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The Mineral Intrusion Project:
Report of Progress During Fiscal Year 1993

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A cooperative investigation by the Kansas Geological Survey and Big Bend Groundwater Management District No. 5

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Executive Summary

The intrusion of natural saltwater from Permian bedrock formations into the freshwater resources of the overlying Great Bend Prairie aquifer is a problem of long-standing concern in the eastern portion of Groundwater Management District No. 5. The Kansas Water Office has funded the Kansas Geological Survey to undertake, in cooperation with Big Bend Groundwater Management District No. 5, an investigation into the nature and extent of the saltwater intrusion, the effects of natural and anthropogenic factors (especially groundwater withdrawals) on the saltwater interface on both local and regional scales, and the implications for groundwater resource management and development in the area.

The Mineral Intrusion Project has completed its first year. The overall issues and experimental approach of the study were defined in Buddemeier et al. (1992). Major efforts in the areas of literature review and data compilation have resulted in the production of reports that both review and advance the present state of knowledge about the mineral intrusion problem (Young, 1992; Whittemore, 1993; this report). In addition to further compiling available data, this report presents the results of experimental studies during fiscal year 1993.

One major accomplishment has been the development and verification of sensitive down-hole geophysical logging techniques that permit identification of the depth and characteristics of the saltwater interface or transition zone in the aquifer formations surrounding a network of deep monitoring wells. This method uses focused electromagnetic (EM) induction logging combined with measurement of natural gamma radioactivity in the formation. The gamma log is used to correct the EM log for lithologic effects, leaving a signal more closely related to the conductivity (salinity) of the pore water. Computer smoothing and curve-fitting techniques are used to generate parameters that objectively reflect the depth and thickness of the transition zone.

These logging and data processing techniques have been used to survey the existing monitoring well network and to obtain the first regional assessment of the distribution of the saltwater interface and of the saturated thicknesses of fresh and saltwater within the eastern Great Bend Prairie aquifer. Field observations have also demonstrated the ability to detect changes in interface characteristics.

An intensive study site has been established in northeastern Stafford County to investigate the local effects of groundwater pumping on the saltwater interface. Two deep monitoring wells have been installed on an irrigated site, and 30 feet of the Permian bedrock was cored during one of the installations. The core description indicates that the bedrock consists of layered siltstones and sandstones. The dimensions of this layering may help explain previous observations of local hydrologic variability in the Permian formation and will provide some basis for estimating the spatial scales over which the formation may possibly be treated as homogeneous.

In addition to the monitoring well installations at the intensive study site, several existing shallower wells were also logged, surveyed, and sampled for chemical analysis. Initial results have indicated two complicating factors for the study. One is short-range discontinuities in major aquifer features such as clay layers within the saturated zone but above the saltwater interface, and the other is the presence of chemically detected oil-brine pollution in at least two of the shallower wells. The observed contamination will make it necessary to place more emphasis than was originally planned on chemical identification of brine sources, both at the intensive study site and in general regional investigations.

The hydrologic and geochemical data will ultimately provide input for a computer model of saltwater-interface behavior that will make it possible to develop predictions of conditions in the future and in areas lacking detailed measurements. A series of potential models have been evaluated for their suitablity for this application, and a candidate model (the SWIFT-II 3-dimensional flow and transport model) has been identified and is undergoing testing.

Future work will continue the description of aquifer characteristics and the variations of hydrologic parameters and the salt water interface over time. These results will help determine the dependence of the interface on geologic, natural hydrologic, and water-use parameters. These relationships will be modeled as part of an approach to providing decision support to the water users and responsible management agencies in the eastern Great Bend Prairie aquifer.

I. Introduction

The Mineral Intrusion Project is a research effort to understand the hydrologic, water-quality, and water-resource management implications of natural saltwater intrusion into the freshwater Great Bend Prairie aquifer in the eastern portion of Groundwater Management District No. 5 (GMD5). It is funded by the Kansas Water Office (KWO) and is being carried out by the Kansas Geological Survey (KGS), in collaboration with GMD5.

The region of the study is shown in fig. 1. In much of this area a bedrock aquifer of Permian age is in direct hydraulic connection with the base of the Great Bend Prairie (alluvial) aquifer. This connection, which in most other parts of the state is blocked by intervening confining layers of low permeability, permits the brines that are found naturally in the Permian bedrock to move upward and contaminate the freshwater of the overlying aquifer. The nature and extent of the connection is illustrated by the map and vertical section shown in fig. 2.

Groundwater use in eastern GMD5 is limited by actual and potential water-quality problems, many of which result from contamination of the freshwater by Permian saltwater discharge. In order to support efficient use and management of water resources in the area, the Mineral Intrusion Project includes among its objectives both an understanding of regional controls on the saltwater interface and its responses to groundwater withdrawal, and research into the local effects of high-volume pumping on the depth and characteristics of the saltwater interface.

A detailed statement of the problem, including a description of study objectives and experimental approaches, has been prepared by Buddemeier et al. (1992). Young (1992) has compiled and reviewed the available information on the geology and hydrology of the Permian aquifer. Whittemore (1993) has collected and discussed the available information on water quality derived from the network of monitoring wells in the area installed and operated cooperatively by KGS and GMD5.

