red River valley, Taos County, New Mexico.

Field Number	Sample Description	Depth (cm)	^{137}Cs Activity (dpm/g)	Percent Moisture	Al_2O_3 Wt. percent	CaO Wt. percent	FeO Wt. percent	K_2O Wt. percent	MgO Wt. percent	Na_2O Wt. percent	P_2O_5 Wt. percent	TiO_2 Wt. percent	SiO_2 Wt. percent
02QNM101La	clay and algae, medium tan	1	--	0.77	22.67	0.83	5.40	2.53	1.43	0.51	0.37	0.20	66.06
02QNM101Lb	clay and algae, medium tan	2	--	0.77	22.67	0.54	6.95	3.85	1.66	0.35	0.41	0.25	63.32
02QNM101Lc	clay and algae, medium tan	3	--	0.66	20.78	0.47	7.59	4.46	1.99	0.42	0.46	0.35	63.48
02QNM101Ld	beginning of black-streaked clay, some orange	4	--	0.58	20.78	0.46	7.20	4.46	1.99	0.47	0.48	0.40	63.76
02QNM101Le	half black, half tan colored clay	5	--	0.75	22.67	0.55	5.66	3.25	1.66	0.40	0.41	0.20	65.19
02QNM101Lf	mostly tan clay, one third black	6	--	0.80	22.67	0.54	6.69	3.13	1.51	0.32	0.41	0.18	64.54
02QNM101Lg	90 percent tan, 10 percent black clay	7	--	0.70	22.67	0.46	7.98	4.10	1.99	0.36	0.46	0.25	61.74
02QNM101Lh	90 percent tan, 10 percent black clay, orange streaking	8	--	0.62	20.78	0.46	7.46	4.46	1.99	0.35	0.48	0.30	63.72
02QNM101Li	80 percent black clay with orange and tan streaks	9	--	0.76	22.67	0.60	6.30	3.37	1.66	0.36	0.44	0.23	64.36
02QNM101Lj	medium-brown clay	10	--	0.82	22.67	0.74	5.66	2.05	1.21	0.36	0.34	0.12	66.85
02QNM101Lk	mix of gray, brown-orange clay	11	--	0.77	20.78	0.72	6.30	2.65	1.49	0.46	0.39	0.18	67.01
02QNM101Ll	mix of gray, brown-orange clay	12	--	0.79	20.78	0.75	6.18	2.65	1.54	0.47	0.37	0.18	67.08
02QNM101Lm	darker gray clay	13	--	0.78	18.90	0.76	5.66	2.41	1.48	0.47	0.37	0.18	69.77
02QNM101Ln	gray-black clay	14	--	0.79	20.78	0.79	6.05	2.53	1.54	0.44	0.41	0.18	67.27
02QNM101Lo	darker gray clay	15	--	0.78	22.67	0.84	6.30	2.65	1.61	0.49	0.41	0.20	64.82
02QNM101Lp	darker gray clay	16	--	0.79	20.78	0.80	5.53	2.41	1.46	0.44	0.39	0.17	68.01
02QNM101Lr	brown-gray clay	18	--	0.78	22.67	0.76	5.40	2.53	1.39	0.42	0.37	0.18	66.27
02QNM101Ls	brown-gray clay	19	--	0.76	20.78	0.71	5.40	2.89	1.53	0.46	0.37	0.22	67.64
02QNM101Lt	olive-brown clay	20	--	0.76	20.78	0.68	5.27	3.01	1.58	0.42	0.37	0.23	67.65
02QNM101Lu	olive-brown to black clay	21	--	0.77	22.67	0.78	4.89	2.53	1.46	0.40	0.37	0.18	66.72
02QNM101Lv	almost black clay	22	--	0.78	22.67	0.86	4.76	2.29	1.29	0.35	0.34	0.17	67.27
02QNM101Lw	black clay	23	--	0.75	20.78	0.98	6.05	1.81	1.33	0.32	0.32	0.12	68.30
02QNM101Lx	black clay	24	--	0.72	22.67	0.94	5.79	1.81	1.21	0.38	0.37	0.10	66.74
02QNM101Ly	black clay	25	--	0.76	22.67	0.94	4.12	1.93	1.26	0.49	0.37	0.17	68.07
02QNM101Lz	darker gray clay	26	--	0.79	26.45	0.96	3.47	1.69	1.08	0.40	0.32	0.12	65.50
02QNM101Laa	black and olive-brown clay	27	--	0.76	24.56	0.87	4.12	2.05	1.19	0.43	0.34	0.17	66.27
02QNM101Lab	black and olive-brown clay, H_2S smell?	28	--	0.60	22.67	0.67	5.66	3.49	1.82	0.46	0.39	0.30	64.53
02QNM101Lac	part of tan band of clay	29	--	0.64	22.67	0.67	5.15	3.61	1.82	0.66	0.41	0.28	64.72
02QNM101Lad	part of tan band of clay	30	--	0.60	22.67	0.67	5.15	4.22	1.99	0.54	0.44	0.35	63.98
02QNM101Lae	part of tan band of clay, more black	31	--	0.53	22.67	0.64	5.79	4.34	2.32	0.54	0.44	0.37	62.89
02QNM101Laf	mostly black clay	32	--	0.69	20.78	0.76	7.59	3.25	1.99	0.59	0.55	0.28	64.19
02QNM101Lag	black clay	33	--	0.72	18.14	0.88	7.72	1.93	1.82	0.73	0.44	0.27	68.08
02QNM101Lah	black sticky clay	34	--	0.65	18.71	0.96	7.72	3.13	2.16	0.96	0.32	0.32	65.73
02QNM101Lai	black sticky clay	35	--	0.64	18.90	0.86	7.20	3.25	2.16	0.85	0.32	0.30	66.17
02QNM101Laj	black sticky clay	36	--	0.67	18.90	0.87	7.33	2.89	1.82	0.73	0.41	0.23	66.81
02QNM101Lak	black sticky clay	37	--	0.61	18.90	0.96	7.20	3.01	1.99	0.77	0.37	0.27	66.53
02QNM101Lal	black sticky clay	38	--	0.64	18.52	0.96	7.08	3.13	2.32	0.89	0.30	0.32	66.49
02QNM101Lam	black sticky clay	39	--	0.62	18.14	0.92	7.20	3.13	2.32	0.90	0.27	0.30	66.80
02QNM101Lan	black sticky clay	40	--	0.53	18.90	0.92	7.20	3.49	2.49	1.04	0.23	0.37	65.36
02QNM101Lao	black clay	41	--	0.56	18.90	0.95	7.72	3.49	2.32	0.90	0.27	0.33	65.11
02QNM101Lap	black clay	42	--	0.47	17.76	1.10	6.95	3.25	2.16	0.89	0.23	0.40	67.27
02QNM101Laq	black clay	43	1.56	0.41	17.38	1.21	6.43	3.25	1.99	0.98	0.21	0.45	68.10
02QNM101Lar	black sticky clay	44	--	0.41	16.25	1.21	6.43	3.13	1.82	1.00	0.18	0.43	69.54
02QNM101Las	black sticky clay	45	--	0.47	16.44	1.23	6.95	3.13	1.66	0.97	0.21	0.42	69.00
02QNM101Lat	black sticky clay	46	1.23	0.63	18.90	1.06	8.36	2.65	1.99	0.71	0.32	0.33	65.68
02QNM101Lau	black sticky clay	47	--	0.66	20.78	0.91	6.95	3.37	1.99	0.61	0.37	0.25	64.77
02QNM101Lav	black sticky clay, H_2S smell?	48	1.88	0.59	20.78	0.92	6.43	3.61	2.32	0.77	0.34	0.35	64.46
02QNM101Law	black sticky clay, H_2S smell?	49	2.55	0.55	20.78	0.92	6.43	3.61	2.49	0.84	0.34	0.38	64.19
02QNM101Lax	black sticky clay, a little tan clay	50	2.98	0.57	20.78	0.91	6.18	3.37	2.32	0.82	0.37	0.35	64.90
02QNM101Lay	black sticky clay, a little tan clay	51	2.33	0.55	18.90	0.87	5.92	3.37	2.16	0.84	0.34	0.37	67.24
02QNM101Laz	almost half-tan clay	52	2.19	0.53	18.90	0.92	6.56	3.37	2.32	0.94	0.32	0.40	66.26
02QNM101Lba	tan and black clay, gravel bits	53	--	0.45	18.52	0.78	5.92	3.37	1.99	0.86	0.30	0.33	67.93
02QNM101Lbb	black clay, gravel	54	0.55	0.20	14.74	0.51	3.60	3.61	1.31	1.16	0.16	0.30	74.61
02QNM101Lbc	black clay, gravel	55	0.36	0.22	14.55	0.50	3.86	3.01	1.23	1.20	0.16	0.28	75.21
	Minimum				14.55	0.46	3.47	1.69	1.08	0.32	0.16	0.10	61.74
	25th percentile				18.90	0.67	5.56	2.56	1.48	0.42	0.32	0.18	64.73
	Median				20.78	0.84	6.30	3.13	1.82	0.53	0.37	0.28	66.27
	75th percentile				22.67	0.92	7.17	3.46	1.99	0.85	0.41	0.35	67.27
	85th percentile				22.67	0.96	7.34	3.61	2.32	0.91	0.44	0.37	68.07
	90th percentile				22.67	0.97	7.59	4.02	2.32	0.97	0.44	0.40	68.24
	95th percentile				22.67	1.14	7.72	4.38	2.32	1.01	0.47	0.41	69.62
	Maximum				26.45	1.23	8.36	4.46	2.49	1.20	0.55	0.45	75.21

during the entire period of operation of the Questa mine, beginning with the development of the open pit mine in 1965, and has a resolution of less than 1 year (55 sampling intervals during a 41-year period).

We used the hydrologic data to interpret the geochemical profiles. Stream-flow data indicate that the flood-of-record occurred in 1979 (table 4). Hydrologic data indicate that the years prior to and immediately following the flood were low-water years. Numerous changes in the concentrations of both major and minor elements occurred at about the middle of the core from upper Fawn Lake (table 2 sample 02QNM102Ly and table 5) at a depth of 25 cm. In particular, the concentrations of the major elements Na, K, Mg, Al, Fe, and Ti are elevated, whereas the major constituent SiO_2 is low, and the concentrations of trace elements V, Cr, Co, Ni, Li, Be, Sr, Ba, P, and F, excluding the base metals, are elevated. Stratigraphic work for Molycorp (core SED-CO3 from upper Fawn Lake, fig. 2*A*; URS Corp., written commun., 2004) suggests that the interval represented by the 1979 flood may be somewhat deeper. Since both the previous and subsequent years were substantially drier (fig. 5), we argue that the stream would not mobilize the heavy mineral suites seen in this interval prior to or following the 1979 flood event. We suspect that the 1979 event may have deposited several centimeters of sediment in upper Fawn Lake. Using these

Table 1. Analytical, statistical, and descriptive data from the core from Eagle Rock Lake, lower Red River valley, Taos County, New Mexico—*Continued*.

As	Ba	Be	Cd	Ce	Co	Cr	Cu	Eu	F	Ho	La	Li	Mn	Mo	Nd	Ni	Pb	Sr	V	Y	Yb	Zn
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
16	780	14	12	280	85	54	530	10	2,080	6	140	49	2,100	26	240	240	130	170	70	170	9	2,700
14	300	9	6	170	31	62	300	5	2,380	<4	94	35	2,200	25	130	110	200	240	82	88	5	1,500
17	200	5	4	130	14	74	120	2	2,310	<4	76	30	1,100	22	76	56	180	320	99	34	2	610
20	470	3	2	110	8	79	62	<2	2,050	<4	65	26	420	16	55	33	150	370	100	16	1	240
11	820	10	7	190	55	64	390	6	2,350	<4	99	32	560	17	150	150	160	230	82	110	6	1,800
12	640	14	9	230	53	56	500	8	2,430	4	120	37	720	22	200	180	180	220	74	140	8	2,200
12	250	7	6	160	37	69	240	4	2,330	<4	87	38	750	27	110	120	220	270	94	62	4	1,300
13	560	4	3	120	15	75	130	<2	2,450	<4	74	32	660	25	68	52	250	320	100	29	2	520
14	800	10	7	190	49	64	380	6	2,180	<4	98	33	970	24	150	140	190	260	84	100	6	1,800
14	710	16	11	260	80	44	660	10	2,450	6	130	40	1,400	22	240	240	120	150	60	180	10	3,000
17	820	12	12	230	92	56	500	8	2,060	4	120	48	1,700	23	190	250	150	170	74	130	7	2,600
12	790	11	12	220	93	57	480	7	1,980	4	110	49	2,200	22	180	240	150	160	76	130	7	2,600
13	720	11	11	220	92	55	480	7	1,990	4	110	47	2,400	21	180	240	140	150	71	130	7	2,600
17	780	13	12	240	97	58	550	8	1,990	5	120	48	2,600	23	200	270	140	160	75	140	8	3,000
<10	820	13	13	260	100	60	540	9	1,910	5	130	51	2,700	27	210	270	160	170	79	150	8	2,800
11	740	13	12	260	94	54	530	9	1,880	5	130	47	2,600	27	210	260	140	150	71	160	9	2,900
17	780	14	12	300	77	50	530	11	1,820	6	150	46	2,000	26	250	220	140	180	68	180	10	2,700
16	810	10	11	260	71	55	400	8	2,030	5	140	46	1,900	24	200	200	160	190	75	140	7	2,300
15	810	10	10	260	65	58	390	8	2,110	5	140	41	2,000	26	200	190	180	200	78	140	7	2,300
14	760	13	13	380	100	55	490	10	2,180	6	190	39	1,900	34	280	260	150	160	70	180	10	2,800
17	510	14	14	450	140	47	520	11	2,260	7	230	36	1,800	46	340	300	130	140	62	210	11	2,900
13	280	15	19	500	220	39	570	12	2,160	8	250	31	2,100	96	360	450	97	110	52	230	12	3,900
11	500	18	20	640	220	44	670	14	2,310	10	320	38	2,200	69	450	470	100	110	53	280	14	4,600
18	670	17	10	600	74	54	650	13	2,340	9	310	44	2,000	68	420	200	110	130	62	270	13	2,800
16	650	19	11	680	64	46	820	15	2,820	12	350	36	2,000	89	490	180	99	120	52	320	15	2,800
16	680	17	10	600	76	51	680	13	2,840	9	310	42	1,900	77	430	200	110	120	58	270	13	2,800
10	320	10	10	350	90	72	420	7	817	5	200	51	2,000	68	230	230	200	220	89	140	7	2,400
16	1,000	8	5	260	51	79	310	5	1,880	<4	150	51	1,800	48	160	150	200	220	96	99	5	1,400
14	1,100	6	7	220	38	87	230	4	2,150	<4	130	42	1,700	43	130	100	210	280	110	70	4	1,100
11	860	5	4	170	18	94	140	3	2,060	<4	110	35	1,700	40	97	68	190	320	110	47	2	610
21	200	8	7	240	77	77	320	5	1,880	<4	150	41	2,000	100	170	160	130	200	89	100	5	1,500
20	140	8	9	180	94	65	370	5	1,820	<4	100	44	2,000	150	140	220	100	160	77	89	5	1,700
13	150	6	6	140	61	78	310	4	1,790	<4	82	48	2,000	130	100	150	110	180	91	61	4	1,200
17	140	7	5	130	44	76	280	3	1,960	<4	74	46	1,800	130	91	110	120	170	88	52	3	930
<10	140	8	6	160	58	62	350	4	1,870	<4	88	46	1,800	160	120	130	130	140	75	69	4	1,200
<10	140	9	7	160	58	69	370	4	2,280	<4	88	52	2,000	250	120	140	140	150	77	65	4	1,200
<10	130	8	6	120	50	79	340	3	2,190	<4	68	56	2,000	360	85	120	170	170	89	50	3	980
13	130	6	5	110	47	79	290	3	1,970	<4	64	52	1,800	300	74	120	160	170	90	42	3	890
<10	150	5	3	110	25	86	200	2	1,890	<4	65	44	1,600	150	63	68	160	190	100	31	2	550
11	140	6	4	130	39	83	280	2	2,080	<4	77	47	1,600	180	77	90	180	200	99	38	3	750
12	180	6	3	230	26	80	160	2	1,670	<4	140	40	1,400	88	130	64	140	200	87	60	4	530
<10	260	5	3	260	20	81	81	2	1,590	<4	150	37	1,200	42	140	49	120	220	85	63	4	400
<10	240	4	2	270	18	72	58	<2	1,380	<4	160	35	1,000	49	140	42	110	190	77	65	4	340
<10	210	5	3	290	30	66	95	2	1,350	<4	170	36	930	75	160	61	96	170	72	75	4	490
12	150	7	6	170	57	72	270	3	1,870	<4	94	46	1,100	180	100	120	140	170	84	55	4	920
<10	140	8	6	130	56	72	340	4	2,010	<4	72	49	980	180	92	140	170	160	87	51	3	1,100
<10	170	8	5	130	43	88	320	4	2,020	<4	76	53	960	140	90	120	170	200	99	48	3	970
<10	180	8	4	140	32	95	320	4	2,170	<4	79	54	950	130	91	110	160	230	100	48	3	870
<10	180	9	4	140	33	89	350	4	2,030	<4	78	54	880	110	100	120	140	220	98	56	4	1,000
<10	200	8	4	140	33	85	320	4	2,000	<4	77	52	770	82	97	120	140	210	97	55	4	1,000
12	230	8	4	140	37	82	300	4	1,850	<4	76	58	800	62	96	110	130	190	98	58	4	930
<10	180	7	3	120	36	72	260	4	1,830	<4	72	49	690	49	89	110	120	180	87	51	4	870
<10	580	4	2	80	19	61	110	<2	1,350	<4	50	29	440	27	47	56	84	160	61	24	2	380
<10	210	4	2	77	17	53	110	<2	1,400	<4	47	25	410	25	48	52	77	170	62	24	2	360
10	130	3	2	77	8	39	58	2	817	4	47	25	410	16	47	33	77	110	52	16	1	240
12	180	6	4	140	33	55	263	4	1,873	5	77	36	963	25	93	110	120	160	71	51	3	875
14	310	8	6	205	54	68	340	5	2,025	6	110	44	1,750	49	140	140	140	180	82	73	4	1,250
17	755	13	11	260	79	79	498	8	2,188	7	148	49	2,000	108	200	220	170	220	93	140	8	2,600
17	801	14	12	303	93	82	531	10	2,331	9	171	51	2,100	150	241	241	181	231	99	180	10	2,800
17	817	15	12	429	96	86	564	11	2,371	9	221	52	2,200	174	322	260	197	267	100	201	11	2,870
20	834	17	13	600	114	88	664	13	2,450	10	310	54	2,470	205	424	281	204	320	100	270	13	3,000
21	1100	19	20	680	220	95	820	15	2,840	12	350	58	2,700	360	490	470	250	370	110	320	15	4,600

Table 2. Analytical, statistical, and descriptive data from the core from upper Fawn Lake, lower Red River valley, Taos County, New Mexico.