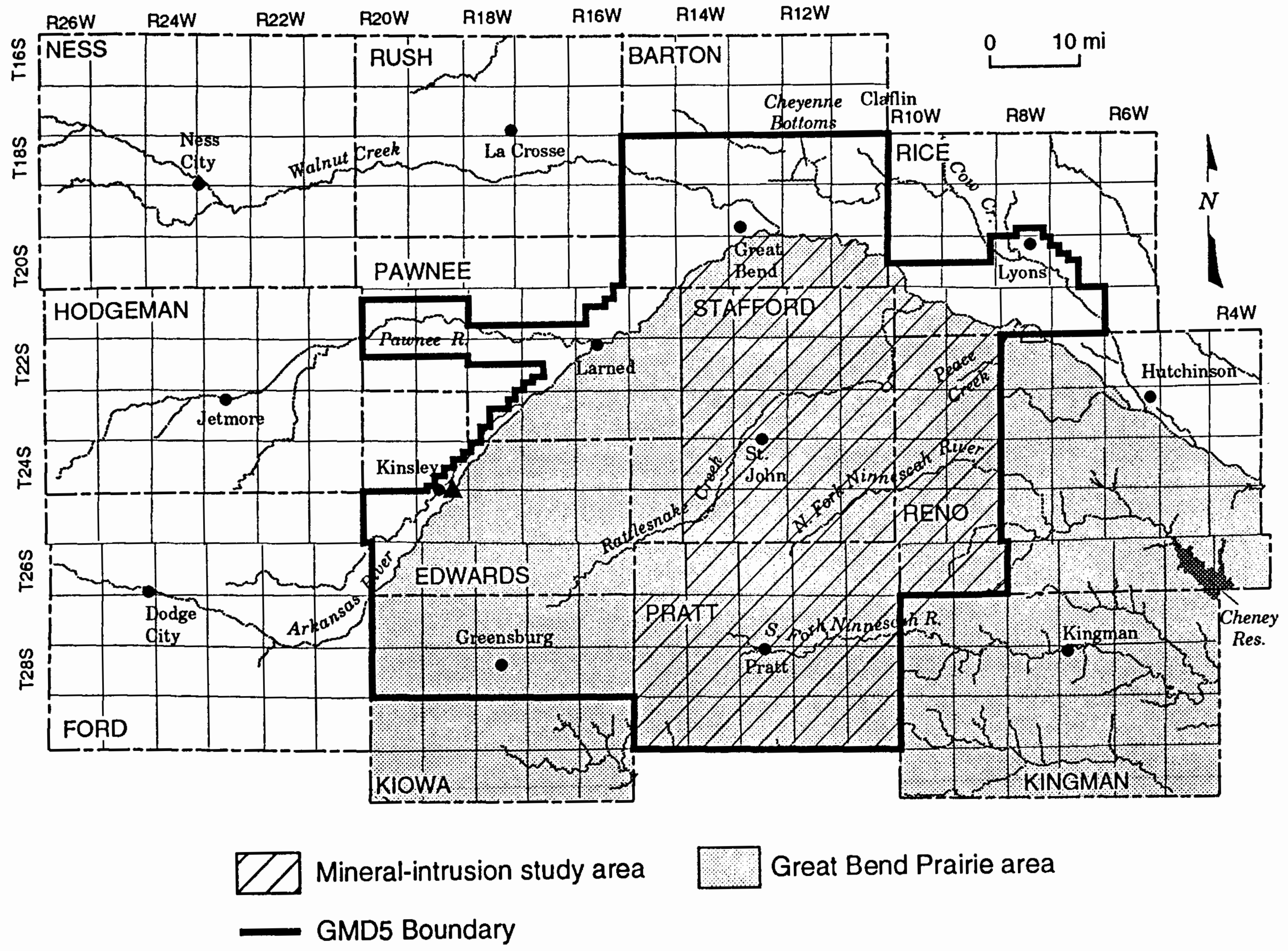


Figure 1. Major features in the region of Big Bend Groundwater Managment District (GMD5) and location of the Mineral Intrusion study area.