Field Number	Sample Description	Depth (cm)	^{137}Cs Activity (dpm/g)	Percent Moisture	Al_2O_3 Wt. percent	CaO Wt. percent	FeO Wt. percent	K_2O Wt. percent	MgO Wt. percent	Na_2O Wt. percent	P_2O_5 Wt. percent	TiO_2 Wt. percent	SiO_2 Wt. percent
02QNM102La	tan-buff, wet clay	1	0.25	0.64	17.76	0.58	6.82	3.98	1.82	0.53	0.44	0.32	67.77
02QNM102Lb	tan-buff, wet clay	2	–	0.56	18.90	0.54	7.72	4.46	1.99	0.50	0.50	0.37	65.03
02QNM102Lc	tan-black mix of clay	3	–	0.54	18.90	0.55	7.33	4.46	2.16	0.55	0.50	0.33	65.22
02QNM102Ld	tan-black mix of clay, mottled, orange	4	–	0.56	18.90	0.62	6.82	4.10	2.16	0.66	0.48	0.38	65.89
02QNM102Le	tan-black clay, mostly black	5	–	0.45	18.52	0.62	6.56	3.98	2.16	0.69	0.48	0.37	66.64
02QNM102Lf	tan-black clay, mostly black	6	–	0.52	18.90	0.56	6.95	4.22	2.32	0.59	0.50	0.40	65.56
02QNM102Lg	tan-black clay, mostly black	7	0.21	0.55	18.90	0.55	6.56	4.10	2.16	0.57	0.50	0.40	66.27
02QNM102Lh	90 percent black clay	8	–	0.56	17.19	0.80	6.43	3.49	2.16	0.93	0.37	0.33	68.29
02QNM102Li	90 percent black clay	9	–	0.51	18.14	0.87	7.20	3.61	2.49	1.08	0.44	0.42	65.75
02QNM102Lj	90 percent black clay	10	–	0.52	18.52	0.76	7.20	3.73	2.49	0.92	0.50	0.37	65.51
02QNM102Lk	90 percent black clay	11	–	0.61	17.95	0.83	7.33	3.61	2.32	0.85	0.44	0.32	66.35
02QNM102Ll	90 percent black clay	12	–	0.67	16.82	0.94	6.95	3.37	1.99	0.81	0.44	0.35	68.34
02QNM102Lm	90 percent black clay	13	–	0.71	16.06	1.34	7.20	3.13	1.82	0.78	0.41	0.33	68.91
02QNM102Ln	90 percent black clay	14	0.46	0.73	14.36	3.88	7.20	2.65	1.82	0.97	0.41	0.28	68.41
02QNM102Lo	90 percent black clay	15	–	0.71	14.36	3.62	7.08	2.53	1.82	1.01	0.44	0.28	68.86
02QNM102Lp	90 percent black clay	16	–	0.64	15.68	3.75	6.43	2.89	2.16	1.19	0.30	0.35	67.25
02QNM102Lq	90 percent black clay	17	–	0.62	17.01	4.82	6.56	3.25	2.32	1.23	0.30	0.37	64.15
02QNM102Lr	90 percent black clay	18	–	0.65	15.68	6.70	6.18	3.01	2.16	0.94	0.25	0.32	64.77
02QNM102Ls	90 percent black clay	19	–	0.60	17.19	3.48	5.79	3.37	2.16	0.96	0.27	0.33	66.44
02QNM102Lt	90 percent black clay	20	–	0.76	17.57	1.47	6.05	3.37	2.16	1.12	0.30	0.38	67.58
02QNM102Lu	90 percent black clay	21	0.40	0.57	20.78	1.87	6.56	4.10	2.49	0.75	0.37	0.37	62.71
02QNM102Lv	90 percent black clay	22	–	0.54	20.78	2.54	6.43	3.98	2.49	0.75	0.39	0.35	62.28
02QNM102Lw	90 percent black clay	23	–	0.53	18.71	2.54	6.30	3.61	2.32	0.78	0.37	0.33	65.03
02QNM102Lx	90 percent black clay	24	–	0.54	18.33	1.87	6.43	3.61	2.32	0.88	0.34	0.37	65.84
02QNM102Ly	90 percent black clay	25	–	0.54	28.34	1.87	10.03	5.54	3.65	1.33	0.55	0.60	48.07
02QNM102Lz	90 percent black clay	26	–	0.51	18.90	1.07	6.82	3.73	2.49	0.88	0.37	0.40	65.35
02QNM102Laa	90 percent black clay	27	0.48	0.49	18.90	1.08	6.43	3.73	2.32	0.89	0.34	0.37	65.93
02QNM102Lab	90 percent black clay	28	–	0.46	14.55	0.96	4.76	2.89	1.66	0.69	0.27	0.32	73.90
02QNM102Lac	90 percent black clay	29	0.47	0.50	18.71	1.74	6.43	3.73	2.16	1.04	0.34	0.42	65.43
02QNM102Lad	90 percent black clay	30	–	0.53	17.76	2.54	6.69	3.49	2.16	1.00	0.32	0.38	65.65
02QNM102Lae	90 percent black clay	31	0.54	0.51	18.71	1.47	6.30	3.85	2.32	0.84	0.34	0.37	65.79
02QNM102Laf	90 percent black clay	32	–	0.52	17.76	1.29	6.30	3.61	2.16	0.78	0.30	0.28	67.52
02QNM102Lag	90 percent black clay	33	0.62	0.59	15.87	2.01	6.69	3.13	1.99	0.75	0.27	0.28	68.99
02QNM102Lah	90 percent black clay	34	–	0.57	17.57	2.41	7.59	3.49	2.16	0.73	0.25	0.27	65.53
02QNM102Lai	90 percent black clay	35	0.72	0.60	17.38	2.01	7.20	3.37	2.16	0.73	0.23	0.27	66.65
02QNM102Laj	90 percent black clay	36	–	0.58	17.38	1.61	7.46	3.37	2.16	0.92	0.25	0.30	66.55
02QNM102Lak	90 percent black clay	37	1.02	0.63	16.82	1.61	6.95	3.25	2.32	1.08	0.23	0.32	67.43
02QNM102Lal	90 percent black clay	38	–	0.59	17.01	1.47	6.56	3.25	2.32	1.01	0.23	0.33	67.81
02QNM102Lam	90 percent black clay	39	1.13	0.56	16.63	1.12	6.30	3.25	2.32	1.04	0.23	0.33	68.77
02QNM102Lan	90 percent black clay	40	–	0.53	16.63	1.10	6.18	3.25	2.16	1.13	0.25	0.37	68.94
02QNM102Lao	90 percent black clay	41	1.13	0.51	16.25	1.03	5.92	3.13	2.16	1.11	0.25	0.37	69.79
02QNM102Lap	90 percent black clay	42	–	0.51	17.01	1.04	6.05	3.37	2.32	1.06	0.25	0.38	68.51
02QNM102Laq	some bluff clay	43	1.20	0.46	18.14	0.78	6.18	3.73	2.16	0.85	0.30	0.30	67.57
02QNM102Lar	some bluff clay	44	–	0.37	18.90	0.79	5.79	4.10	2.32	0.90	0.27	0.33	66.60
02QNM102Las	some bluff clay	45	1.22	0.40	18.52	0.90	6.43	3.85	2.32	0.88	0.30	0.37	66.44
02QNM102Lat	almost all buff clay with gray	46	–	0.37	20.78	0.62	6.43	4.46	1.99	0.53	0.34	0.38	64.47
02QNM102Lau	almost all buff clay with gray	47	1.10	0.35	18.33	0.60	5.40	3.98	1.99	0.58	0.32	0.33	68.47
02QNM102Lav	almost all buff clay with gray	48	1.60	0.43	18.90	0.91	6.30	3.98	2.16	0.89	0.27	0.40	66.19
02QNM102Law	almost all buff clay with gray	49	2.48	0.45	17.76	1.03	6.18	3.61	2.32	1.08	0.27	0.37	67.38
02QNM102Lax	gravel on bottom	50	1.76	0.36	16.06	0.82	5.27	3.49	1.82	1.12	0.25	0.30	70.86
	Minimum				14.36	0.54	4.76	2.53	1.66	0.50	0.23	0.27	48.07
	25th percentile				16.86	0.81	6.30	3.28	2.16	0.75	0.27	0.32	65.54
	Median				17.76	1.09	6.50	3.61	2.16	0.88	0.33	0.35	66.50
	75th Percentile				18.85	1.87	6.95	3.98	2.32	1.03	0.43	0.37	68.17
	85th percentile				18.90	2.54	7.20	4.10	2.32	1.08	0.47	0.38	68.68
	90th percentile				18.90	3.50	7.33	4.11	2.49	1.12	0.50	0.40	68.91
	95th percentile				20.78	3.82	7.53	4.46	2.49	1.16	0.50	0.41	69.43
	Maximum				28.34	6.70	10.03	5.54	3.65	1.33	0.55	0.60	73.90

same criteria, we identified the 1979 flood event in core from Eagle Rock Lake at a depth of 28–31 cm. Concentrations of Ti and the trace elements V, Cr, Co, Ni, and Li, excluding the base metals, are elevated. Although the Molycorp core from this part of Eagle Rock Lake is thicker than our core, this interval matches well with that identified by URS Corp. (written commun., 2004; fig. 2*B*) using stratigraphic descriptions of the core intervals. On the basis of the stratigraphic work by URS Corp., the thickness of the sediment in Eagle Rock Lake appears to be more than a single 1-cm sampling interval. We would suggest that it may be as much as 4- or 5-cm thick given the changes in the geochemistry (tables 2 and 5). Using these criteria, the sedimentation rate in Eagle Rock Lake both prior to and following the 1979 event would be very similar. And it would be about the same in the upper part of the upper Fawn Lake core. Attempts to match the other peaks in the geochemical data with specific changes in the hydrograph (fig. 5) would be ad hoc, so we assume that the sedimentation rate was approximately uniform in the two lakes during the period of record.

Table 2. Analytical, statistical, and descriptive data from the core from upper Fawn Lake, lower Red River valley, Taos County, New Mexico—*Continued*.

As ppm	Ba ppm	Be ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Eu ppm	F ppm	Ho ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nd ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Yb ppm	Zn ppm
11	190	3	4	89	14	65	180	<2	1,820	<4	58	30	750	21	46	48	240	210	88	21	2	480
13	190	3	3	95	6	70	120	<2	1,890	<4	63	30	560	25	46	31	280	220	96	15	1	280
16	190	3	3	95	7	76	120	<2	2,100	<4	64	30	480	24	45	32	320	220	99	15	1	280
14	240	3	4	97	14	79	180	<2	1,870	<4	64	30	460	24	48	45	280	220	100	20	2	400
<10	290	3	4	93	15	76	210	<2	1,840	<4	62	30	450	20	48	49	270	220	98	22	2	460
<10	260	3	3	95	12	78	190	<2	1,930	<4	63	30	460	24	45	42	310	240	100	18	1	380
11	210	3	4	97	10	78	180	<2	2,000	<4	65	29	450	24	47	39	310	230	100	17	1	350
10	160	3	4	85	19	82	220	<2	1,980	<4	55	30	470	27	46	51	190	200	100	23	2	480
10	350	3	4	90	20	95	260	<2	1,700	<4	58	34	540	24	48	57	190	240	110	25	2	520
15	340	3	3	89	15	99	260	<2	2,150	<4	59	32	500	26	45	51	220	250	110	21	2	440
12	180	3	4	86	27	88	280	<2	1,910	<4	56	31	470	44	46	64	210	220	110	24	2	540
19	140	3	5	86	36	72	290	<2	1,590	<4	53	30	470	38	49	80	170	200	91	31	2	730
11	110	3	6	80	39	66	290	<2	1,530	<4	50	29	470	34	48	89	150	190	86	32	2	780
15	120	3	7	76	67	62	380	2	1,270	<4	47	30	560	22	50	130	110	230	78	41	3	1,100
11	120	3	8	78	72	64	410	2	1,200	<4	48	30	600	18	52	140	100	230	80	45	4	1,200
<10	160	3	4	83	39	76	260	<2	1,340	<4	52	34	620	12	49	80	120	250	94	32	3	640
13	180	2	3	86	28	84	250	<2	1,480	<4	54	35	630	15	48	67	130	280	100	28	2	480
12	150	2	4	82	28	70	230	<2	1,440	<4	51	31	580	21	46	70	150	270	90	26	2	500
<10	240	3	4	86	31	71	210	<2	1,680	<4	56	33	610	14	48	73	190	220	93	28	2	560
<10	250	3	4	93	31	77	210	<2	1,540	<4	61	34	630	16	52	68	190	210	100	29	2	500
<10	230	3	4	100	23	87	220	<2	1,870	<4	70	34	670	18	52	66	310	240	110	24	2	510
12	320	3	4	99	29	88	260	<2	2,020	<4	66	34	700	19	52	72	270	270	110	26	2	600
15	330	3	4	94	30	85	250	<2	1,770	<4	61	32	660	20	49	70	240	250	100	25	2	570
15	430	3	3	92	23	91	240	<2	1,850	<4	59	33	610	19	48	58	210	240	110	24	2	490
<10	510	4	4	150	29	150	350	2	2,120	<4	94	50	880	34	74	81	320	360	170	34	3	650
14	440	3	3	98	17	98	230	<2	1,990	<4	64	33	590	22	50	49	220	250	120	22	2	410
13	350	3	3	94	17	88	200	<2	1,820	<4	60	33	540	22	48	49	220	230	110	21	2	380
<10	400	2	2	72	16	66	140	<2	1,710	<4	46	24	420	17	38	38	170	180	82	16	1	290
<10	430	3	3	96	22	86	200	<2	1,740	<4	61	33	590	25	50	54	200	250	110	23	2	430
12	180	3	3	94	26	82	210	<2	1,650	<4	59	31	600	29	50	60	180	260	100	24	2	480
11	230	3	3	98	19	86	180	<2	1,800	<4	58	32	560	24	47	46	220	220	110	22	2	370
<10	150	3	3	91	20	82	190	<2	1,820	<4	54	31	560	28	44	50	220	200	100	20	2	380
13	120	3	3	83	28	73	200	<2	1,640	<4	48	29	550	39	42	61	180	190	89	23	2	510
15	130	3	4	94	27	74	220	<2	1,690	<4	54	33	580	41	48	63	200	200	93	25	2	540
13	120	3	4	93	31	75	250	<2	1,750	<4	54	33	580	44	48	74	200	190	94	28	2	640
<10	140	3	4	92	34	79	260	<2	1,600	<4	53	34	600	48	49	81	180	190	97	30	2	670
12	140	3	4	93	29	79	260	<2	1,540	<4	54	34	620	41	50	75	180	200	97	30	3	650
10	150	3	4	94	28	86	250	<2	1,530	<4	54	34	610	36	49	71	180	200	100	30	2	610
<10	170	3	3	94	23	86	260	<2	1,580	<4	55	34	590	37	48	64	160	200	100	29	3	570
<10	180	3	3	90	24	84	250	<2	1,530	<4	52	34	560	33	47	60	160	200	100	29	2	540
11	200	3	3	91	19	85	240	<2	1,470	<4	53	33	540	28	46	56	150	200	99	28	2	500
<10	200	3	3	97	20	88	250	<2	1,560	<4	57	34	550	27	49	57	170	210	100	29	2	520
13	240	3	2	96	18	86	190	<2	1,860	<4	57	32	480	21	46	42	210	180	110	20	2	330
<10	770	2	2	94	11	86	120	<2	1,760	<4	56	35	450	15	43	29	230	200	110	17	2	190
10	250	2	2	97	9	88	160	<2	1,930	<4	58	35	480	17	47	29	180	220	110	20	2	220
<10	240	3	<2	100	<1	80	96	<2	2,050	<4	63	31	410	20	48	20	250	230	100	15	1	150
<10	320	2	<2	97	3	72	77	<2	1,890	<4	59	29	420	19	44	23	230	190	95	14	1	140
16	240	3	2	100	15	78	130	<2	1,710	<4	61	36	500	41	50	38	200	190	100	22	2	290
14	230	3	2	96	16	81	140	<2	1,650	<4	58	37	500	29	48	41	160	200	100	24	2	300
<10	250	3	2	79	13	74	150	<2	1,460	<4	47	30	410	22	40	38	130	190	91	20	2	320
10	110	2	2	72	3	62	77	2	1,200	<4	46	24	410	12	38	20	100	180	78	14	1	140
11	160	3	3	87	15	74	180	2	1,565	<4	54	30	473	20	46	43	170	200	94	20	2	373
13	220	3	4	94	22	81	220	2	1,745	<4	58	33	560	24	48	57	200	220	100	24	2	485
14	283	3	4	96	29	86	258	2	1,885	<4	61	34	600	32	49	70	230	240	110	29	2	568
15	347	3	4	97	31	88	260	2	1,963	<4	63	34	620	38	50	75	270	250	110	30	2	640
15	403	3	4	98	34	88	281	2	2,002	<4	64	35	633	41	50	80	283	251	110	31	3	652
16	436	3	6	100	39	97	323	2	2,078	<4	66	36	687	43	52	85	310	270	110	33	3	758
19	770	4	8	150	72	150	410	2	2,150	<4	94	50	880	48	74	140	320	360	170	45	4	1,200

Lake Sediment Geochemistry

Sedimentation rates in the two lakes are interpreted to be approximately constant except for the 1979 event. The resulting model gives a good correlation of peaks in metal concentrations between lakes and highlights the difference between the sediment in both cores. Spikes in metal concentrations in both lakes may be associated with smaller flood events recorded at the Questa gage (table 4). The presence of the head gates that limit the inflow to the lakes to approximately 2 cfs has resulted in reducing the amount of sediment transported into the lakes at high flow. The irrigation company that owns and operates the lakes also reportedly reduces the flow during peak runoff (URS Corp., written commun., 2004). The distribution of major and trace elements in sediment cored from Eagle Rock Lake and upper Fawn Lake is shown in figures 7–12, plotted as a function of depth. Peak spikes in concentration of the major and trace elements are summarized in table 5. Peaks were defined as elevated

Table 3. Analytical data from debris fans, modern and geochemical baseline sediment, and mill tailings samples, lower Red River valley, Taos County, New Mexico.

Field Number	Sample Description	Latitude DD	Longitude DD	Al_2O_3 Wt. percent	CaO Wt. percent	FeO Wt. percent	K_2O Wt. percent	MgO Wt. percent	Na_2O Wt. percent
Modern streambed sediment samples									
Red River									
02QNM-116S	Sample taken downstream from Hottentot Creek	36.70710	−105.43282	10.96	0.35	3.09	2.65	0.73	0.51
02QNM-117S	Sample taken upstream from confluence with Goose Creek	36.67313	−105.37953	13.79	2.66	5.66	2.65	1.66	2.56
02QNM-115S	Sample taken downstream from SW Hanson Creek	36.69787	−105.47443	12.47	0.48	4.25	3.01	1.08	0.90
02QNM-114S	Sample taken upstream from Columbine Creek	36.68218	−105.51032	12.47	0.45	4.25	2.89	1.09	0.90
02QNM-112S	Sample taken downstream from Columbine Creek	36.68378	−105.5223	12.84	0.49	4.25	3.01	1.09	0.97
02QNM-111S	Sample taken upstream from Goat Hill Campground	36.68737	−105.53987	13.03	0.62	3.86	3.01	1.16	1.19
02QNM-110S	Sample taken at stream gauge site	36.70332	−105.5682	13.60	0.50	4.12	3.13	1.09	1.17
02QNM-118S	Sample taken 4 mi downstream from Questa Ranger Station at Red River State Fish Hatchery	36.68420	−105.64925	12.84	0.95	3.47	2.89	1.03	2.02
Tributaries									
03QNM201S	Hottentot Creek	36.70780	−105.42975	16.24	0.31	4.37	3.85	0.99	0.35
03QNM202S	SE Straight Creek scar tributary	36.70882	−105.4372	17.19	0.92	7.46	3.98	2.82	1.24
03QNM203S	SE Straight Creek scar tributary	36.70843	−105.4409	16.62	0.29	7.46	4.10	1.99	0.75
03QNM204S	Straight Creek	36.70793	−105.44407	13.98	0.49	5.92	3.49	1.46	0.78
03QNM205S	Tributary upstream from Hanson Creek	36.70375	−105.46072	13.41	1.54	5.27	3.25	1.34	1.62
03QNM206S	Hanson Creek	36.70390	−105.46178	16.24	0.50	6.18	3.85	1.13	0.53
03QNM207S	SW Hanson Creek scar tributary	36.70225	−105.46423	15.68	0.91	7.85	3.73	2.16	1.08
03QNM208S	Sediment from catchment basin near Red River across road from Molycorp mill	36.69515	−105.4881	18.51	0.49	6.69	4.10	1.66	0.65
02QNM-113S	Columbine Creek sediment sample	36.67712	−105.51517	13.60	2.24	6.18	2.41	1.56	3.50
Composite talus fan samples									
03KVTF10	Mallette Creek tributary fan	36.72503	−105.39968	13.22	1.23	3.47	3.37	0.93	2.29
03KVTF1	Graveyard Canyon fan	36.71107	−105.42058	13.22	0.80	6.69	2.89	0.93	1.35
03KVTF2	Hottentot Creek fan	36.70787	−105.42995	17.57	0.10	5.02	4.10	1.08	0.40
03KVTF3	Straight Creek fan	36.70853	−105.44403	14.36	0.41	6.82	3.61	1.48	0.63
03KVTF4	Little Hansen Creek fan	36.70227	−105.46378	15.11	1.33	8.23	3.73	2.16	1.05
03KVTF5	Small fan immediately downstream from Little Hanson Creek	36.70175	−105.46722	13.03	1.33	4.12	3.13	1.24	1.75
03KVTF5b	Small fan immediately downstream from Little Hanson Creek (duplicate sample)	36.70175	−105.46722	13.03	3.50	4.12	3.13	1.39	1.75
03KVTF6	Sample from fan remnant of Sulfur Gulch	36.69445	−105.49818	14.92	1.22	7.08	3.61	2.32	1.75
03KVTF9	Little Goathill fan	36.68520	−105.52717	14.92	1.29	8.23	3.37	1.64	1.75
03KVTF8	Goathill fan	36.68675	−105.53818	13.03	0.27	6.05	3.85	0.76	0.81
03KVTF7	Capulin fan	36.69855	−105.54973	15.49	0.87	7.46	3.85	1.24	1.19
Background sediment sites									
03QNMB120	Red River upstream from Goose Creek confluence	36.66387	−105.54973	13.22	2.52	4.63	2.41	1.58	2.02
03QNMB124	Red River upstream from Fawn Lake Camp	36.70642	−105.54973	12.84	0.97	5.02	2.89	1.49	1.31
03QNMB121	Red River upstream from Columbine Creek	36.68302	−105.51005	13.98	1.25	7.20	3.13	1.82	1.75
02QNM-105Ba	Composite sample from river deposit	36.68058	−105.51112	14.36	1.09	5.27	3.25	1.82	1.62
02QNM-105Bb	upstream from confluence with			13.22	0.88	4.37	3.13	1.46	1.48
02QNM-105Bc	Columbine Creek			13.41	0.87	4.50	3.01	1.38	1.35
02QNM-105Bd				12.09	0.90	5.02	2.89	1.26	1.48
02QNM-106Ba	Composite sample from river deposit	36.68155	−105.51768	14.36	0.99	8.62	3.25	1.99	1.62
02QNM-106Bb	downstream from confluence with			13.98	0.92	9.39	3.13	1.99	1.62
02QNM-106Bc	Columbine Creek on pipeline access			13.41	0.95	7.20	3.01	1.99	1.75
02QNM-106Bd	road			12.66	0.98	6.69	3.01	1.54	1.62
02QNM-107Ba	Composite sample from river deposit	36.68433	−105.52565	12.47	1.02	10.16	2.77	1.43	1.35
02QNM-107Bb	downstream from confluence with			12.66	1.23	6.30	3.01	1.43	1.32
02QNM-107Bc	Columbine Creek on pipeline			12.66	1.96	6.95	3.13	1.59	1.35
02QNM-107Bd	access road			13.98	0.84	3.60	3.25	1.39	1.62
02QNM-107Be				14.17	0.74	4.89	3.13	1.59	1.48
02QNM-107Bf				13.60	1.09	4.63	2.89	1.58	2.02
02QNM-107Bg				13.60	1.23	4.76	2.89	1.53	2.29
02QNM-104Ba	Composite sample from tributary fan	36.68483	−105.53405	14.73	1.68	5.02	2.77	1.21	3.10
02QNM-104Bb	on south side of Red River			15.11	1.27	4.37	3.49	0.93	3.37
02QNM-104Bc	downstream from Goat Hill Gulch			14.17	1.11	3.60	3.37	0.85	3.50
02QNM-104Bd				14.17	1.54	3.73	3.25	0.98	2.97
02QNM-103Ba	Composite sample from Goat Hill	36.68538	−105.53405	14.92	0.06	5.15	4.10	0.81	0.55
02QNM-103Bb	Gulch fan			15.11	0.06	5.15	4.34	0.85	0.54
02QNM-103Bc				10.77	0.31	14.15	2.53	0.98	1.29
02QNM-103Bd				13.41	0.06	4.89	3.98	0.71	0.51
03QNMB123	Upstream from Capulin Canyon	36.69425	−105.54672	14.54	0.97	6.18	3.01	1.82	1.62
02QNM-108Ba	Red River alluvial deposit about	36.70082	−105.55785	14.36	1.27	6.18	2.89	2.16	2.02
02QNM-108Bb	1 mi upstream from USDA FS			11.71	1.54	12.86	2.41	1.58	1.48
02QNM-108Bc	Ranger Station at Eagle Rock Lake			12.84	1.05	4.89	3.01	1.36	1.35
03QNMB122	Red River upstream from USDA FS Questa Ranger Station	36.70242	−105.56493	13.41	0.78	5.40	2.89	1.61	1.62
Mill tailings samples									
03QNM209T	Tailings from area south of highway 38, along banks of the Red River and across road from Questa mill plant entrance	36.69470	−105.4961	10.39	1.54	8.75	3.49	0.56	1.89
03QNM101T	Tailings from 2 ft inside tailings pipe at Columbine Park pipe yard (Molycorp)	36.68347	−105.52455	0.76	0.57	56.61	0.17	0.23	0.13
03QNMGHCGT	Goathill Campground tailings (1981)	36.68935	−105.54152	13.60	1.40	6.05	3.13	1.59	1.89
03QNMCAPT	Tailings from Capulin pipe break site	36.69558	−105.54823	14.36	3.36	2.32	5.30	0.86	1.89
03QNM210T	Tailings from pipe line break (1979?)	36.70082	−105.55922	13.22	1.36	5.02	2.89	1.41	2.02
03QNM211T	Tailings from pipe line break (1979?)	36.70128	−105.55937	14.54	1.25	5.79	3.25	1.62	1.62