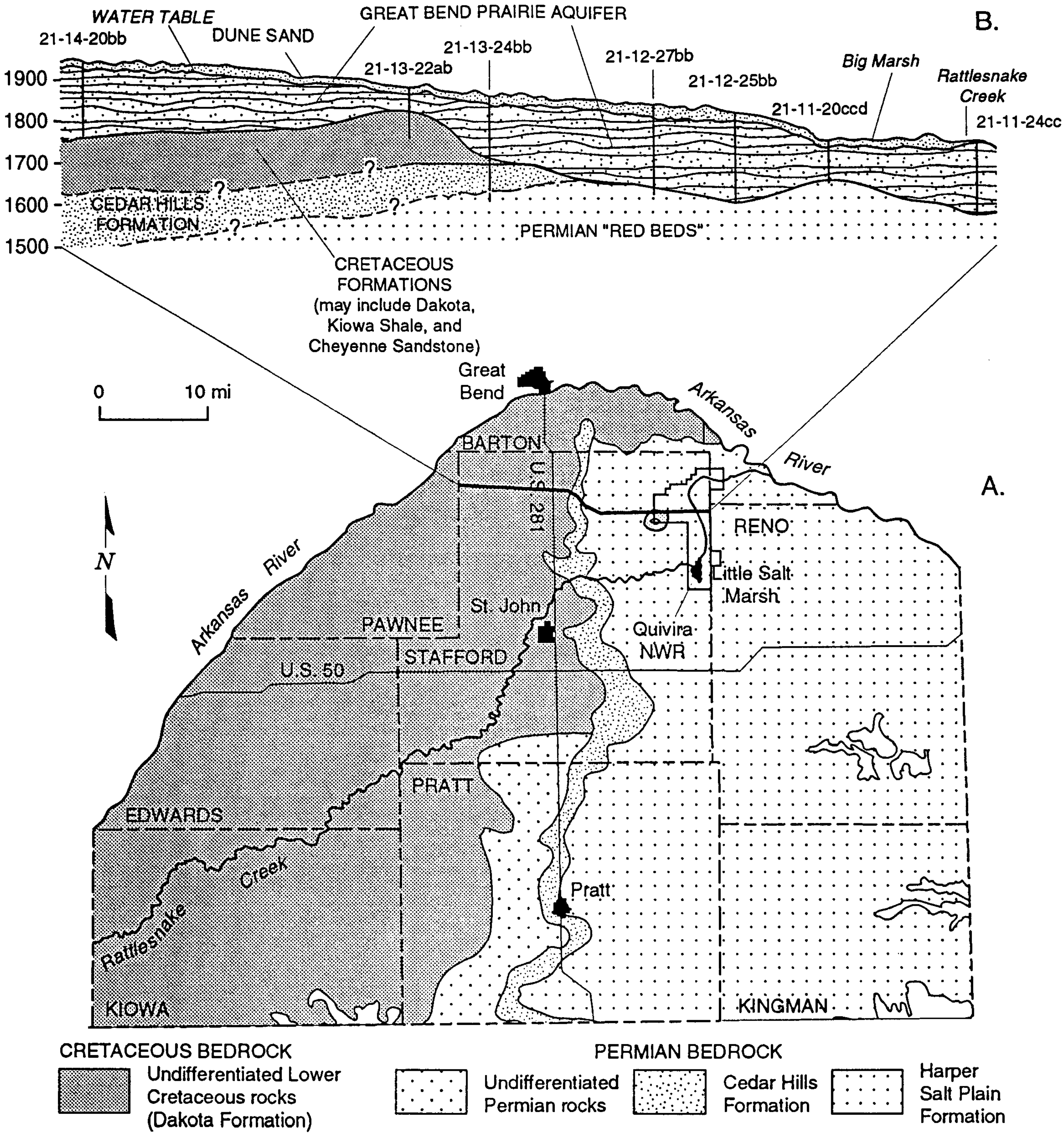


Figure 2. A. Bedrock geology underlying the Great Bend Prairie aquifer and areas in which the Permian formation has the potential to contribute saltwater to the overlying aquifer. B. Vertical section from west to east across the region, showing the relation of the alluvial Great Bend Prairie aquifer to the underlying Dakota and Permian formations.

The purpose of this report is to summarize and present the results of project work (other than that already reported in previous publications) accomplished during fiscal year 1993. Also included are additional data obtained from other sources since preparation of the earlier review documents. Although results are discussed and interpreted when warranted, this is primarily a report designed to provide a convenient compilation of data and a description of activities and methods. Additional interpretive reports will be prepared as appropriate over the life of the project.

II. Field Installations and Measurements

Logging, surveying, and sampling

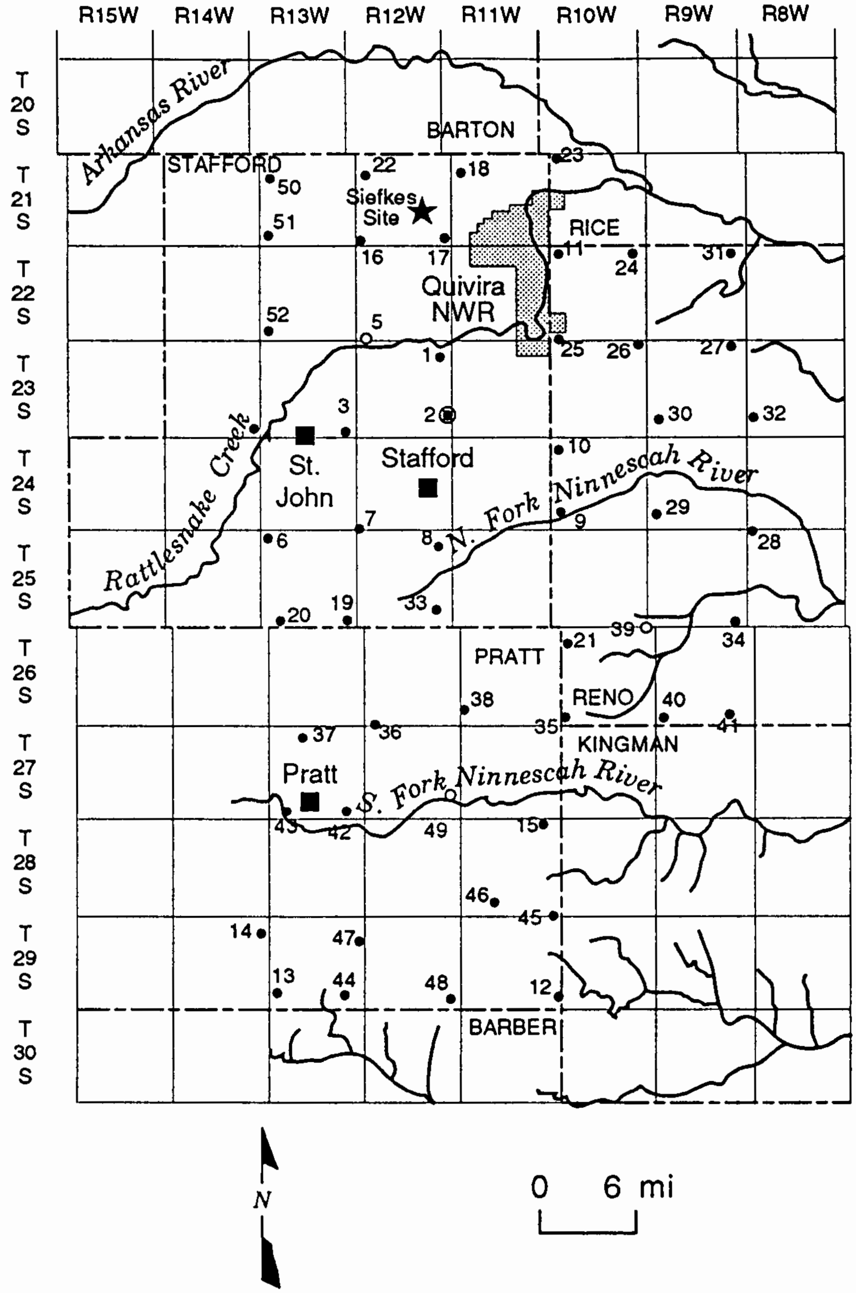
Nearly all of the KGS/GMD5 monitoring well sites were logged for natural gamma activity and formation conductivity as determined by electromagnetic induction. Natural gamma logging provides a record of the distribution of naturally occurring radioactive elements such as potassium, uranium and thorium. In formations such as the Great Bend Prairie aquifer, clays and silts typically show higher levels of radioactivity than sands and gravels. Formation conductivity reflects a combination of two factors: the salt content of the groundwater in the formation and the natural electrical conductivity of the minerals. In saline areas the effect of salt water dominates the conductivity signal, but where the water is fresh, clays exhibit higher intrinsic conductivity than the sands and gravels. Figure 3 shows the locations and status of the wells in this network. They are discussed in more detail by Whittemore (1993). Wells at sites 5, 39, and 49 have not yet been logged because of access problems, primarily due to washouts and flooding.

Logging was carried out using a Century Geophysics UL-1000 data logger, portable draw-works, and a model 9510 combination gamma-EM tool. Logging procedures followed the manufacturer's recommendations, which results in an electronic depth profile of data points collected at 0.1-foot intervals; repeat measurements and logging runs at slower speeds were used to test reproducibility of readings and to improve statistical confidence in gamma counts. Prior to logging, water levels were measured and recorded for each well. Site inspections were also conducted to document well condition. This first round of logging took place in March, April, and May. At most sites, both the Permian well and the deep-aquifer well were logged. Appendix A contains copies of the well log data sheets which show well construction, basic stratigraphic information, water levels, and gamma and EM log records prepared after processing of the electronic log records by the methods described below.

To monitor local and sub-regional effects of groundwater withdrawal on the saltwater interface, two study areas were identified for progressively more detailed investigation at different spatial scales. One area to be studied at an intermediate spatial scale is an east-west corridor centered on monitoring well sites 11, 16, 17, 18, and 22, and extending to sites 50 and 51 to the west and 24 and 31 to the east (see figs. 3 and 4). This corridor spans the range of conditions from confined Permian in the west to natural saltwater discharge in and beyond the Quivira marshes in the east and will be referred to hereafter as the transect. The Permian wells at sites 11, 16, 17, 18, and 22 in the central part of the transect area were relogged in mid-May to obtain initial data on interface variability. Water-level changes at these sites are listed in table 1; logs are included in Appendix A.