Table 3. Analytical data from debris fans, modern and geochemical baseline sediment, and mill tailings samples, lower Red River valley, Taos County, New Mexico—*Continued*.

P_2O_5 Wt. percent	TiO_2 Wt. percent	SiO_2 Wt. percent	As ppm	Ba ppm	Be ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	F ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nd ppm	Ni ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Yb ppm	Zn ppm
0.16	0.37	81.19	<10	380	2	3	64	12	32	72	--	33	18	610	6	26	32	61	170	60	12	1	250
0.27	0.75	70.00	<10	840	2	3	66	21	82	28	--	34	22	1,300	3	27	39	25	450	110	18	2	110
0.27	0.40	77.14	10	620	3	3	84	25	49	89	--	42	23	880	14	40	57	88	210	66	20	2	430
0.27	0.43	77.24	15	790	3	3	90	26	50	84	--	45	22	910	10	43	58	76	230	67	21	2	470
0.27	0.47	76.60	14	970	3	4	92	25	50	81	--	46	23	1,100	10	44	60	74	240	68	21	2	470
0.25	0.45	76.43	<10	1,100	3	4	82	19	51	86	--	43	23	840	13	40	71	74	240	68	24	2	540
0.25	0.40	75.73	12	1,100	4	4	94	24	54	120	--	47	24	1,200	11	45	69	72	240	69	25	2	600
0.18	0.38	76.22	<10	1,000	3	3	77	21	44	74	--	40	23	870	14	37	58	59	240	63	22	2	520
0.30	0.40	73.18	13	1,100	2	<2	94	<1	48	20	1,540	50	22	180	23	37	10	150	170	77	13	1	44
0.62	0.50	65.27	16	790	2	2	89	2	99	46	1,340	53	26	650	21	33	17	340	280	120	8	<1	110
0.53	0.37	67.89	17	960	2	2	93	5	66	52	1,680	56	29	440	32	33	17	330	230	93	11	1	100
0.39	0.38	73.11	13	930	2	<2	81	4	58	52	1,470	48	27	380	32	29	15	230	180	79	12	1	90
0.37	0.68	72.51	14	1,100	3	<2	98	12	71	70	1,090	50	21	500	90	42	25	100	340	88	24	2	130
0.34	0.52	70.71	18	940	3	2	120	9	68	34	1,480	64	24	310	12	50	24	73	250	84	25	2	81
0.55	0.50	67.55	20	690	2	2	86	6	88	35	1,430	51	22	420	23	34	23	120	550	110	8	<1	71
0.48	0.42	67.01	17	1,100	3	2	100	12	74	92	1,580	54	27	530	34	42	31	170	250	100	16	2	160
0.18	0.58	69.75	<10	840	2	3	64	15	66	27	--	36	27	750	3	27	24	57	260	97	20	2	150
0.25	0.42	74.81	<10	830	3	2	120	10	30	50	--	72	22	1,200	11	53	19	70	270	56	28	2	210
0.30	0.48	73.34	<10	1,000	2	<2	78	20	58	38	--	41	17	720	28	37	32	44	270	83	16	1	130
0.32	0.42	71.00	<10	1,100	2	<2	110	<1	54	22	--	58	23	180	24	42	10	170	190	84	14	1	41
0.41	0.45	71.83	18	800	2	<2	96	1	60	47	--	57	27	330	33	32	13	270	200	81	9	1	74
0.57	0.45	67.36	17	660	2	2	86	7	88	34	--	52	21	390	22	33	20	120	630	110	7	<1	60
0.25	0.55	74.59	<10	950	3	<2	82	15	73	42	--	44	22	900	71	34	33	71	290	81	19	2	140
0.30	0.48	72.29	13	950	2	2	88	16	66	44	--	45	23	1,400	19	35	35	94	350	80	19	2	200
0.44	0.52	68.15	<10	1,000	4	2	98	8	110	150	--	57	32	640	460	41	37	98	420	110	17	1	79
0.46	0.43	67.90	<10	1,200	3	2	110	23	92	150	--	63	31	910	25	46	36	170	470	110	14	1	140
0.23	0.40	74.60	14	960	2	<2	86	3	39	41	--	49	17	250	45	31	10	210	190	66	12	2	37
0.34	0.43	69.12	21	920	4	2	170	10	64	110	--	100	31	850	19	81	25	190	220	89	33	2	190
0.32	0.60	72.70	12	860	2	<2	74	16	67	44	--	42	30	1,100	6	36	32	21	410	92	28	3	100
0.37	0.38	74.73	10	940	2	<2	86	14	68	97	--	43	26	630	26	44	28	110	230	81	19	2	140
0.44	0.48	69.95	20	1,100	3	2	110	28	110	120	--	58	29	1,100	140	56	50	90	330	100	28	2	170
0.32	0.47	71.80	12	1,000	3	4	87	16	72	100	--	46	29	720	19	38	35	100	300	91	18	2	220
0.23	0.47	74.75	<10	1,100	2	3	80	13	63	77	--	43	24	600	16	34	28	84	270	77	16	2	130
0.23	0.40	74.85	<10	1,200	2	2	76	13	57	70	--	41	23	550	12	34	27	90	260	76	15	1	120
0.32	0.43	75.61	12	790	2	2	72	11	63	52	--	39	20	420	14	29	22	84	260	82	11	1	110
0.48	0.47	68.22	18	970	3	4	110	27	97	160	--	59	30	900	85	52	40	100	300	100	22	2	150
0.53	0.48	67.96	18	960	4	4	120	35	86	170	--	66	28	1,000	110	60	38	100	290	100	26	2	140
0.41	0.52	70.75	<10	920	3	3	110	23	88	110	--	60	26	830	71	47	32	95	310	96	20	2	110
0.39	0.43	72.68	<10	940	3	3	100	28	73	100	--	53	22	860	82	44	28	81	280	90	18	2	87
0.34	0.40	70.06	10	1,300	2	4	90	28	67	70	--	42	22	1,200	100	40	31	79	270	82	17	2	120
0.32	0.40	73.33	16	1,100	2	3	84	20	68	95	--	44	23	1,300	60	41	34	90	260	79	18	2	140
0.39	0.42	71.56	13	520	3	3	92	19	73	110	--	49	24	1,000	84	46	37	74	300	86	19	2	130
0.21	0.42	74.69	<10	1,100	2	2	75	9	62	70	--	41	24	300	23	31	26	75	290	80	14	1	110
0.27	0.43	73.29	<10	1,100	2	2	86	14	69	82	--	46	27	380	20	39	31	100	280	84	17	2	140
0.23	0.42	73.54	<10	970	2	2	72	9	67	92	--	39	25	360	15	31	25	76	280	83	15	2	140
0.23	0.42	73.05	<10	960	2	3	72	13	58	73	--	41	28	560	28	32	27	67	290	77	17	2	160
0.14	0.50	70.85	<10	940	4	4	120	24	35	65	--	65	41	2,200	12	52	20	85	230	61	43	4	280
0.11	0.50	70.84	<10	790	5	3	94	11	27	35	--	45	27	1,200	7	30	14	120	210	61	26	3	180
0.11	0.35	72.94	<10	900	4	2	100	6	24	35	--	50	26	1,000	5	38	15	96	160	42	28	3	180
0.14	0.40	72.83	<10	890	3	3	100	9	35	34	--	55	27	1,100	4	42	17	84	170	49	31	3	200
0.27	0.33	73.81	14	500	2	2	130	3	41	38	--	71	16	220	31	48	8	240	310	66	7	<1	47
0.23	0.35	73.39	<10	670	2	2	110	2	37	34	--	61	15	180	19	42	7	220	240	64	8	<1	35
0.99	0.30	68.69	16	880	3	5	44	17	60	85	--	26	16	260	100	24	16	58	210	73	7	1	56
0.27	0.33	75.84	10	520	2	2	97	1	37	37	--	53	14	170	22	37	6	200	160	59	8	<1	28
0.37	0.42	71.08	10	920	3	<2	100	36	82	170	--	50	32	1,400	64	51	36	97	310	95	21	2	150
0.41	0.63	70.08	13	1,400	3	3	100	19	93	84	--	51	30	590	35	46	40	77	370	100	20	2	170
0.44	0.43	67.55	16	900	4	5	94	42	62	110	--	46	23	2,500	130	52	46	58	290	84	24	2	190
0.25	0.42	74.83	<10	1,300	3	3	82	17	62	76	--	44	24	760	29	36	31	83	280	80	16	2	170
0.37	0.45	73.47	14	840	3	<2	87	15	81	120	--	48	26	690	64	44	32	74	290	89	20	2	110
0.18	0.30	72.90	10	310	5	2	47	22	44	92	--	31	19	310	1,100	20	25	180	220	41	7	<1	99
0.11	0.12	41.30	80	640	<1	14	62	820	<1	1,200	--	35	4	360	1,600	53	630	1,600	640	80	6	<1	850
0.37	0.52	71.46	<10	1,300	3	2	88	18	81	84	--	48	26	890	130	40	35	89	310	100	21	2	160
0.30	0.25	71.37	<10	700	4	2	64	2	31	140	--	40	24	860	370	22	20	200	400	53	17	2	210
0.30	0.50	73.28	13	930	3	2	90	14	67	69	--	50	28	870	52	40	30	71	280	85	23	2	170
0.34	0.48	71.10	<10	1,200	3	2	99	22	83	86	--	54	29	990	53	45	38	80	330	98	22	2	200

concentrations of individual elements that generally occur during a short period of time relative to the time frame of the record in the core. We have grouped the elements in terms of their primary mineralogical residence sites in silicic rock that occurs in the study area.

The sedimentary record cored in upper Fawn Lake differs markedly from that cored in Eagle Rock Lake (table 5, figs. 7–12). For the most part, the geochemical data from sediment from upper Fawn Lake show minor variations throughout the period sampled. The single most striking feature of the geochemical data from the upper Fawn Lake core is the large number of trace elements that were concentrated during what we interpret as the 1979 flood event. Many of the trace elements enriched at this depth in the core occur primarily or exclusively in heavy-mineral phases that would be mobilized during high flow (tables 2 and 5). Minerals identified by x-ray defraction in the upper Fawn Lake core sample (02QNM102Ly, depth of 25 cm, and within the interval identified as the 1979 flood event) included quartz with minor amounts of montmorillonite, muscovite (illite or sericite), kaolinite, and potassium feldspar (R. Driscoll, written commun., 2003). In contrast, data from sediment from Eagle Rock Lake are substantially different. Plots of three groups of elements, the large-ion-lithophile (LIL) elements (figs. 9 and 10), the major and minor elements (figs. 7 and 8), and the deposit-related metals (fig. 12) generally show markedly different geochemical behavior in the sediment from Eagle Rock Lake before and after the flood-of-record in 1979 (table 5). Many elements show marked changes in the baseline geochemical concentrations after the 1979 flood event (shown by the gray bands on figs. 7–12). Many of the elements in the heavy-mineral phases (Mo, Cu, Zn, Cd, Ba, and Be) had peak concentrations during the 1979 flood event and concentrations of the REE were increasing. Minerals were identified by x-ray defraction in two samples from Eagle Rock Lake. Sample 02QNM101Lax (depth of 50 cm and below the depth of the 1979 flood record) contained quartz, muscovite (illite or sericite), and minor clinochlore. Sample 02QMN101Lz (depth of 26 cm; contained highest concentration of Ce) included quartz and minor amounts of montmorillonite like that found in upper Fawn Lake. Fluorite and REE-bearing minerals were not found at concentrations sufficient to identify by X-ray diffraction (about 1 percent by volume). No pyrite or molybdenite was identified and no iron oxide minerals that might be carriers of REE, Nb, and Y were identified (R. Driscoll, written commun., 2003). Correlation of peak concentrations of the elements associated with heavy-mineral phases and the abrupt change in geochemical baselines in this interval (figs. 7–12) is the basis of the calibration of the geochronology of the two cores in the 1979 flood record. Using these calibration points and assuming a uniform sedimentation rate, the data form the sedimentation model shown in figure 13. This model indicates a slightly higher rate of sedimentation at the core site in upper Fawn Lake prior to the 1979 flood and a slightly higher rate of sedimentation at the core site in Eagle Rock Lake following the 1979 flood event. However, the sedimentation rate, as shown by the work of Allen and others (unpub. data, 1999) and by URS Corp. (written commun., 2004), varies significantly within the lake, from the inlet to the outlet, and, as pointed out by URS Corp. (written commun., 2004), probably has varied during the period of record in the lake.

Table 4. Mean daily peak flow at the Questa gage (08265000), lower Red River valley, Taos County, New Mexico

[Flow expressed in cubic ft per second (cfs)]

Year	Period	Mean daily peak-flow rate (cfs)	Number of days flow exceeded 300 cfs
1965	June 18–20	320	3
1973	June 14–15	314	2
1979	May 20–July 3	557	44
1983	May 30–June 2	332	4
1984	May 23–May 28	372	6
1985	May 10–11	319	2
1985	June 9–June 13	322	5
1986	June 8–June 9	325	2
1991	May 21–May 24	469	4
1993	May 28	301	1
1994	May 16–June 8	399	21
1995	June 14–June 23	359	10
1997	June 2–June 8	347	7

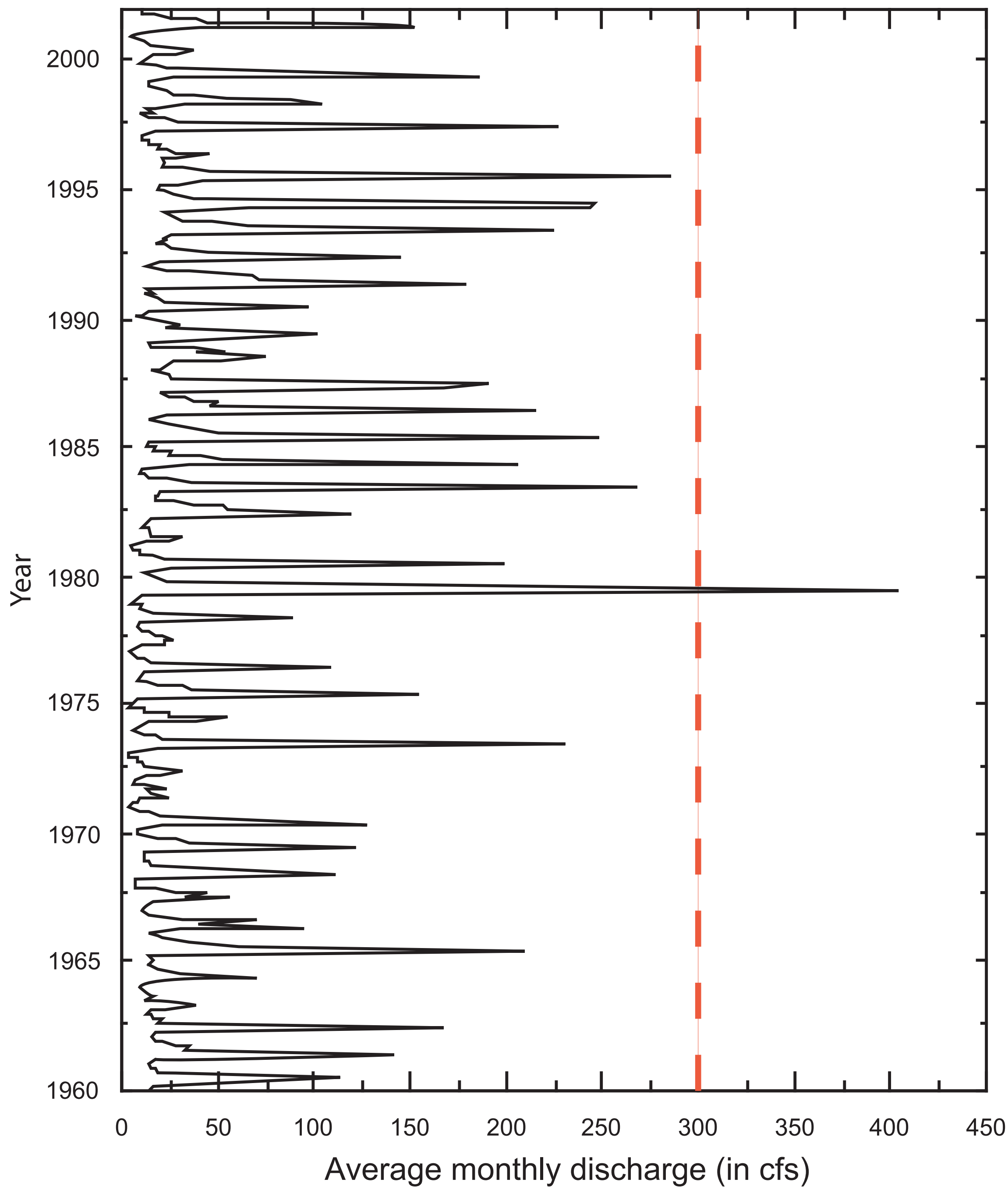

Figure 5. Plot of monthly discharge (cfs) versus time (1960–2002) at the gage (08265000) at Questa, New Mexico (http://nm.waterdata.usgs.gov/nwis). The flood-of-record occurred in spring, 1979 (table 4).

Table 5. Summary of the geochemical data from cores from upper Fawn Lake and Eagle Rock Lake, Red River valley, Taos County, New Mexico.