An intensive study site was established within the transect corridor with the cooperation of Mr. Dennis Siefkes, landowner. This site is centered on an irrigation well in the southeast quarter of section 27, Township 21S, Range 12W that becomes progressively more salty during the pumping season. A number of existing stock, domestic, and oil-field supply wells within approximately one-half mile of the irrigation well provide a network of shallow and intermediate-depth monitoring points. In addition, KGS installed monitoring wells that were completed in the Permian bedrock and at the base of the alluvial aquifer in the vicinity of the irrigation well. The monitoring well design and installation are discussed in more detail in the following section. Figure 5 presents a map of the Siefkes site, table 2 identifies the wells by use and location, and table 3 presents the characteristics of and recent measurements on the wells. Available well logs are included in Appendix B.

The two new monitoring wells at the Siefkes site were logged after installation in mid-April, and again in mid-May and early July for comparison. In addition, the accessible existing (oil-field supply and stock) wells in the vicinity were logged; data are included in Appendix A. Water levels were recorded for each well prior to logging and



- ● Wells logged for natural gamma and induction (spring 1993)
- ○ Wells not yet logged because of access limitations (sites 5, 39, 49)
- ◉ Plugged wells (site 2)
- ★ Intensive study site

Figure 3. Observation wells in the KGS/GMD5 monitoring-well network and status as of June 1993.

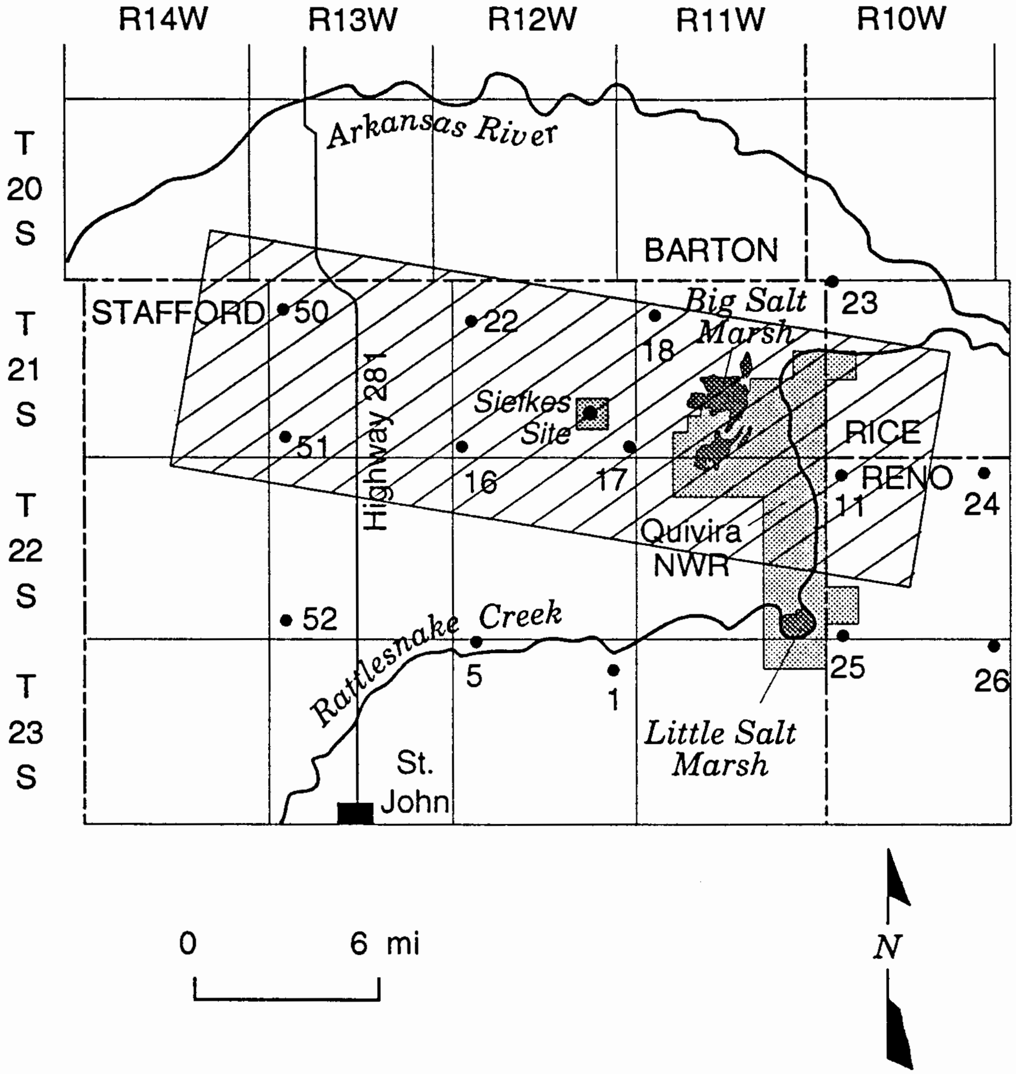


Figure 4. Monitoring-well sites in the transect corridor area of the Mineral Intrusion Project. See Figure 5 for detail of the Siefkes Site intensive study area.

again on May 25. All of the logged wells at the Siefkes site were surveyed in late May to obtain elevations and locations; table 3 summarizes the relevant well-elevation and water-level data. Water samples were collected from the new monitoring wells, as well as from oil-field supply, stock, and domestic wells at the Siefkes site. Wells with installed pumps were pumped to remove several casing volumes before sampling. A portable submersible pump was used to develop the oil-field supply wells before sampling; the smaller diameter monitoring wells were airlifted to remove approximately 10 casing volumes of water prior to sampling. The Permian monitoring well was sampled at the bottom of the hole. Water-quality results are reported and discussed below.