Upper Fawn Lake

		Silicates								Oxides			Sulfides							Accessory minerals										
Depth (cm)	Year	Na	K	Mg	Ca	Al	Si	Fe	Mn	Ti	V	Cr	Pb	Co	Ni	Mo	Cu	Zn	Cd	Li	Be	Sr	Ba	P	F	La	Ce	Nd	Yb	Y
1	2002								■				■																	
2			■					■					■											■						
3			■					■					■											■	■					
4													■										■	■						
5													■										■	■						
6			■					■		■			■									■	■	■						
7										■			■									■		■	■					
8		■					■																							
9		■						■		■	■	■								■		■	■	■						
10		■						■			■	■										■	■	■	■					
11								■			■	■				■								■						
12							■	■								■		■						■						
13							■	■								■		■	■											
14		■			■		■	■							■		■	■	■											■
15		■			■		■	■							■		■	■	■					■			■		■	■
16		■			■													■				■					■			
17		■			■						■	■						■		■		■								
18		■			■																	■								
19		■			■																					■	■	■	■	■
20		■																												
21			■			■					■	■	■	■								■		■						
22			■		■	■			■		■	■	■	■				■				■		■	■					
23					■						■		■									■		■						
24											■	■	■									■	■							
25	1979	■	■	■		■		■			■	■	■	■	■		■	■		■	■	■	■	■	■					
26	1979							■		■	■	■	■									■	■	■						
27	1979									■	■	■	■									■	■							
28							■																■							
29		■								■	■		■									■	■	■						
30		■			■			■		■	■											■								
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44			■								■		■							■			■							
45			■					■			■						■			■		■								
46			■			■		■					■	■								■		■	■					
47			■				■						■										■							
48			■					■			■		■			■				■										
49	1964	■						■		■	■			■						■										
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Table 5. Summary of the geochemical data from cores from upper Fawn Lake and Eagle Rock Lake, Red River valley, Taos County, New Mexico—*Continued*.

Eagle Rock Lake

		Silicates								Oxides			Sulfides							Accessory minerals										
Depth (cm)	Year	Na	K	Mg	Ca	Al	Si	Fe	Mn	Ti	V	Cr	Pb	Co	Ni	Mo	Cu	Zn	Cd	Li	Be	Sr	Ba	P	F	La	Ce	Nd	Yb	Y
1	2002																													
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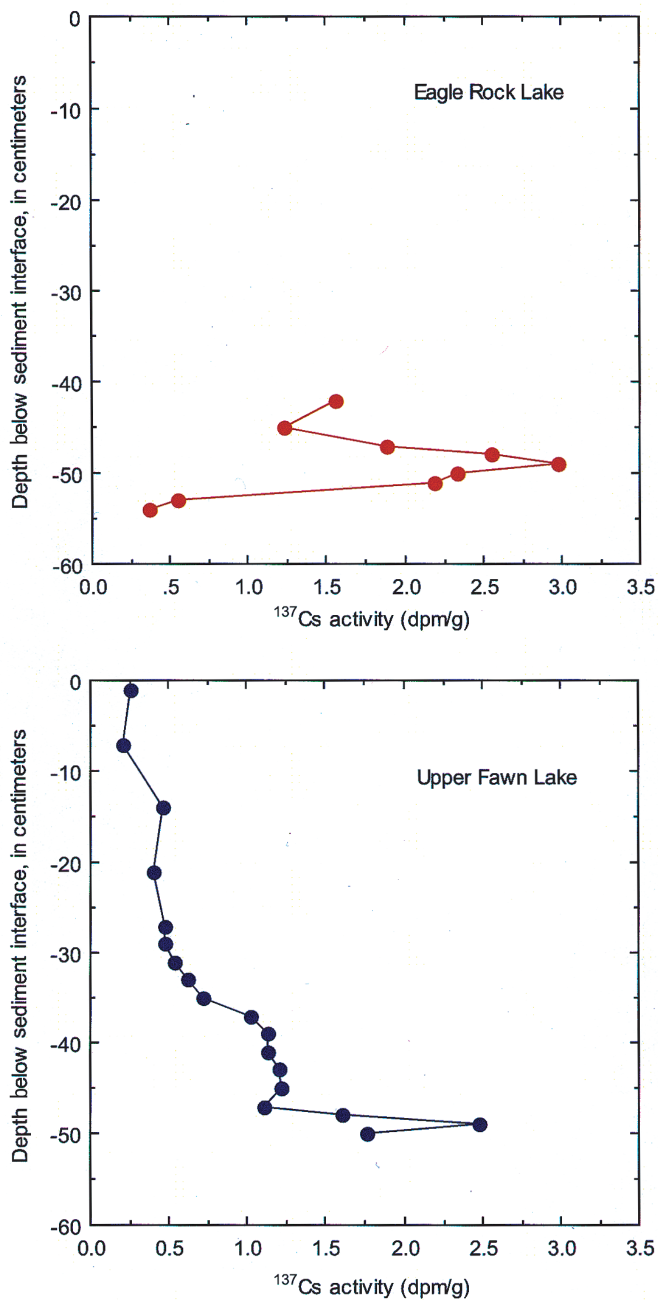


Figure 6. Plot of ^{137}Cs concentration versus depth (cm) in the Eagle Rock Lake and upper Fawn Lake cores. Well-defined peaks in ^{137}Cs activity occur at slightly different depths in the two lakes, but both are quite close to the bottom of the core where we encountered fragmented bedrock. Since the lakes originated as borrow pits dug to complete the paving of N. Mex. Highway 38 from Questa to the town of Red River, the differences in sedimentation at the bottom of the core reflects the fact that roadwork began at Questa in the mid-1950s and was completed at the town of Red River in 1961. Head gates were installed by the local irrigation organization, which subsequently limited flow through and thus sediment accumulation in the two lakes.

Element Anomalies

Sediment in upper Fawn Lake is characterized by occasional peaks in element concentrations above the general geochemical baseline recorded in the sediment core (table 5). Enrichment of different suites of elements occur throughout the core. The element suites K, Fe, Pb, P, and Ti and V, Cr, and Pb have peaks that occur at some intervals, whereas the suite Na, Ca, Fe, Ni, Cu, Zn, and Cd peaks occur at other depths in the core (table 5 and figs. 7–12). The two primary sources for sediment for upper Fawn Lake are Precambrian rock upstream of the town of Red River (Jackson and others, 2003) and the altered areas that occur between Red River and upper Fawn Lake (fig. 1). Ludington and others (2005) document the high erosion rates that occur in the altered areas during summer rainstorms. The element suites formed during wet years (Fe, V, Cr, and Pb) contain many of the elements enriched in sediment from the scar areas (table 3). Finally, there is a pronounced Ca and Sr peak in the core from 14- to 18-cm depth, which we interpret as an anthropogenic source—probably concrete associated with building activity in the floodplain in the town of Red River or vicinity.

Peak concentrations in the Eagle Rock Lake core are much more varied and frequent. We identify several periods where different trace-element suites appear in the Eagle Rock Lake core. Examination of the elemental associations prior to the 1979 flood shows that the element suite Al, Ti, V, Cr, Cu, Zn, Li, and F peaked in the interval between 48 to 52 cm, and that the element suite K, Mg, V, Cr, Pb, Mo, and Li peaked in the interval from 40 to 41 cm (tables 5 and 6 and figs. 7–12). The rare earth element anomalies begin to appear in the core from Eagle Rock Lake periodically at a depth of 45 cm, after excavation of the open pit. However, at the 1979 flood event, there were abrupt changes in the concentrations of many of the major elements (figs. 7 and 8). These fundamental changes indicate that a new source of sediment was introduced into the Red River floodplain downstream from Fawn Lakes following the 1979 flood event (shown as gray bands on figs. 7–12). Following the 1979 flood event, there was a dramatic increase in the concentration of Al, Ba, Co, and Ni and a dramatic decrease in the concentrations of Na, K, Mg, Fe, Ti, Cr, and V in the sediment cored at Eagle Rock Lake. The REE and F peaks (fig. 10) lag somewhat behind the 1979 flood event in the Eagle Rock Lake core but correspond with the 1979 flood event in the upper Fawn Lake core. Note also that the REE anomalies in the Eagle Rock Lake core greatly exceed those in the upper Fawn Lake core.

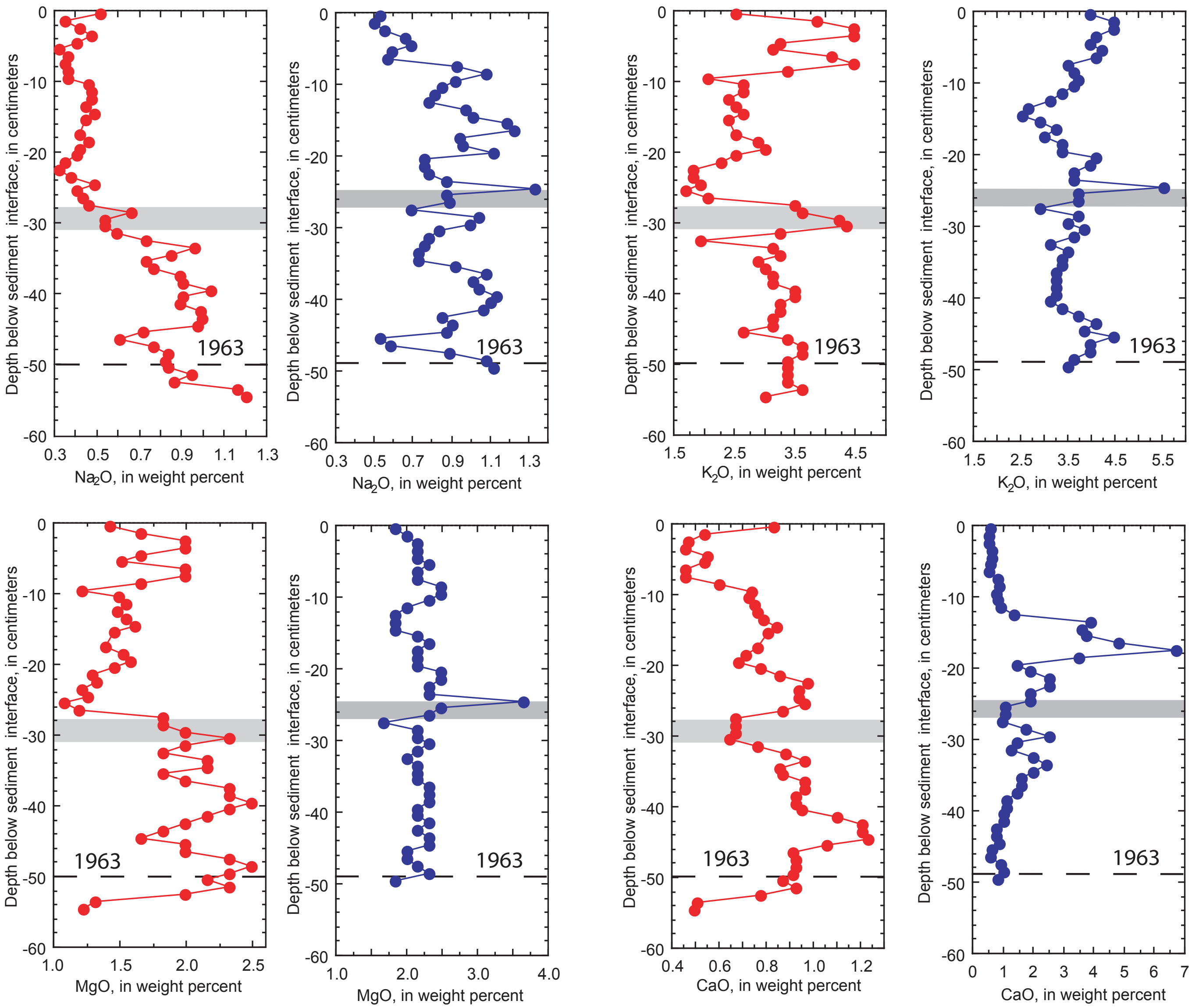


Figure 7. Plot of concentrations of Na_2O, K_2O, MgO, and CaO, expressed as oxides, versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record.

Comparison of the Data from the Two Lake-Sediment Cores

Comparisons of the sediment geochemical data from the two lake cores are in figure 14. Five major elements, Na_2O, MgO, FeO, Al_2O_3, and TiO_2, and six trace elements, Ba, Sr, Cr, V, Cu, and Zn, are presented as box plots to show the difference between sediment deposited in the two lakes before and after 1979. The 1979 core intervals plotted are shown in table 5. The range of values between the 25th and 75th percentiles is remarkably small for many elements. Figures 14*A* and 14*B* compare element concentrations in sediment from upper Fawn Lake prior to and subsequent to the 1979 flood. The small ranges and median concentrations from pre-1979 and post-1979 sediment are very similar indicating no change in the source of sediment following the 1979 flood. In contrast, the geochemical data from Eagle Rock Lake (figs. 14*C* and 14*D*) show the marked contrast between sediment deposited prior and subsequent to the 1979 flood with only Sr, V, and Cr showing little change with time. Those changes are also shown relative to the data from upper Fawn Lake in figures 14*E* and 14*F*. All five of the major elements showed substantial changes in concentration indicating a new source of sediment following the 1979 flood. In fact, the concentration ranges of the major elements Na_2O, MgO, FeO, Al_2O_3 and TiO_2 do not even overlap between the 25th and 75th percentiles. In figures 14*G* and 14*H*, we compare the geochemical data from sediment in Eagle Rock Lake from pre-1979 with all of the data from the sediment core from upper Fawn Lake. Only concentrations of Cu and Zn are elevated in the pre-1979 sediment from Eagle Rock Lake relative to that in sediment from upper Fawn Lake.

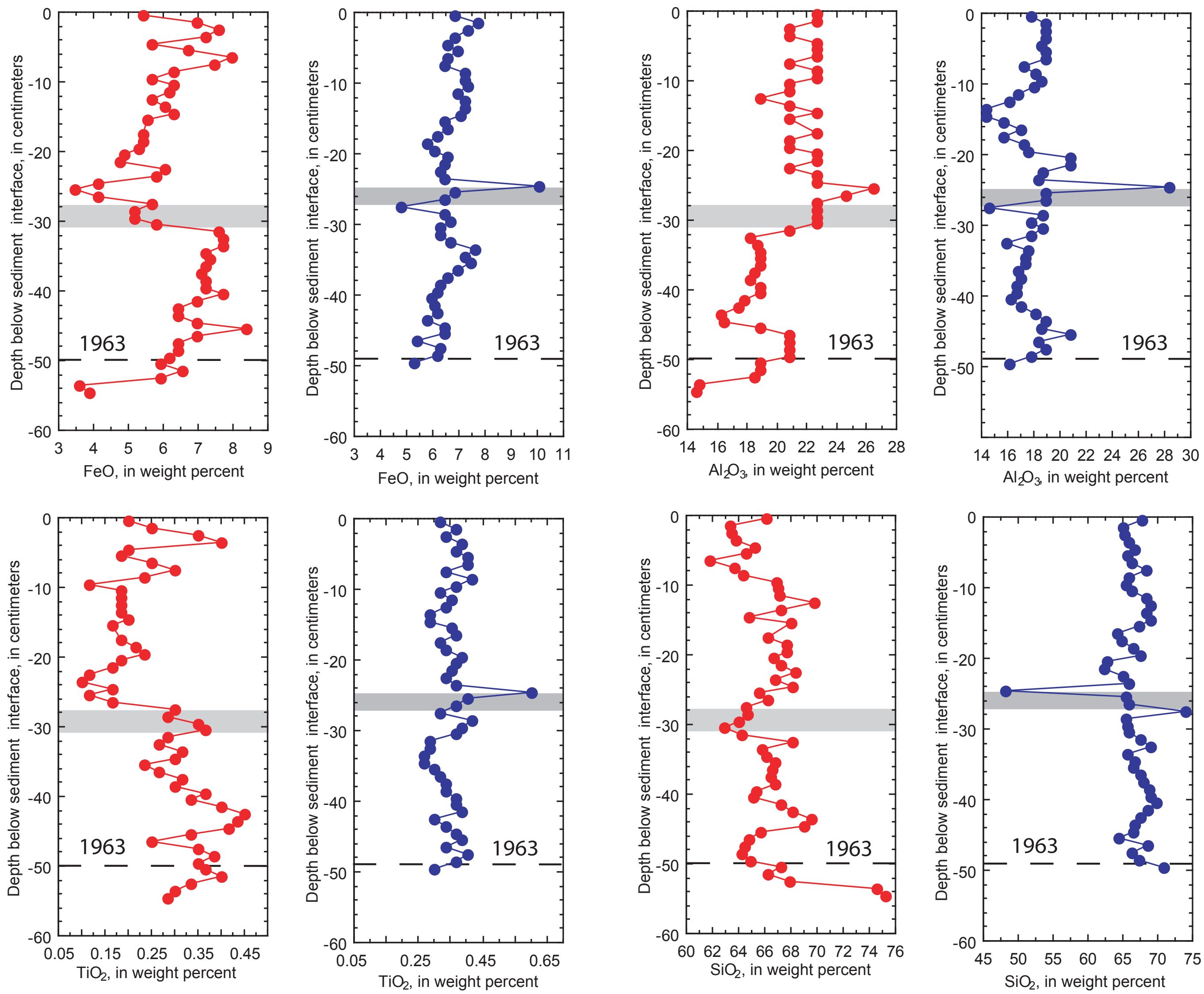


Figure 8. Plot of concentrations of FeO, Al_2O_3, TiO_2, and SiO_2, expressed as oxides, versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record. Concentrations of SiO_2 were determined by subtracting the sum of the major element concentrations from 100.

Element Suites that May Be Related to Mining

Different element suites can be associated directly with the mining and processing of ore at the Questa mine (table 6). There is a pattern of molybdenum enrichment in the Eagle Rock Lake core from the early 1960s (fig. 12). There are also increases in concentrations of Cu, Zn, Co, and Ni (figs. 11 and 12), all of which are associated with porphyry molybdenum deposits (see for example Carten and others, 1993). We interpret this progressive enrichment with time of this suite of elements to indicate that the beginning of development of open-pit mining at Questa, which began in 1965, was having an increasing effect on the availability of this suite of elements to erosion and transport by the Red River. Concentrations of elements present in the Precambrian rock in the pyroxene/amphibole suite were reduced with time, and concentrations of elements associated with sulfide mineral phases associated with the Questa ore body increased. The most direct and compelling evidence of this hypothesis is the increase of the size of the molybdenum peak with the continued development of the open pit (1963–1967; table 6 and fig. 12). The Mo peak begins to increase prior to the development of the open pit because the mine waste from the underground vein mining that occurred from 1921 to 1958 at the site would have had to be removed prior to open-pit development.

A second peak of Mo enrichment, which occurs between 36 and 40 cm (1970–1978, table 6), does not have any other

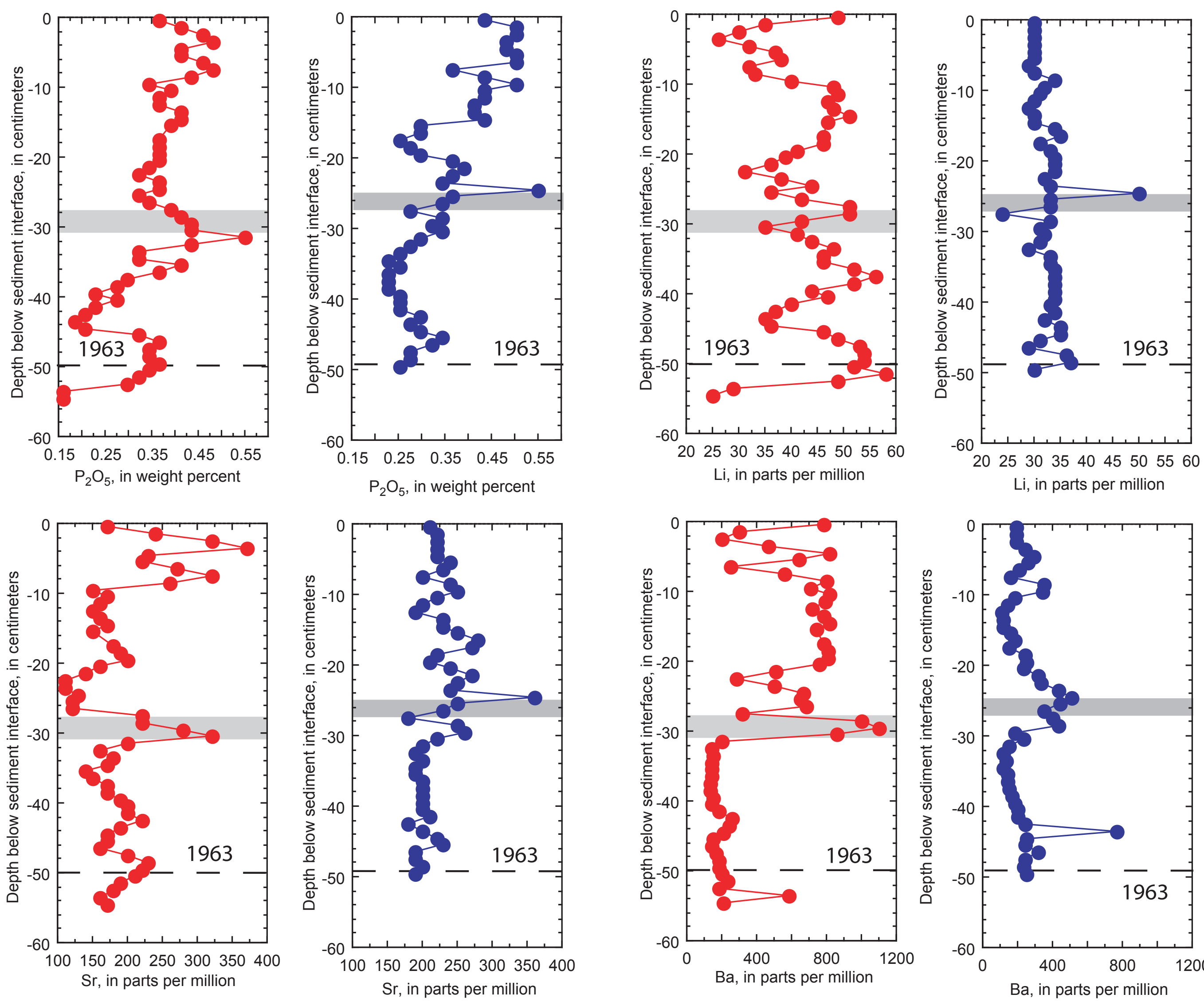


Figure 9. Plot of concentrations of P_2O_5, expressed in weight percent, and Li, Sr, and Ba, expressed in parts per million (ppm), versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record. Crustal abundance values (Fortescue, 1992) of these elements are: P (1,120 ppm), Li (18 ppm), Sr (384 ppm), and Ba (390 ppm).

deposit-related metals associated with this buildup (fig. 12). We interpret this prominent peak at 38-cm depth as either a product spill (truck accident) or perhaps a buildup of Mo in the lake sediment following a period of high ore production at the Questa mine. The peak concentration of Mo tailed off quickly suggesting that the peak may have been the result of changes in mill operation that reduced the air pollution from the mill. A similar high peak concentration of Mo deep in the cores from Eagle Rock Lake was also reported by Allen and others (unpub. data, 1999). The cause of this peak cannot be determined without access to detailed production and maintenance records from the Questa mill, which have not been made available by Molycorp.