Monitoring well installations

Two monitoring wells, one screened in Permian bedrock and one screened near the base of the Great Bend Prairie aquifer, were installed to monitor the dynamics of the groundwater system and the effects of pumping. This site and the well locations are shown in fig. 5; well characteristics are tabulated above.

The primary purpose of the monitoring wells is to provide access points for the use of EM logging to monitor changes in the locations and characteristics of the saltwater interface in response to seasonal irrigation pumping. The secondary purpose is to provide measurements of changes in head in different zones of the aquifers and to obtain water-quality samples.

Because the monitoring wells span the water-quality transition zone in the aquifer, extreme care was taken to ensure that the boreholes did not provide a pathway for artificial upward migration of brine. The wells were drilled by the KGS Exploration Services Section using mud-rotary techniques. Installations consist of 3" dia. PVC casing above 2" PVC screen; boreholes were grouted with neat cement from the top of the screen to well above the saltwater interface and finished with bentonite fill to the surface. More detailed descriptions of the well installation and construction procedures and

Table 1: Fluid Levels and Other Information From Transect Wells.

Well	Location	Top of screen (bls)	Depth (bls)	Land surface elev.	Elev. top of screen	Elev. bottom of well	Date	Depth to Water	Fluid level elev.
16-1	21-12-31CCC	243	248	1872	1629	1624	03/25/93	29.0	1843.0
				1872			05/19/93	27.7	1844.3
16-2		198	203	1872	1674	1669	03/25/93	19.2	1852.8
				1872			05/19/93	16.9	1855.1
17-1	21-12-36DDC	129	134	1804	1675	1670	03/24/93	45.7	1758.3
				1804			05/19/93	44.7	1759.3
17-2		102	107	1804	1702	1697	03/25/93	10.8	1793.2
17-3		41	46	1804	1763	1758	03/25/93	11.6	1792.4
18-1	21-11-07BBB	231	236	1810	1579	1574	03/25/93	34.0	1776.0
				1810			05/21/93	31.8	1778.2
18-2		197	202	1810	1613	1608	03/25/93	32.5	1777.5
				1810			05/21/93	30.4	1779.6
22-1	21-12-06CCB	231	236	1855	1624	1619	03/25/93	29.3	1825.7
				1855			05/21/93	28.0	1827.0
22-2		206	211	1855	1649	1644	03/25/93	24.7	1830.3
				1855			05/21/93	23.0	1832.0
22-3		35	45	1855	1820	1810	03/25/93	16.1	1838.9
11-1	22-10-06CBB	237	241	1763	1526	1522	03/27/93	31.9	1731.1
				1763			05/20/93	30.6	1732.4
11-2		61	66	1763	1702	1697	03/27/93	13.5	1749.5
				1763			05/20/93	10.0	1753.0

NOTES : (1) All depths are in feet below land surface (bls); elevations are in feet above mean sea level. The first number of the well ID indicates the site location (fig. 3); the second identifies the specific well. Wells with the suffix -1 are completed in the upper part of the Permian bedrock, wells with -2 are completed near the base of the alluvial aquifer, and the -3 wells are at shallow to intermediate depths in the alluvial aquifer. Site numbers may be preceded by MS (for monitoring site). (2) Elevations are taken from the original installation logs and have not been re-surveyed. At a given site the ground-surface elevations of the individual wells may vary by as much as a foot, so small differences in depth to water between wells are not significant.

Table 2: Well Identifications in the Siefkes Intensive Study Area.

Well ID	Description	Legal location
I	Irrigation well near center of SE/4 Sec. 27 T21S-R12W	21-12-27DACC-1
IM	2" (monitoring) well near irrigation well	21-12-27DACC-2
WOS	Oil-field supply well west of irrigation well	21-12-27DBDC
NOS	Oil-field supply well north of irrigation well	21-12-27ACDD
S	Stock well southeast of irrigation well	21-12-27DDDC
EOS	Oil-field supply well east of irrigation well	21-12-26CDCC
P	KGS Permian monitoring well	21-12-27DACC-3
DA	KGS deep-aquifer monitoring well	21-12-27DADD
NEOS	Oil-field supply well northeast of irrigation well	21-12-26BDB
SOS	Oil-field supply well south of irrigation well	21-12-34AAB
DW	Domestic well west of Siefkes residence	21-12-26CC
DE	Domestic well east of Siefkes residence	21-12-26CCD

NOTE: (1) Well designations in the left-hand column may be preceded by MI-SS- (for Mineral Intrusion, Siefkes Site). (2) The legal location ID is derived from the (township)-(range)-(section number) followed by letters that denote quarters of the next larger subdivision, where A = NE, B = SE, C = SW and D = NW. Numerical suffixes are used to distinguish wells where there are more than one in the smaller indicated quarter. For a more complete description and examples, see Appendix B of Mitchell et al, 1993.

Table 3: Information for Wells in the Siefkes Intensive Study Area.

Well	Location	Top of screen (bls)	Depth (bls)	Land surface elev.	Elev. top of screen	Elev. bottom of well	Date	Depth to water	Fluid level elev.
I	21-12-27DACC	60	120	1840.7					
WOS	21-12-27DBDC	65	85	1839.4	1774.4	1754.4	03/24/93	14.2	1825.2
				1839.4			05/25/93	11.2	1828.2
IM	21-12-27DACC		60	1840.7	1840.7	1780.7	03/24/93	15.2	1825.5
				1840.7			05/25/93	12.8	1827.9
NOS	21-12-27ACDD	100	120	1839.0	1739.0	1719.0	03/24/93	16.8	1822.2
				1839.0			05/25/93	13.8	1825.2
S	21-12-27DDDC	80	90	1836.3	1756.3	1746.3	03/26/93	16.0	1820.3
EOS	21-12-26CDCC	80	100	1832.9	1752.9	1732.9	03/26/93	18.6	1814.3
				1832.9			05/25/93	16.0	1816.9
P	21-12-27DACC	198	228	1839.6	1641.6	1611.6	04/17/93	23.0	1816.6
				1839.6			05/20/93	22.2	1817.4
				1839.6			05/25/93	22.0	1817.6
DA	21-12-27DADD	157	167	1839.8	1682.8	1672.8	04/17/93	22.6	1817.2
				1839.8			05/20/93	20.9	1818.9
				1839.8			05/25/93	20.7	1819.1
NEOS	21-12-26BDB	90	105	1840*	1750*	1735*	03/27/93	27.2	1812.8*
							05/25/93	24.4	1815.6*
SOS	21-12-34AAB	80	105	1841.0	1761.0	1741.0	05/25/93	14.8	
1826.2									
							07/07/93	13.4	
	1827.6								
							07/08/93	12.7	
	1828.3								

*Elevations approximate, estimated from topographic map. All other elevations surveyed.