There are various peaks in concentration of Cu, Zn, Co, Ni, and REE that may be explained by breaks in the pipeline that carried mill wastes to the repository. The mill-waste pipeline parallels N. Mex. Highway 38 from the mill site (fig. 1) to a tailings repository west of the town of Questa. URS Corp. (written commun., 2003) has documented hundreds of pipeline breaks from Molycorp records during the life of the Questa mine. The vast majority of these spills were small and readily cleaned up by Molycorp (URS Corp., written commun., 2003). At the site of the 1981 Goat Hill Campground (fig. 1), there is a substantial amount of mill tailings dispersed among the trees. The U.S. Department of Agriculture (USDA) Forest Service provided photographs of this 1981 pipeline break (fig. 15*A*). The photographs appear to indicate that a substantial amount of mill waste was lost during this event. Analysis of four mill-waste samples

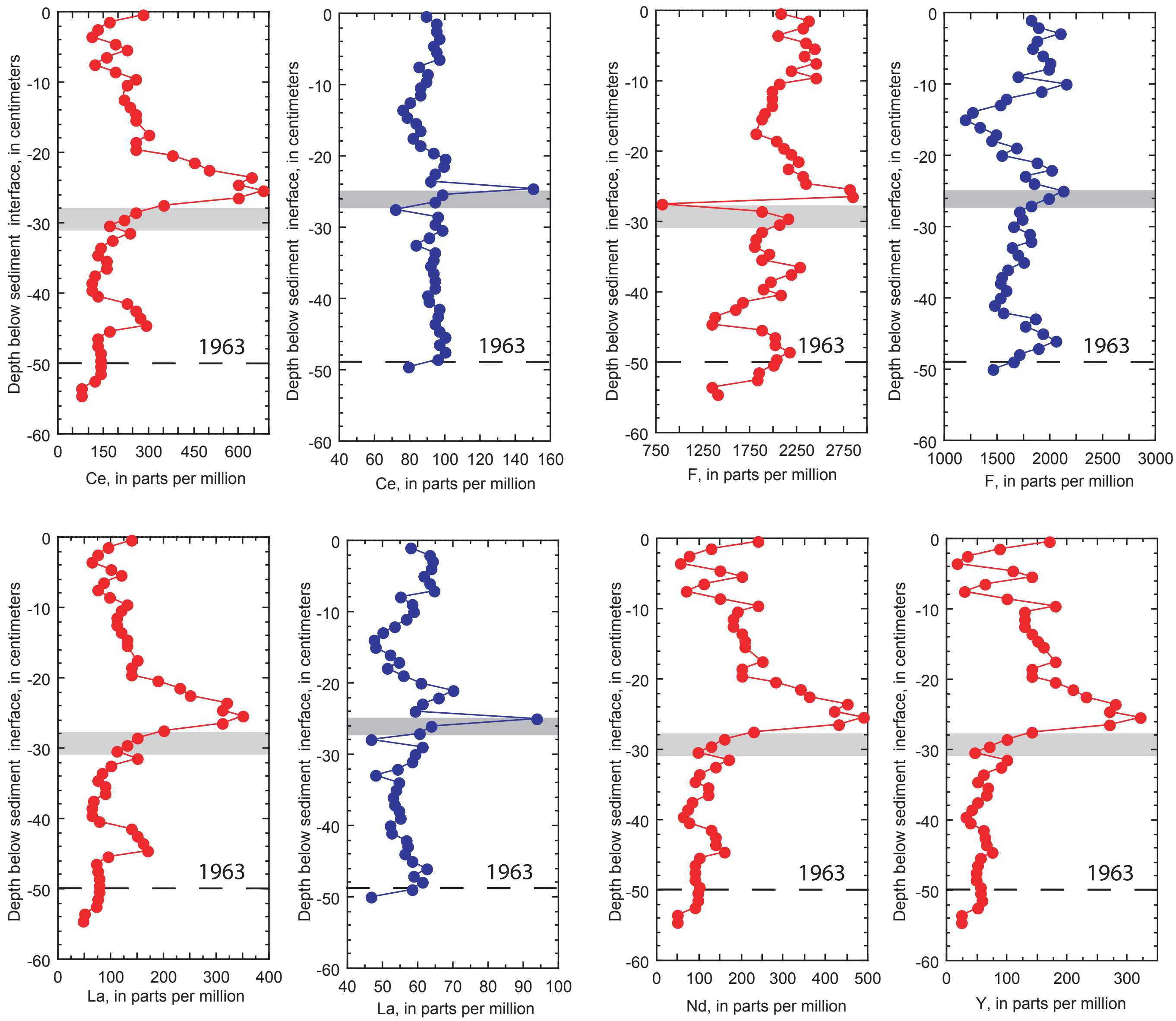


Figure 10. Plot of concentrations of Ce, F, La, Nd, and Y, expressed in parts per million (ppm), versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record. Crustal abundance values (Fortescue, 1992) of these elements are: F (544 ppm), La (34.6 ppm), Ce (66.4 ppm), Nd (39.6 ppm), and Y (31 ppm).

collected in 2003 (table 3) along the Red River at the Goat Hill, Capulin, and 1979 flood pipeline-break sites have remarkably similar compositions and relatively low average metal concentrations (Mo, 340 ppm; Cu, 94 ppm; Pb, 120 ppm; Zn, 170 ppm; Co, 16 ppm; and Ni, 30 ppm), which are very similar to those in the mill waste stream analyzed by Molycorp (B. Walker, written commun, 2004). However, a fifth sample of mill waste (03QNM101T) collected inside a piece of pipe in the Molycorp pipeline yard, where it had been protected from weathering, gave higher concentrations of the metals listed in table 3 (Mo, 1,600 ppm; Cu, 1,200 ppm; Pb, 1,600 ppm; Zn, 850 ppm; Co, 820 ppm; and Ni, 630 ppm). Concentrations of As (80 ppm) and Cd (14 ppm) were also elevated in this sample of mill waste (table 3). This suite of metals reside in the sulfide phases in the Questa ore body (Ross and others, 2002), and, with the exception of Mo, they are not recovered in the milling process. They appear to be a heavy-mineral suite concentrated in the pipe. A sixth sample collected from a site on the south side of Highway 38 across from the Molycorp mill (03QNM209T, table 3) contains elevated concentrations of Mo (1,100 ppm), but concentrations of other metals are similar to those found in the mill tailings samples. Concentrations of the REE in the mill tailings samples do not approach peak concentrations of REE found in the core from Eagle Rock Lake (fig. 10 and table 3).

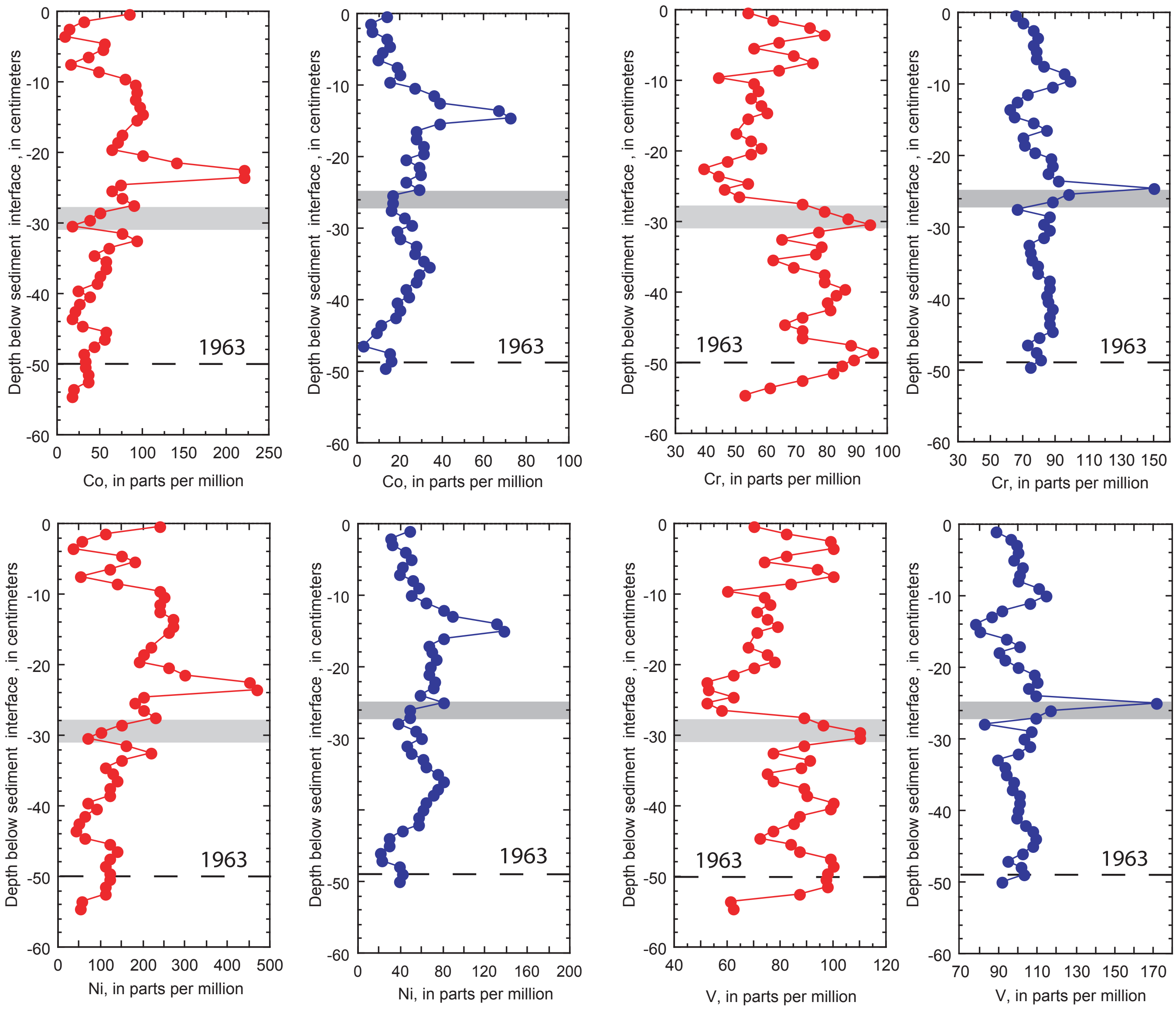


Figure 11. Plot of concentrations of Co, Cr, Ni, and V, expressed in parts per million (ppm), versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record. Crustal abundance values (Fortescue, 1992) of these elements are: Co (29 ppm), Cr (122 ppm), Ni (99 ppm), and V (136 ppm).

REE from the Magmatic Hydrothermal Breccia, Questa Ore Body

Concentrations of REE in rock of the Questa caldera are high and enriched in light REE typical of highly evolved silicic volcanic rock. Plots of the chondrite-normalized REE data from volcanic and plutonic rock from the study area (figs. 16*A* and 16*B*) show that the median REE concentrations from the upper Fawn Lake core are quite similar to that from the Amalia Tuff and some of the granitic plutons. The range of REE concentrations in sediment from upper Fawn Lake is small when compared to the range from Eagle Rock Lake (tables 1 and 2). REE concentrations in sediment from the core from Eagle Rock Lake are substantially higher than rock typical of the evolved rhyolitic Amalia Tuff (fig. 16*A*), have a small Eu anomaly, and are more enriched than the REE concentrations in the peralkaline granite (fig. 16*B*). Whereas Lipman (1983) and Johnson and others (1989) report lavas that are somewhat more evolved and have greater REE enrichment than those patterns shown in figure 16*A*, ranges of REE concentrations in the Eagle Rock Lake core far exceed values reported for typical volcanic and plutonic rock (fig. 16*B*) from the caldera. Neither the Oligocene volcanic rock of the Latir caldera nor the REE present in the mill tailings can account for the REE anomalies in the Eagle Rock Lake sediment (fig. 10).

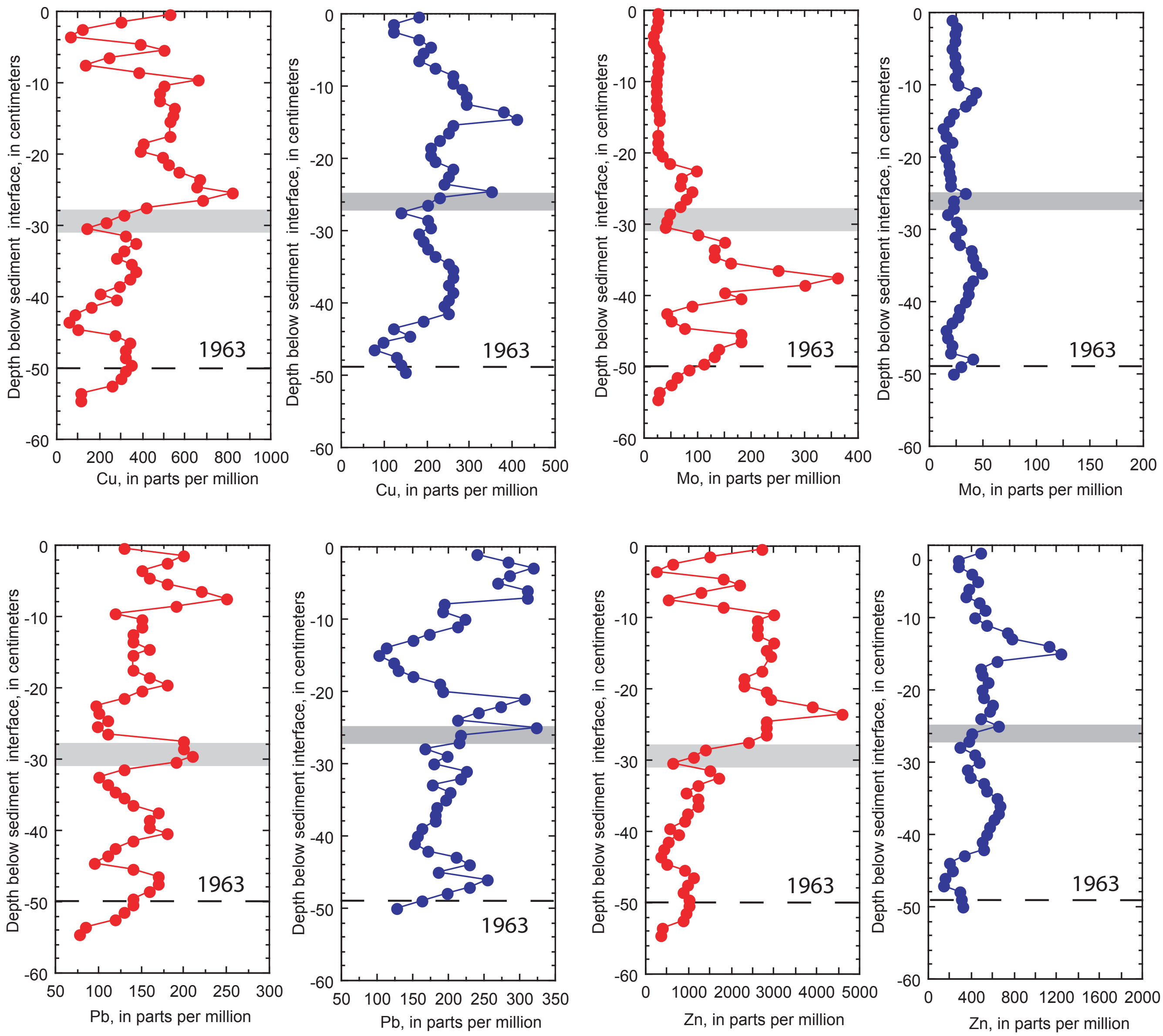


Figure 12. Plot of concentrations of Cu, Mo, Pb, and Zn, expressed in parts per million (ppm), versus depth below the sediment interface for the cores from upper Fawn Lake (blue) and Eagle Rock Lake (red). Bands are shown where we interpret the geochemical and stratigraphic data to indicate the sediment deposited by the 1979 flood-of-record. Crustal abundance values (Fortescue, 1992) of these elements are: Cu (68 ppm), Mo (1.2 ppm), Pb (13 ppm), and Zn (76 ppm).

The magmatic hydrothermal breccia associated with the D ore body described in Ross and others (2002) contains abundant fluorite. Since this is the residual or pegmatitic phase from the hydrothermal crystallization process, we requested samples of the magmatic hydrothermal breccia from Molycorp for chemical analysis to evaluate possible enrichment of the REE in this late crystallization phase of the deposit. Meghan Jackson (Molycorp) provided about a dozen samples of the magmatic hydrothermal breccia from the D ore body and one sample of fluorite from veins exposed in Sulfur Gulch (QSFG, table 7). We analyzed the Sulfur Gulch fluorite and four samples of the magmatic hydrothermal breccia from the D ore body (fig. 17). Samples analyzed were selected on the basis of their variation in texture. Three of the five samples (QF-2, QF-3, and QF-4) were disaggregated, and the white and green non-sulfide phases were separated by handpicking for analysis. Sample descriptions accompany figure 17 and the analytical results are in table 7. The white phase was a carbonate-rich phase that was almost completely dissolved in HNO_3. The data from the carbonate phases indicate that they are enriched in Mn and Li but were not particularly enriched in any of the other trace elements. In contrast, the fluorite phase in samples QF-3 and QF-4, which appeared to be equigranular with discrete banded layers of fluorite and calcite, contained elevated REE concentrations. However, the concentrations are not sufficient to explain the REE anomalies in the Eagle Rock Lake sediment core without some enrichment mechanism. This is in contrast with the data from a more coarsely crystalline vein fluorite and carbonate sample (QF-2) where both Mn and the REE concentrations are not as enriched in either the calcite or fluorite phases in the other two samples. This more coarsely crystalline vein material does have substantially more Ba in the calcite, however, than the other calcite magmatic hydrothermal breccia samples (table 7). Fluorite from the vein sampled in Sulfur Gulch (QSGF-1) contains low concentrations of Mn, Ba, and REE. These two samples may represent fluorite veins that formed prior to ore deposition.

Electron backscatter photomicrographs taken on the SEM by Sharon Diehl (written commun., 2003) show that three REE-bearing phases occur as small inclusions in the fluorite: a hexagonal mineral identified as synchysite, a Ca, REE-rich carbonate, a REE-rich $CaSO_4$, and a REE-rich Ca phosphate mineral (fig. 18). Geoff Plumlee (oral commun., 2003) identified microscopic occurrences of a rare-earth carbonate-fluoride mineral, possibly synchysite, in bedrock drill cuttings from drill hole SC-5B in Straight Creek (Ludington and others, 2005) where they appear to be associated with hydrothermal quartz-pyrite-carbonate veins and disseminations in the altered rock. The magmatic hydrothermal breccia forms a substantial component of the ore bodies mined at Questa (B. Walker, Molycorp., oral commun., 2003). Analyses of F in both the sediment from the altered areas (table 3) and from the Eagle Rock Lake core over the interval where the REE anomaly occurs (table 1 and fig. 19) indicate that there are increased F concentrations (2,840 ppm) coincident with the increase in the REE concentrations that is about double the 1,450 ppm F that could be attributed to erosion from the altered areas upstream of the Questa deposit. Spills of mill tailings resulting from pipeline breaks such as the Goat Hill Campground spill could account for the REE anomalies found in the Eagle Rock Lake core providing some mechanism of REE enrichment could be found. Fluorine concentration data from the core interval where the REE peak occurred in the sediment from Eagle Rock Lake indicate that peak F enrichment occurred subsequent to the 1979 flood event. Weathering of the REE from REE-bearing carbonate minerals in the fluorite would occur rapidly in the locally acidic microenvironment of the tailings deposit as a result of weathering of the sulfide minerals present in the mill tailings. The REE, which have low solubilities in near-neutral SO_4^{-2} solutions and follow the behavior of aluminum (Verplanck and others, 1999), would be immediately precipitated at the pH of the water in the Red River as $REE_2(SO_4)_3$ and transported as colloids to be incorporated into the sediment core from Eagle Rock Lake. Although we cannot demonstrate that the 1981 Goat Hill Campground spill (fig. 15) was responsible for the REE anomaly found in the Eagle Rock Lake core, we have found no other

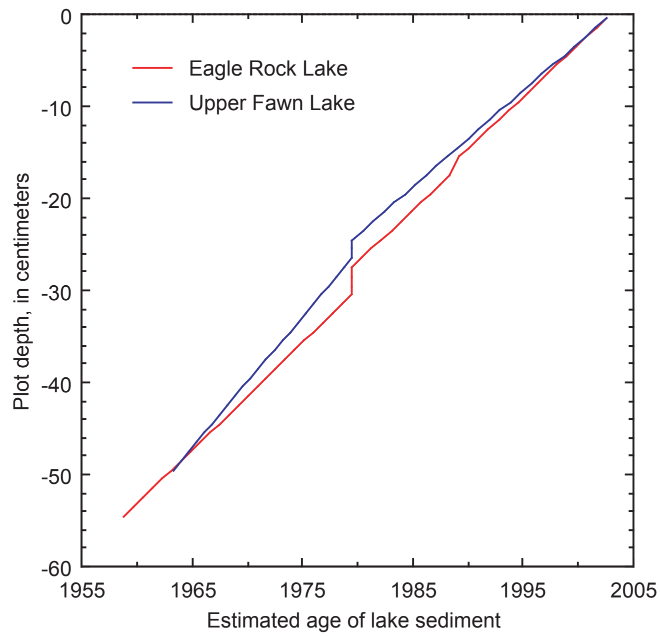


Figure 13. Plot of the sedimentation rate used for both the Eagle Rock Lake and upper Fawn Lake cores. The depth of the 1964 ^{137}Cs peak and the geochemical data from the 1979 flood-of-record were used to constrain the sedimentation model (tables 1, 2, and 5).

Table 6. Dates for some trace element anomalies in the sediment core from Eagle Rock Lake, lower Red River valley, Taos County, New Mexico.

Molybdenum	Copper-Zinc	Cobalt-Nickel	Rare Earth Elements
	1961–1966	1966–1967	
1963–1967			
			1967–1970
1970–1978			
		1977	
	1973–1979		
1980–1985			
	1980–1987	1983–1986	1979–1986
			1988–1990
	1988–1995	1989–1994	
	1997–1999	1998–1999	1998–1999
	2002	2002	

plausible sources of elevated REE and F other than those in the fluorite and carbonate magmatic hydrothermal breccia that could account for these anomalies .

Results from Stream-Sediment Survey

The geochemical data from the NURE and from our sediment study of both premining and modern stream sediment are summarized in figures 20 and 21. Distances are plotted as river-km measured upstream from the confluence of the Red River with the Rio Grande River; the Questa open pit is at 18–22

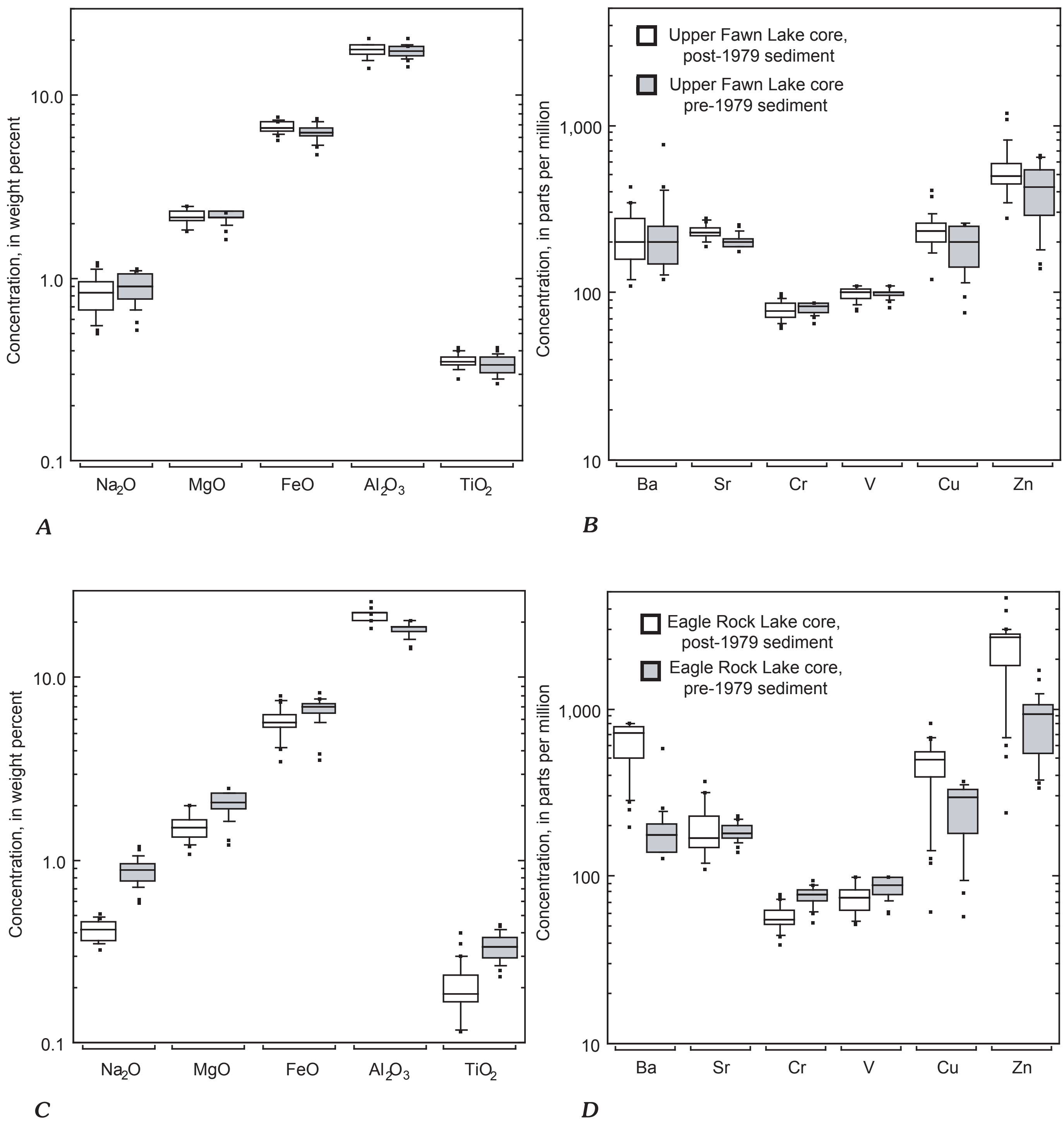


Figure 14 (above and facing page). Box plot comparing geochemical data (breaks are as shown in table 5). The median value for each element is bracketed by the 25th and 75th percentile of the data forming the box; the 10th and 90th percentiles are indicated by the lines above and below the box; and the 5th, 95th, minimum, and maximum values are shown as black dots above and below the 10th and 90th percentiles. ERL, Eagle Rock Lake. *A*. Major element data for Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from the pre-1979 (n=23) and the post-1979 (n=24) intervals from upper Fawn Lake core (table 2). *B*. Trace element data for Ba, Sr, Cr, V, Cu, and Zn from the pre-1979 (n=23) and the post-1979 (n=24) intervals from upper Fawn Lake core (table 2). *C*. Major element data for Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from the pre-1979 (n=24; ERL pre-1979) and the post-1979 (n=26; ERL post-1979) intervals from Eagle Rock Lake core (table 1). *D*. Trace element data for Ba, Sr, Cr, V, Cu, and Zn from the pre-1979 (n=24; ERL pre-1979) and the post-1979 (n=26; ERL post-1979) intervals from Eagle Rock Lake core (table 1).

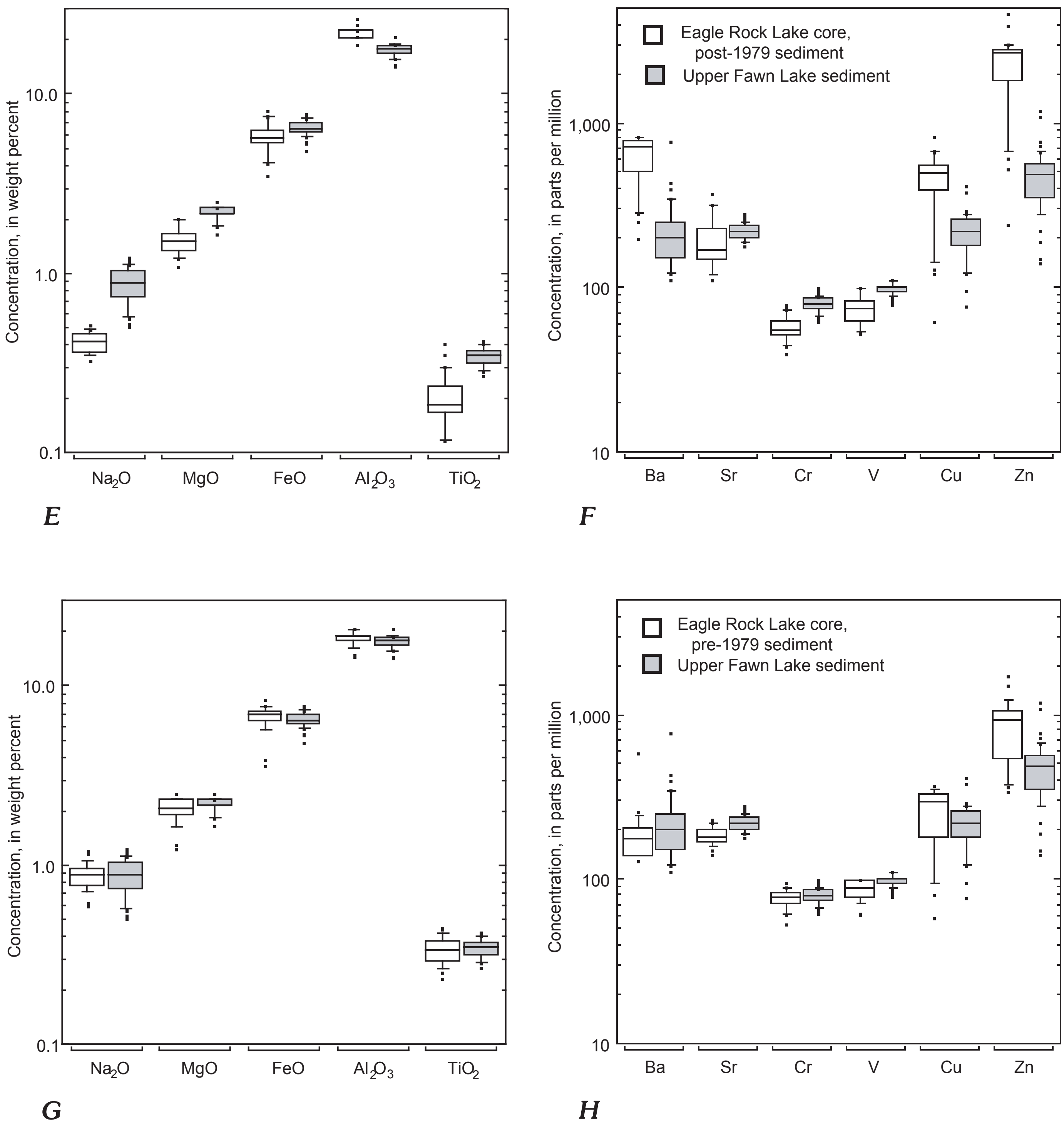


Figure 14 (continued). Box plot comparing geochemical data (breaks are as shown in table 5). The median value for each element is bracketed by the 25th and 75th percentile of the data forming the box; the 10th and 90th percentiles are indicated by the lines above and below the box; and the 5th, 95th, minimum, and maximum values are shown as black dots above and below the 10th and 90th percentiles. ERL, Eagle Rock Lake. *E*. Major element data for Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from upper Fawn Lake core (table 2, n=50) and the post-1979 (table 1, n=26) intervals from Eagle Rock Lake core. *F*. Trace element data for Ba, Sr, Cr, V, Cu, and Zn from upper Fawn Lake core (table 2, n=50) and the post-1979 (table 1, n=26) intervals from Eagle Rock Lake core. *G*. Major element data for Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from upper Fawn Lake core (table 2, n=50) and the pre-1979 (table 1, n=24) intervals from Eagle Rock Lake core. *H*. Trace element data for Ba, Sr, Cr, V, Cu, and Zn from upper Fawn Lake core (table 2, n=50) and the pre-1979 (table 1, n=24) intervals from Eagle Rock Lake core.

Figure 15. Photographs of the 1981 mill tailings spill at the USDA Forest Service Goat Hill Campground showing the tailings spill from the pipeline break (*A*), the cleanup by Molycorp (*B*), and (*C*) mill tailings sediment in the Red River, winter of 1981. (Photos from USDA Forest Service files provided by George Long, Questa Ranger Station, N. Mex., 2003).

river-km. The variation of Sr, Cr, V, and Mo in the Red River sediment is small relative to source areas, whereas Ba, Ce, and Cu show an increase downstream of the Questa deposit. Zinc shows a broad zone of enrichment in the Red River sediment downstream of the altered areas as well. Concentrations of all metals shown are generally higher in the altered areas and in the south-flowing tributaries in the NURE data, except for Zn, than in the Red River sediment (2002). Many of the north-flowing tributaries, which in part drain unaltered Precambrian rock south of the Red River, have metal concentrations near that in the Red River sediment or have concentrations lower than the altered areas. Median sediment values from upper Fawn Lake match well for Sr, are lower than the Red River sediment for Ba, and elevated for the other six elements shown (figs. 20 and 21, table 9)—plotting in the field defined by data from the tributaries. Concentrations of Cu (220 ppm) plot above the range shown in fig. 21. Relative to the concentrations found in the Red River sediment, median values in the post-1979 sediment of Eagle Rock Lake for Cr and V match well (fig. 20 and table 8), but values for Ba and Sr are lower. Median concentrations in the sediment core of Eagle Rock Lake after 1979 (table 8) are twice that in the Red River sediment for Mo, but median concentrations for Ce (260 ppm), Cu (500 ppm), and Zn (2,650 ppm) plot above the upper boundary of the diagram for these elements (fig. 21). We conclude that sediment supplied by the Red River *at low flow* in 2002 is not the same source of sediment in the post-1979 core from Eagle Rock Lake.

Comparison of Lake Sediment Geochemistry with Other Sources

Sediment from upper Fawn Lake is not dominated by material eroded from the altered areas such as were sampled in Hottentot and Straight Creeks (fig. 1), but the contribution from the altered areas to the trace-element suite is significant (fig. 22). Comparison of the sediment data from the altered areas with upper Fawn Lake sediment (figs. 22*A* and 22*B*) shows higher concentrations of MgO, Al_2O_3, Cr, V, Cu, and Zn and lower concentrations of Ba in sediment of upper Fawn Lake than in sediment from the altered areas. The sediment composition of the core from upper Fawn Lake is interpreted as a mixture of sedimentary material from the basin upstream of upper Fawn Lake (Jackson and others, 2003) and the altered scar areas. Comparison with the pre-1979 sediment from Eagle Rock Lake with the altered areas shows identical patterns for this selected element suite (figs. 22*C* and 22*D*).

Comparison of the geochemical data from the post-1979 sediment from Eagle Rock Lake with the altered areas shows a different trend (figs. 22*E* and 22*F*). Concentrations of Al_2O_3, Cu, and Zn are elevated and Na_2O and TiO_2 are lower in post-1979 sediment from Eagle Rock Lake than those found in the sediment from the altered scar areas. Allen and others (unpub. data, 1999) document the presence of an aluminum precipitate in the sediment of Eagle Rock Lake in the core sampled near the inlet. All three of these elements (Al_2O_3, Cu, and Zn) show enrichment in the lake sediment

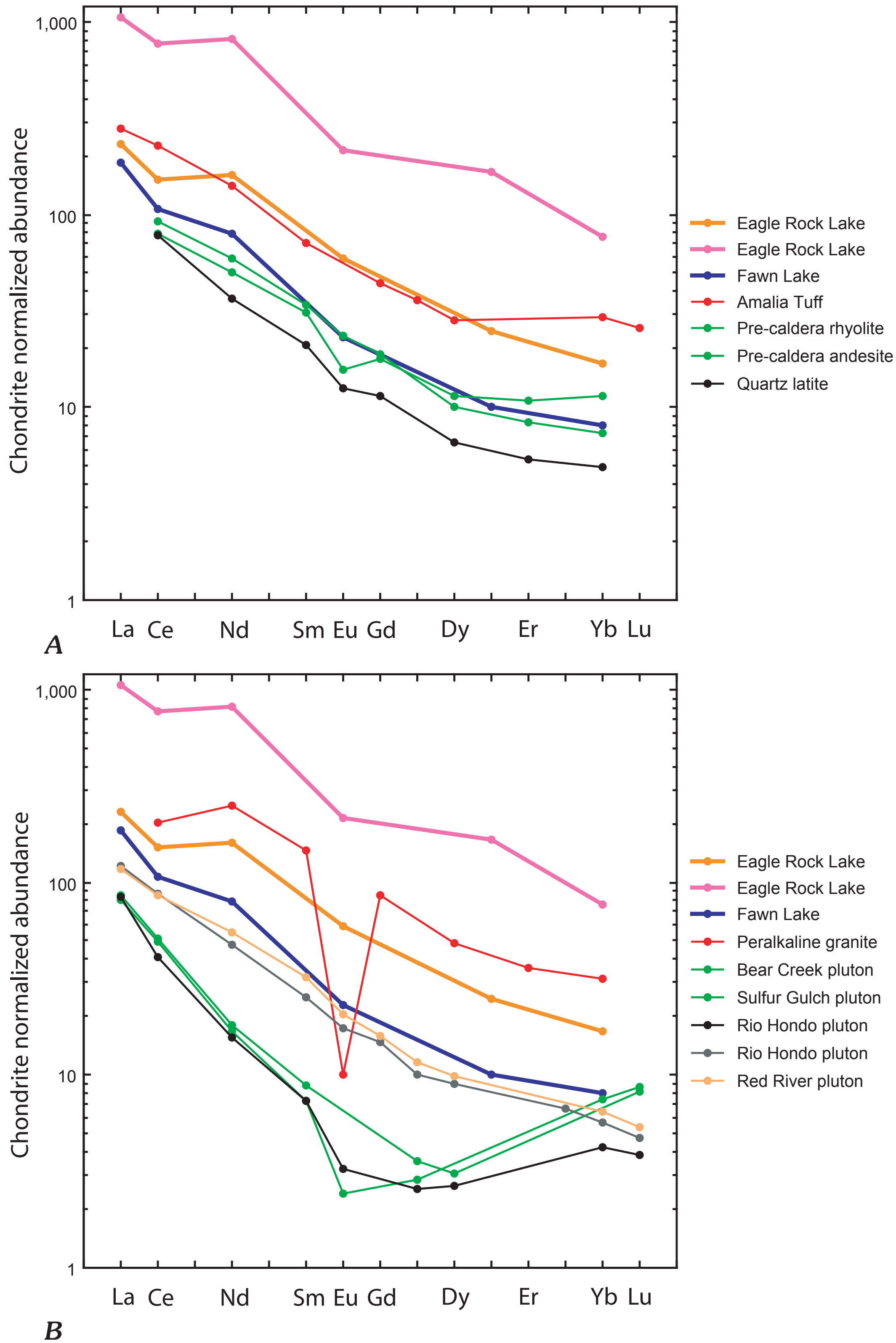


Figure 16. Plot of chondrite-normalized REE patterns for volcanic (*A*) and plutonic (*B*) rocks from the study area. REE data from Eagle Rock Lake are the minimum and maximum values recovered from the sediment core (table 1), whereas the REE data from upper Fawn Lake is from the sample with the median value for cerium (table 2). REE data for the igneous and volcanic rocks are from Lipman and others (1982) and from Johnson and others (1989).

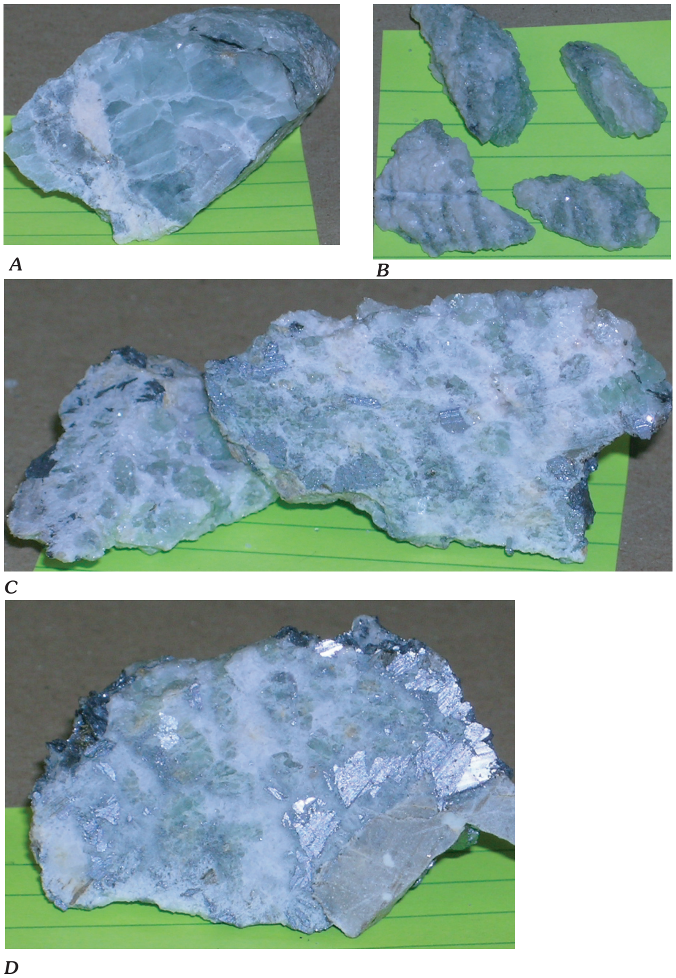


Figure 17. Photographs of four fluorite samples from the D ore body (samples supplied by Meghan Jackson, Molycorp, 2003). Analytical data are in table 7. *A*. Sample QF-2 is a coarsely crystalline fluorite sample, possibly from a vein. Green mineral is fluorite, white mineral is calcite, and minor amounts of molybdenite were visible in the specimen. Calcite and fluorite separates were handpicked and analyzed from this sample. *B*. Sample QF-3 is laminated with more calcite (white) than fluorite (green). Minor amounts of molybdenite were visible in the specimen. Grain size ranged from 2–4 mm. Calcite and fluorite separates were handpicked and analyzed. *C*. Sample QF-4 is a coarse-grained mixture of calcite (white), fluorite (green), and molybdenite (gray) with minor amounts of pyrite (brass color). Fluorite accumulations range in size from about 2 mm to 1 cm. Calcite and fluorite separates were handpicked and analyzed. *D*. Sample QF-5 is a medium- to coarse-grained mixture of calcite (white), fluorite (green) and molybdenite (gray) with minor amounts of pyrite (brass color). Fluorite accumulations range in size from about 2 mm to 1 cm. Sample contains wall rock inclusion on the lower right. No mineral separates were picked from this sample.

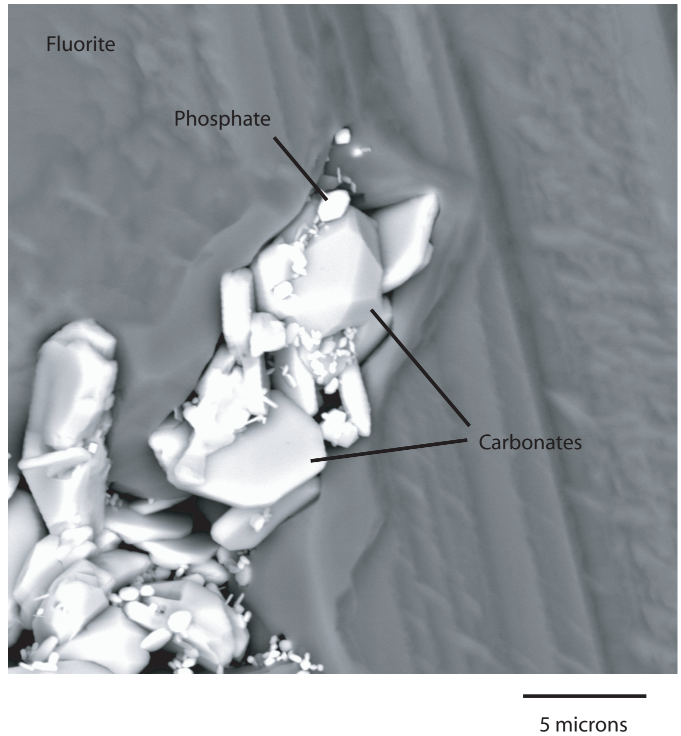


Figure 18. Electron backscatter photomicrograph showing REE-bearing phosphate and carbonate minerals identified as small inclusions in the fluorite from the D ore body, Questa mine (Sharon Diehl, analyst, 2003).

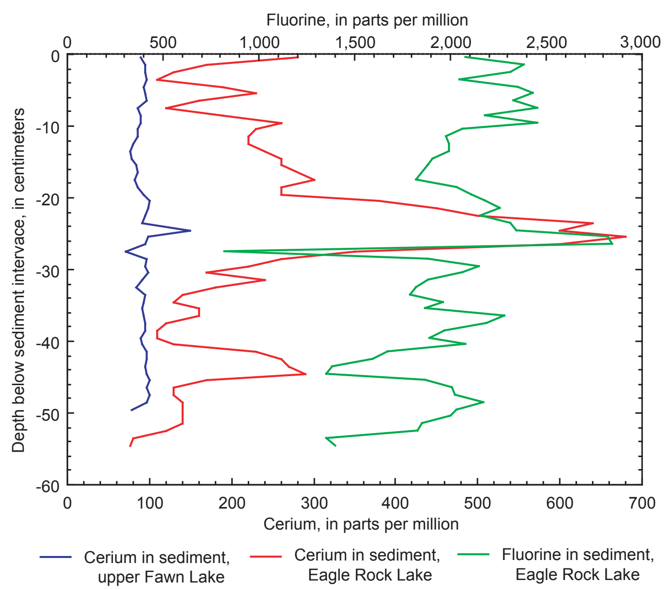


Figure 19. Plot of concentration of REE Ce from cores from upper Fawn Lake and Eagle Rock Lake and F in sediment core from Eagle Rock Lake (table 1) versus depth below the sediment interface. Note the coincidence between the F peak and the beginning of the Ce peak. The Ce peak decays more slowly than the F peak indicating a longer time is required for the REE-bearing minerals to weather and release the REE to the environment.

Table 7. Analyses of fluorite from megabreccia, Questa molybdenum mine area, Red River valley, New Mexico.

										Rare earth elements									
Sample	**Mineral phase**		**Ca**	**Mg**	**Na**	**K**	**Al**	**P**	**Mn ppm**	**La ppm**	**Ce ppm**	**Nd ppm**	**Eu ppm**	**Yb ppm**	**Y ppm**	**Li ppm**	**Be ppm**	**Sr ppm**	**Ba ppm**
QSGF-1																			
	Mixed phases	leach	19.5	0.018	0.013	0.150	0.165	0.005	17	6	6	7	<2	<1	5	2	<1	39	6
	Mixed phases	residue	22.4	<0.005	<0.005	<0.01	0.025	<0.005	<2	7	10	10	<2	<1	48	3	<1	41	<1
	Mixed phases	sum	41.9	0.018	0.013	0.150	0.190	0.005	17	13	15	17	<2	<1	53	5	<1	81	6
QF-2–Carbonate phase																			
	Carbonate (white phase)	leach	24.4	0.095	0.200	3.81	3.65	0.009	31	39	63	29	<2	<1	31	11	2	65	390
	Carbonate (white phase)	residue	0.8	0.006	0.011	0.20	0.22	<0.005	2	18	27	9	<2	<1	4	8	<1	4	27
	Carbonate (white phase)	sum	25.2	0.100	0.211	4.01	3.87	0.009	32	56	90	38	<2	<1	36	19	2	70	420
QF-2–Carbonate phase (replicate)																			
	Carbonate (white phase)	leach	25.1	0.094	0.199	3.85	3.66	0.009	30	44	71	32	<2	<1	33	11	2	67	390
	Carbonate (white phase)	residue	0.2	0.005	0.008	0.15	0.19	<0.005	2	14	21	7	<2	<1	3	8	<1	3	22
	Carbonate (white phase)	sum	25.3	0.100	0.207	4.00	3.85	0.009	32	58	92	39	<2	<1	36	19	2	71	410
QF-2–Fluorite																			
	Fluorite (green phase)	leach	4.9	0.003	<0.005	0.015	0.010	<0.005	16	13	20	11	<2	<1	2	<1	<1	7	<1
	Fluorite (green phase)	residue	33.1	<0.005	<0.005	<0.01	0.032	0.005	<2	60	95	41	<2	<1	39	7	<1	45	24
	Fluorite (green phase)	sum	38.0	0.003	<0.005	0.015	0.042	0.005	16	72	110	52	<2	<1	41	7	<1	52	24
QF-3–Carbonate phase																			
	Carbonate (white phase)	leach	27.9	0.052	0.001	<0.01	0.017	<0.005	2,830	34	52	24	<2	<1	6	<1	<1	170	<1
	Carbonate (white phase)	residue	8.9	<0.005	<0.005	<0.01	0.036	0.010	4	60	98	40	<2	<1	28	16	<1	16	22
	Carbonate (white phase)	sum	36.9	0.052	0.001	<0.01	0.053	0.010	2,830	95	150	63	<2	<1	34	16	<1	190	22
QF-3–Fluorite phase																			
	Fluorite (green phase)	leach	13.9	0.013	0.001	0.013	0.027	0.011	240	170	280	120	2	<1	9	<1	<1	49	<1
	Fluorite (green phase)	residue	33.4	<0.005	0.017	<0.01	0.027	0.010	2	190	320	130	3	5	120	6	<1	75	62
	Fluorite (green phase)	sum	47.3	0.013	0.018	0.013	0.054	0.022	240	360	600	250	5	5	130	6	<1	120	62
QF-4–Carbonate phase																			
	Carbonate (white phase)	leach	17.5	0.087	0.005	0.018	0.072	0.023	2,150	58	97	42	<2	2	27	1	<1	120	3
	Carbonate (white phase)	residue	1.0	<0.005	0.006	<0.01	0.060	<0.005	3	18	28	11	<2	<1	3	31	<1	4	5
	Carbonate (white phase)	sum	18.6	0.087	0.011	0.018	0.132	0.023	2,150	76	130	53	<2	2	30	32	<1	120	8
QF-4–Fluorite phase																			
	Fluorite (green phase)	leach	7.2	0.015	<0.005	0.014	0.014	<0.005	270	140	240	100	2	<1	16	<1	<1	150	53
	Fluorite (green phase)	residue	38.0	<0.005	<0.005	<0.01	0.039	0.017	<2	270	470	200	4	5	130	6	<1	88	94
	Fluorite (green phase)	sum	45.2	0.015	<0.005	0.014	0.054	0.017	270	410	710	300	6	5	150	6	<1	240	150
QF-5																			
	Mixed phases	leach	4.2	0.007	0.007	0.032	0.065	<0.005	24	51	74	21	<2	<1	2	2	<1	24	4
	Mixed phases	residue	19.4	<0.005	0.005	0.011	0.111	0.013	<2	320	540	220	4	2	79	43	<1	53	110
	Mixed phases	sum	23.6	0.007	0.012	0.043	0.176	0.013	24	370	610	240	4	2	81	46	<1	77	110

that may be explained by in-stream addition of metals by low pH ground water. Water-quality data (McCleskey and others, 2003) indicate that dissolved metals enter the Red River at several places downstream from Sulfur Gulch. They document a large inflow of such ground water downstream of Bear Creek (just upstream of site 108, fig. 1).

Data from the composite sampling of the mine-waste dumps around the open pit (Briggs and others, 2003) and from premining sediment from talus debris near and downstream of the Questa deposit (table 3) were examined as possible sources of sediment to account for the observed anomalies in the post-1979 sediment data in Eagle Rock Lake (figs. 23*C* and 23*D*). Comparison of the Na_2O and TiO_2 concentrations in pre- and post-1979 sediment (figs. 23*A* and 23*C*) shows that the concentration of these elements decreased in the post-1979 sediment, whereas addition of sediment from either source would require an increase in these two constituents if they were responsible for the changes observed in the post-1979 Eagle Rock Lake geochemistry. Concentrations of MgO and FeO, however, change in the right direction for additional contributions from these new sources to account for the observed changes, and concentrations of Cr and V (figs. 23*B* and 23*D*) match well with both the altered areas and the mine-waste-pile data. Concentrations of Ba and Sr match well only with the mine-waste-pile data implicating them as a plausible source of sediment found in the post-1979 core interval in Eagle Rock Lake. The most plausible explanation for the change in the geochemistry of the fine-grained and suspended sediment in Eagle Rock Lake is that these geochemical changes can be accounted for by the addition of mill-tailings material to the Red River during the mill-tailings pipeline breaks. Whereas the change in the sedimentary record has been substantial, the actual tonnage of material needed to cause these geochemical changes may not be large. Concentrations of Al_2O_3, Cu, and Zn are higher in both the pre- and post-1979 Eagle Rock Lake sediment than in either the premining sediment or the mine-waste piles (fig. 23).

Elevated concentrations of Cu and Zn, which both Allen and others (unpub. data, 1999) and URS Corp. (written commun., 2004) have shown are related to the chemical precipitation of the aluminous gels, are not explained by the increased sediment load from these two sources. The argument that these are chemical precipitates is also bolstered by results from factor analysis of the data presented in URS Corp. (written commun., 2004) and by the higher water content of the sediment in the upper half of the Eagle Rock Lake core (table 1) when compared with the sediment in the upper half of the upper Fawn Lake core (table 2).

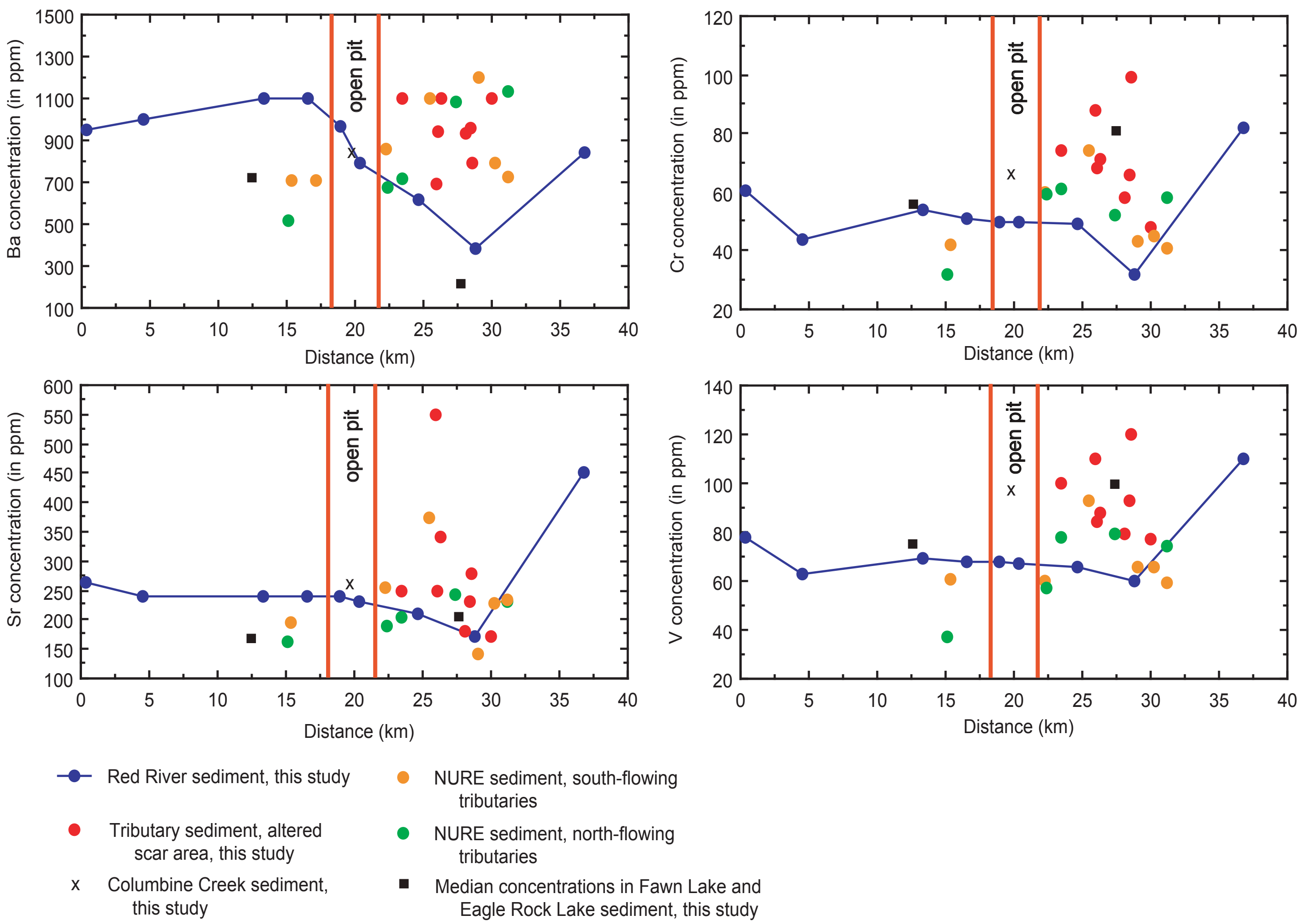


Figure 20. Plots of the concentration of trace elements Ba, Sr, Cr, and V in sediment from the Red River (table 3), sediment from tributary streams (table 3), and sediment from the 1976 NURE study (NURE, 1981). Data are plotted from the confluence of the Red River with the Rio Grande; downstream is to the left at 0 km, the town of Questa is at about 10 km, and the town of Red River is between 31–32 km. Similar geochemical results were obtained from sediment from the Red River upstream of Fawn Lake by Jackson and others (2003). The concentrations of the elements Sr, Cr, and V do not change significantly in sediment of the Red River as it flows past the Questa mine open pit (18–22 km); however, Ba is significantly enriched in Red River sediment downstream of the mine site. These enrichments in Ba are also found in the mine-waste composite samples analyzed by Briggs and others (2003).

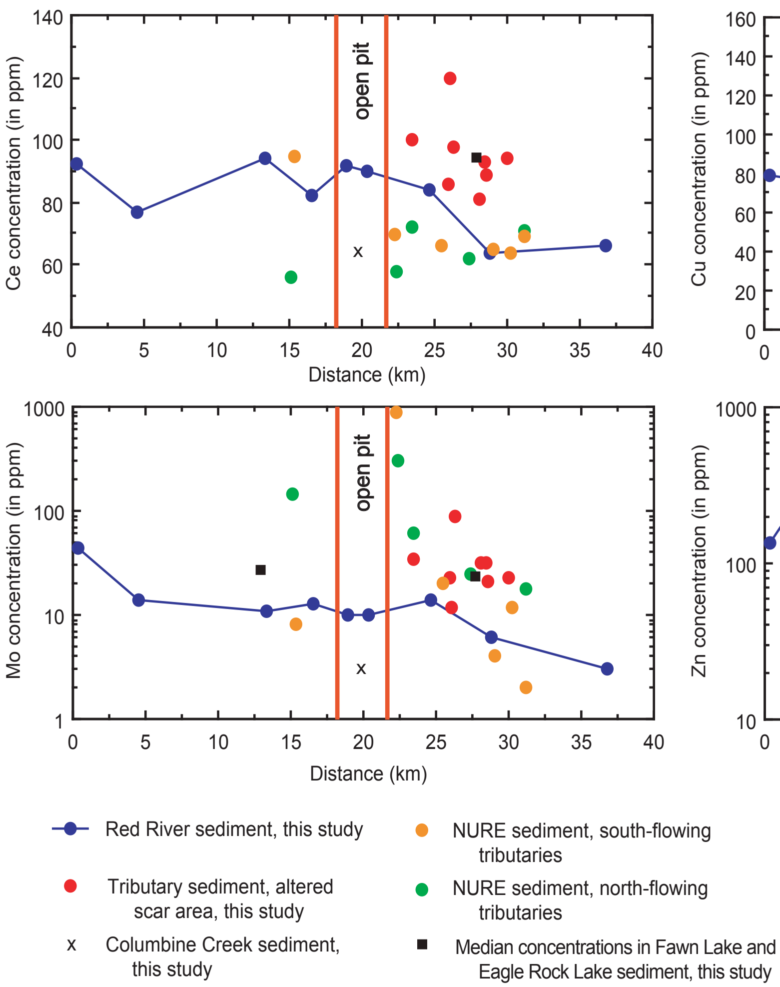


Figure 21. Plots of the concentration of trace elements Ce, Mo, Cu, and Zn in sediment from the Red River (table 3), sediment from tributary streams (table 3), and sediment from the 1976 NURE study (NURE, 1981). Data are plotted from the confluence of the Red River with the Rio Grande; downstream is to the left at 0 km, the town of Questa is at about 10 km, and the town of Red River is between 31 and 32 km. The concentrations of all four elements are enriched in sediment of the Red River before it reaches the Questa mine open pit (18–22 km). Concentrations of these metals in sediment from many of the tributaries are elevated above that of the Red River sediment.

Table 8. Statistics for pre-1979 and post-1979 concentrations of major and trace elements in sediment from Eagle Rock Lake core, lower Red River valley, Taos County, New Mexico.

	Na_2O	K_2O	MgO	CaO	Al_2O_3	FeO	TiO_2	P_2O_5	SiO_2	Mn	V	Cr	Co	Ni	Mo
	Wt. percent	Wt. percent	Wt. percent	Wt. percent	Wt. percent	Wt. percent	Wt. percent	Wt. percent	Wt. percent	ppm	ppm	ppm	ppm	ppm	ppm
Pre-1979															
Minimum	0.59	1.93	1.23	0.50	14.55	3.60	0.23	0.16	64.19	410	61	53	17	42	25
Maximum	1.20	3.61	2.49	1.23	20.78	8.36	0.45	0.55	75.21	2,000	100	95	94	220	360
Median	0.88	3.25	2.07	0.92	18.90	6.95	0.33	0.32	66.51	1,150	88	78	38	115	130
Mean	0.87	3.20	2.05	0.92	18.51	6.71	0.34	0.31	67.10	1,296	86	76	42	108	131
Standard Deviation	0.15	0.36	0.32	0.18	1.73	1.10	0.06	0.09	2.81	536	11	10	19	42	84
Post-1979															
Minimum	0.32	1.69	1.08	0.46	18.90	3.47	0.10	0.32	61.74	420	52	39	8	33	16
Maximum	0.51	4.46	1.99	0.98	26.45	7.98	0.40	0.48	69.77	2,700	100	79	220	470	96
Median	0.42	2.59	1.50	0.76	22.67	5.72	0.18	0.37	66.49	1,950	74	56	77	210	26
Mean	0.41	2.83	1.52	0.72	22.02	5.85	0.20	0.39	66.05	1,726	74	57	81	212	36
Standard Deviation	0.05	0.84	0.26	0.17	1.51	1.09	0.07	0.05	1.89	679	14	10	51	102	23

	Cu	Zn	Cd	Pb	As	Li	Be	Sr	Ba	F	La	Ce	Nd	Y
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Pre-1979														
Minimum	58	340	2	77	11	25	4	140	130	1,350	47	77	47	24
Maximum	370	1,700	9	180	21	58	9	230	580	2,280	170	290	170	100
Median	295	925	4	135	13	47	7	180	175	1,875	78	140	97	55
Mean	259	878	5	133	15	46	7	183	190	1,844	92	158	103	55
Standard Deviation	100	356	1.8	28	4	8	1.6	23	91	266	35	58	32	18
Post-1979														
Minimum	62	240	2	97	11	26	3	110	200	1,820	65	110	55	16
Maximum	820	4,600	20	250	20	51	19	370	820	2,840	350	680	490	320
Median	500	2,650	11	150	14	40	13	170	715	2,180	130	260	200	140
Mean	466	2,387	10	151	15	40	12	191	640	2,219	157	305	231	153
Standard Deviation	182	972	4.2	38	2	7	4.1	69	196	257	84	167	119	78

Table 9. Statistics for concentrations of major and trace elements in sediment from upper Fawn Lake core, lower Red River valley, Taos County, New Mexico.

	Na_2O Wt. percent	K_2O Wt. percent	MgO Wt. percent	CaO Wt. percent	Al_2O_3 Wt. percent	FeO Wt. percent	TiO_2 Wt. percent	P_2O_5 Wt. percent	SiO_2 Wt. percent	Mn ppm	V ppm	Cr ppm
Minimum	0.50	2.53	1.66	0.54	14.36	4.76	0.27	0.23	48.07	410	78	62
Maximum	1.33	5.54	3.65	6.70	28.34	10.03	0.60	0.55	73.90	880	170	150
Median	0.88	3.61	2.16	1.09	17.76	6.50	0.35	0.33	66.50	560	100	81
Mean	0.88	3.63	2.21	1.60	17.91	6.62	0.35	0.35	66.47	551	101	81
Standard Deviation	0.20	0.52	0.28	1.24	2.10	0.77	0.05	0.09	3.32	92	13	13

	Co ppm	Ni ppm	Mo ppm	Cu ppm	Zn ppm	Cd ppm	Pb ppm	As ppm	Li ppm	Be ppm	Sr ppm	Ba ppm
Minimum	3	20	12	77	140	2	100	10	24	2	180	110
Maximum	72	140	48	410	1,200	8	320	19	50	4	360	770
Median	22	57	24	220	485	4	200	13	33	3	220	220
Mean	23	58	26	218	487	4	205	13	32	3	222	243
Standard Deviation	13	23	9	66	200	1.2	55	2	3	0.4	32	122

	F ppm	La ppm	Ce ppm	Nd ppm	Y ppm
Minimum	1,200	46	72	38	14
Maximum	2,150	94	150	74	45
Median	1,745	58	94	48	24
Mean	1,732	58	92	48	25
Standard Deviation	220	8	11	5	6

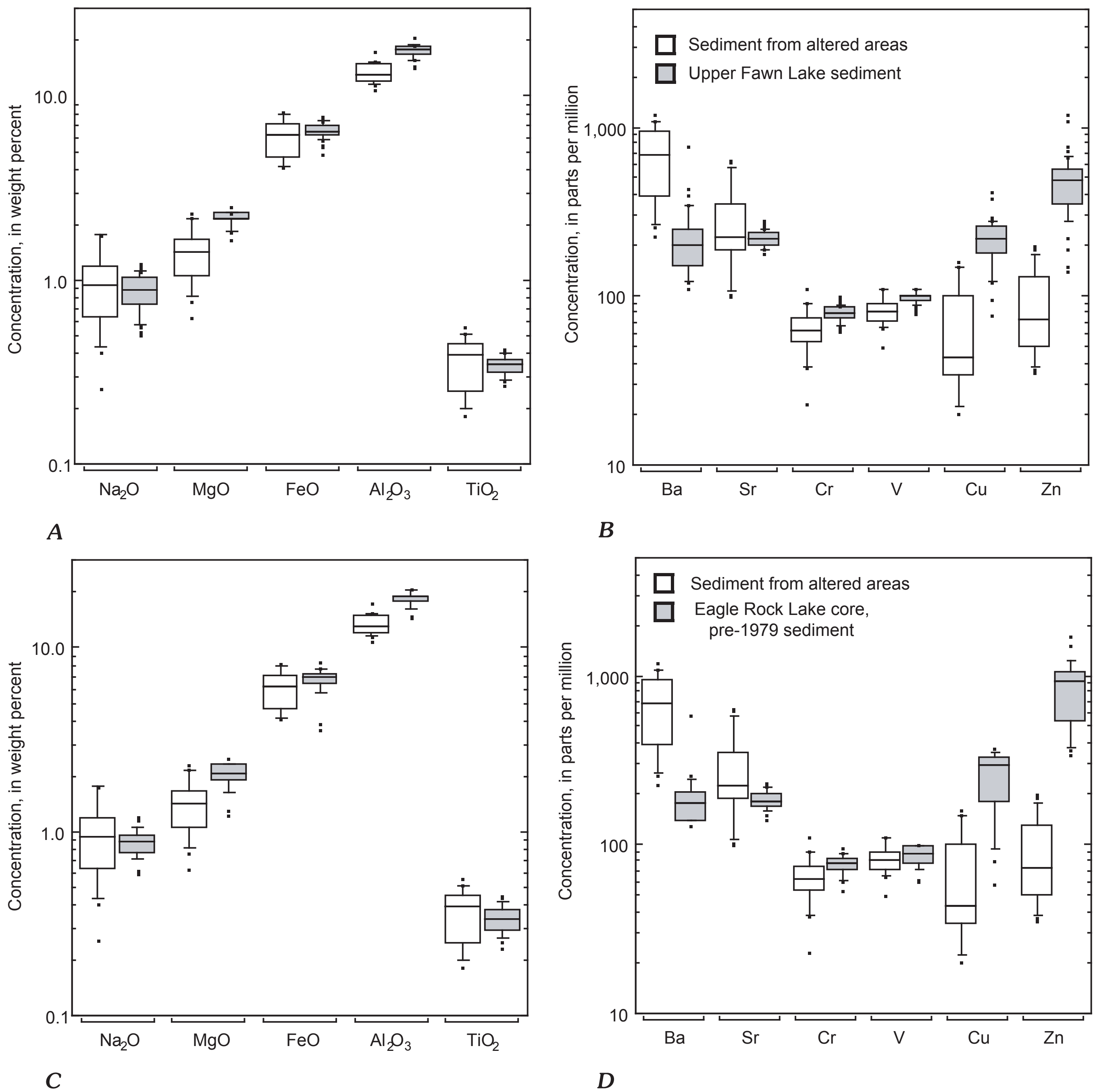
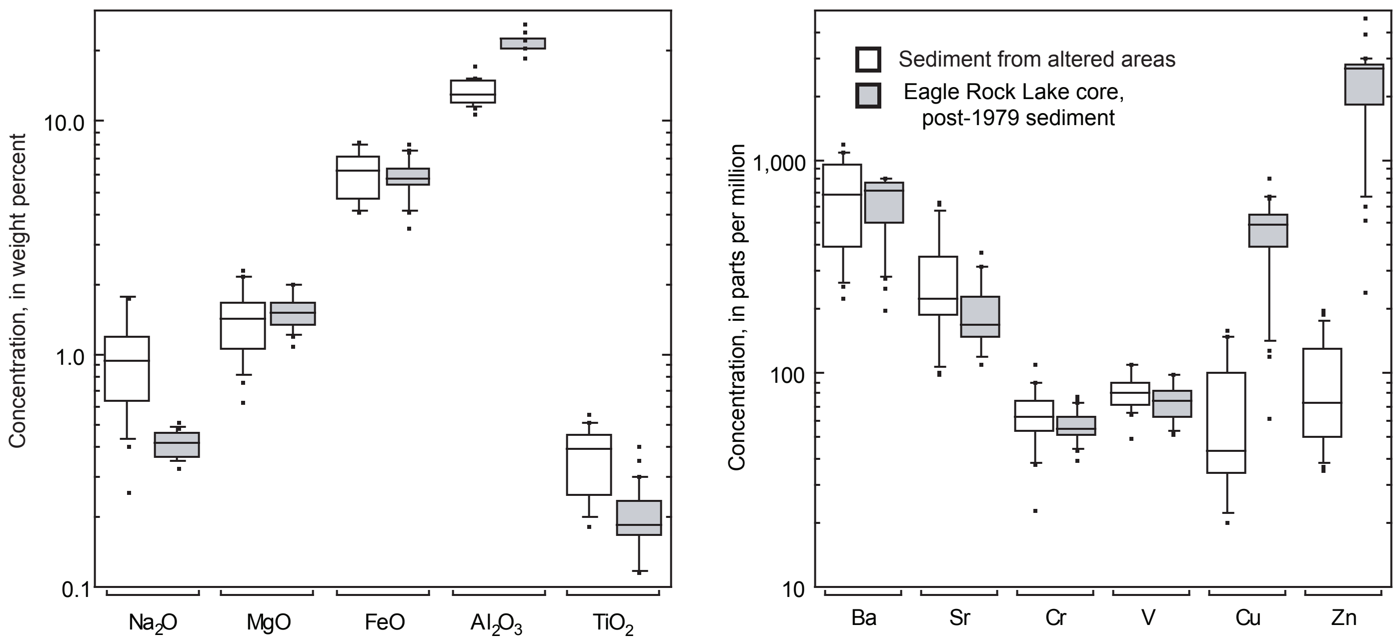


Figure 22 (above and facing page). Box plot comparisons. The median value for each element is bracketed by the 25th and 75th percentile of the data forming the box, the 10th and 90th percentiles are indicated by the lines above and below the box, and the 5th, 95th, minimum, and maximum values are shown as black dots above and below the 10th and 90th percentiles. *A*. Major element concentrations of Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from the upper Fawn Lake core (table 2, n=50) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003). *B*. Trace element concentrations of Ba, Sr, Cr, V, Cu, and Zn from the upper Fawn Lake core (table 2, n=50) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003). *C*. Major element concentrations of Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from the pre-1979 interval of the Eagle Rock Lake core (table 1, n=24) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003). *D*. Trace element concentrations Ba, Sr, Cr, V, Cu, and Zn from the pre-1979 interval of the Eagle Rock Lake core (table 1, n=24) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003).



E *F*

Figure 22 (continued). Box plot comparisons. The median value for each element is bracketed by the 25th and 75th percentile of the data forming the box, the 10th and 90th percentiles are indicated by the lines above and below the box, and the 5th, 95th, minimum, and maximum values are shown as black dots above and below the 10th and 90th percentiles. *E*. Major element concentrations of Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from the post-1979 interval of the Eagle Rock Lake core (table 1, n=26) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003). *F*. Trace element concentrations of Ba, Sr, Cr, V, Cu, and Zn from the post-1979 interval from the Eagle Rock Lake core (table 1, n=26) with composite samples of sediment from the altered areas (table 3, side tributary samples and samples from debris fans, 03KVTF2–03KVTF9, and 9 composite samples from outcrop; Briggs and others, 2003).

Summary and Conclusions

Geochemical data from the study of cores in Fawn and Eagle Rock Lakes has provided a continuous record of sedimentation from their inception. Accuracy of radiometric dating using ^{137}Cs is confirmed by the historical dates provided by the New Mexico Dept. of Highways on the inception of the lakes (URS Corp., written commun., 2004). The geochemical data from upper Fawn Lake provide a reliable and continuous record of the geochemical baseline concentrations during the period from 1961 to 2002. The sedimentary record from the Eagle Rock Lake core indicates very similar sedimentary history from its inception until 1979. Concentrations of Mo, Co, Ni, Cu, and Zn increased during the period from 1963 to 1967, which we interpret as the period when the site for the open pit at the Questa mine was being prepared and work on the open pit began. Other geochemical anomalies shown by REE and fluorine concentrations in the sediment core likely correlate with breaks in the pipeline that transports mill tailings to the repository west of the town of Questa. REE are present in carbonate minerals in the magmatic hydrothermal breccia in the ore deposit. Enrichment of the REE by accelerated weathering of the hydrothermal breccia phase from spilled tailings is required to explain the REE anomalies in sediment from Eagle Rock Lake. The sedimentary record of Eagle Rock Lake changed substantially in 1979 with large increases in concentration for many major elements and metals in sediment in Eagle Rock Lake. This change in source material was dramatic; it has resulted in a change in the source of sediment supplied by the Red River to Eagle Rock Lake for more than two decades. We have shown that the addition of sediment from the altered areas upstream of the mine and the mine-waste piles at the Questa mine are not sufficient to explain all of the observed changes in sediment geochemistry between the pre- and post-1979 break defined by the geochemical data in Eagle Rock Lake (figs. 7–12). Although both mine-waste and premining background sediment from altered areas around the Questa porphyry Mo deposit have the appropriate compositions to be potential sources of this new sediment, existing data are not sufficient to implicate or refute either one. Given the very large disturbance represented by the mine-waste piles at the open-pit site, erosion of the mine wastes must be considered a plausible source of this sediment despite the presence of large berms built by Molycorp to prevent their erosion.

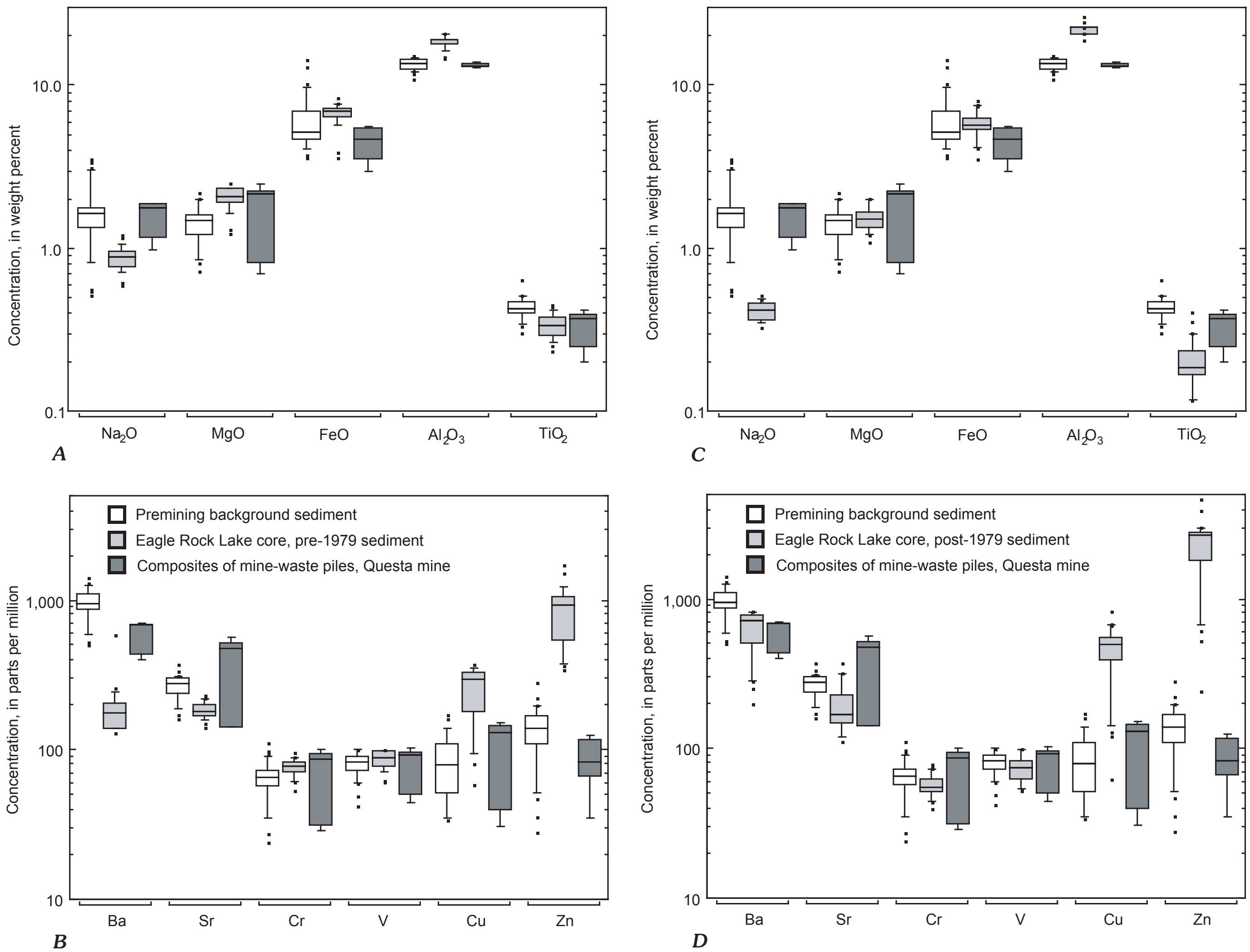


Figure 23. Box plot comparisons. The median value for each element is bracketed by the 25th and 75th percentile of the data forming the box, the 10th and 90th percentiles are indicated by the lines above and below the box, and the 5th, 95th, minimum, and maximum values are shown as black dots above and below the 10th and 90th percentiles. *A*. Major element concentrations of Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from premining sediment (table 3, multiple composite samples from 11 sites) with lake sediment from the pre-1979 interval, Eagle Rock Lake core (table 1, n=24) and mine-waste piles (composite samples from 5 different mine-waste piles at the Questa mine site; Briggs and others, 2003). *B*. Trace element concentrations of Ba, Sr, Cr, V, Cu, and Zn from the premining sediment (table 3, multiple composite samples from 11 sites) with lake sediment from the pre-1979 interval, Eagle Rock Lake core (table 1, n=24) and mine-waste piles (composite samples from 5 different mine-waste piles at the Questa mine site; Briggs and others, 2003). *C*. Major element concentrations of Na_2O, MgO, FeO, Al_2O_3, and TiO_2 from premining sediment (table 3, multiple composite samples from 11 sites) with lake sediment from the post-1979 interval, Eagle Rock Lake core (table 1, n=26) and mine-waste piles (composite samples from 5 different mine-waste piles at the Questa mine site; Briggs and others, 2003). *D*. Trace element concentrations of Ba, Sr, Cr, V, Cu, and Zn from premining sediment (table 3, multiple composite samples from 11 sites) with lake sediment from the post-1979 interval, Eagle Rock Lake core (table 1, n=26) and mine-waste piles (composite samples from 5 different mine-waste piles at the Questa mine site; Briggs and others, 2003).

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