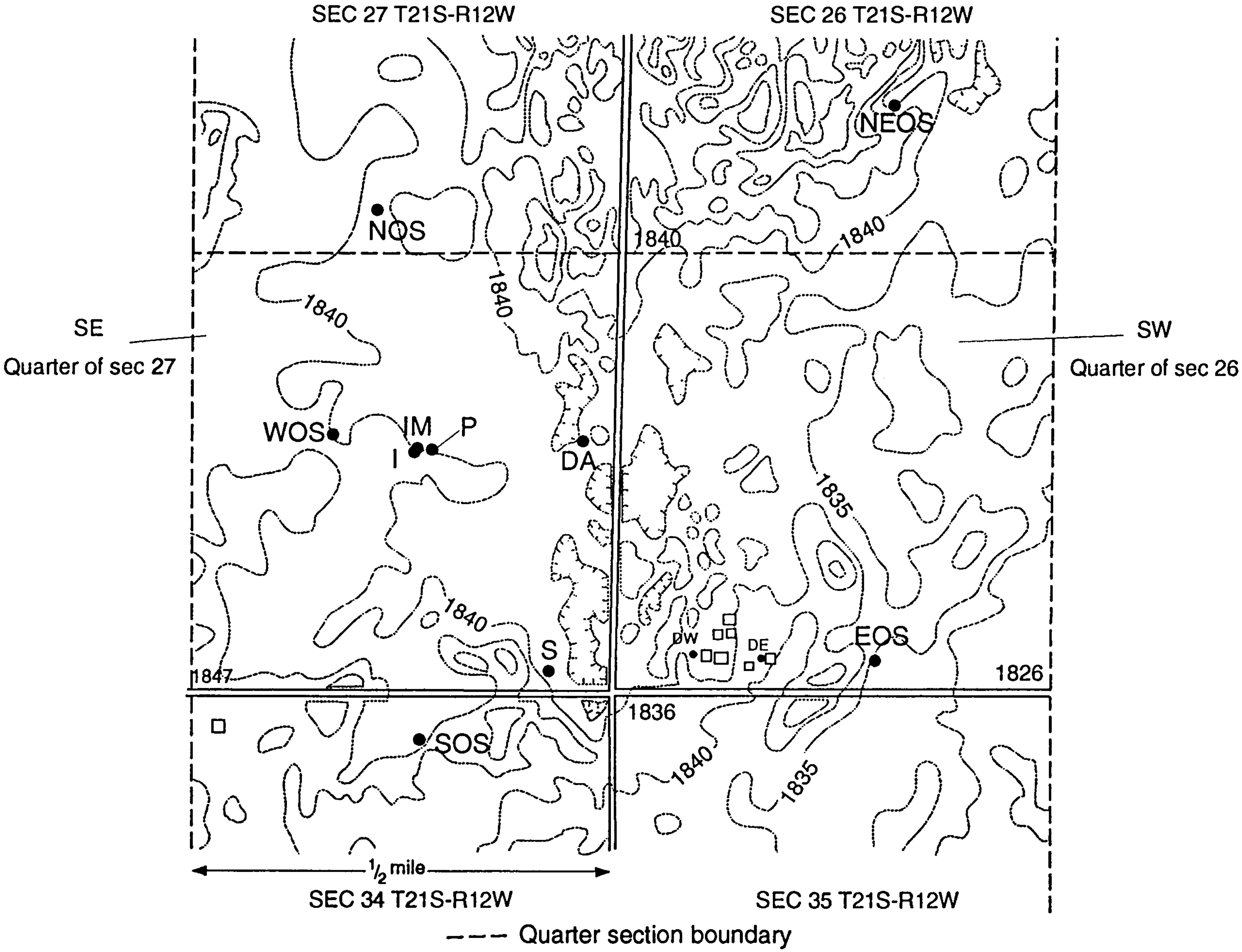


Figure 5. Wells in Siefkes intensive study area. See Tables 2 and 3 for well identification and characteristics. Contours indicate approximate elevation of land surface (feet above mean sea level).

schedules are given in Appendix B, along with available field logs for wells in the intensive study site area.

After installation the screened intervals were developed by airlifting; because of its high salinity, the development water was collected and trucked off-site for disposal. The wells were sampled, logged, and surveyed; the methods and results are described in other sections of this report.

III. Results of Analyses

Water chemistry

The distribution and sources of salinity in groundwater in the Quaternary aquifer and underlying Permian bedrock were determined for the intensive study site in the area of the Siefkes irrigation well. Waters were sampled from the observation wells installed by the KGS and from domestic, stock, oil-field supply, and observation wells existing in the study area, and analyzed at the laboratories of the KGS. The location description, date, and chemical determinations made to date are listed in tables 4 and 5. Not all constituents were determined in all samples because the additional information is not warranted for the purposes of the study. Bromide and iodide measurements will be completed for all samples for salinity identification; additional analyses will be tabulated and discussed in subsequent project reports.

The first two samples collected from the study area were from intermediate depths in the unconsolidated sediments of the Quaternary aquifer. The oil-field supply well west of the Siefkes irrigation well had a chloride concentration less than 100 mg/L (table 4) as predicted for the upper aquifer by the chloride distribution map for GMD5 (plate 3 in Whittemore, 1993). The water chemistry fits the bromide/chloride and sulfate/chloride versus chloride concentration mixing graphs for naturally occurring saltwater in the region (Whittemore, 1993). The stock well southeast of the irrigation well contained a higher chloride content than expected. The source of the additional chloride is oil-field brine, based on the higher bromide/chloride and lower sulfate/chloride ratios than are consistent with the Permian source of salinity that intrudes to the aquifer base.

Other groundwaters from intermediate depths in the aquifer at the study site contain dissolved chloride in the range 91-309 mg/L (table 4). Although the bromide has not yet been determined for these samples, the high chloride in the water from the oil-field supply well east of the Siefkes residence appears to be related to oil-brine contamination based on a sulfate concentration in the same range as for the other samples. If the source were natural intrusion from below or salts concentrated by evapotranspiration and leached from above, the sulfate would be expected to increase with the chloride concentration. In general, the nitrate concentrations are inversely related to the chloride contents for the wells shallower than 115 ft, also indicating that the salinity source for the stock well and oil-field supply well east of the house is not primarily from agricultural practices or animal/human wastes. Quantification of oil-brine contamination will be made after the bromide and iodide measurements are completed.

Water samples were collected during and at the end of development of the observation wells drilled by the KGS (tables 4 and 5). An additional sample was pumped from the Permian observation well because the sample at the end of development had a high pH, indicating reaction with the cement used in well construction. This second Permian sample had a lab pH less than 8 as did the water from the aquifer base well, which is expected for water collected from this area and transported to the lab. The latest sample for each of the two observation wells is the most representative and has the highest salinity. The percentage change with each sampling after well completion should diminish if no appreciable hydrologic changes were occurring; this is to be expected for this area because the irrigation well had not pumped since the previous year. The specific conductance and chloride concentrations for samples from the Permian well increased 9.0% and 20.4%, respectively, from the first to second sample, and 16.8% and 5.7%, respectively, from the second to third sample, suggesting that the ultimate true conductance and chloride of the Permian formation water may be a few percent higher than the latest sample reported here. The conductance and chloride for the second sample from the aquifer base well increased 2.9 and 2.3 percent, respectively, over the first sample, suggesting that the values for the second sample are within a few percent of actual.

When the bromide/chloride and sulfate/chloride ratios for the observation well waters from the aquifer base and Permian bedrock at the Siefkes study site are plotted on

Table 4. Site Locations and Chemical Properties of Groundwater Samples Collected for the Mineral Intrusion Study in the Siefkes Intensive Study Site.*

Well ID and sample	Well location	Sample date	Well Depth (ft)	Field sp.c. mS/cm	Lab sp.c. mS/cm	Lab pH
MI-SS-WOS	21S-12W-27DBDC	3-23-93	85	730	750	
MI-SS-S	21S-12W-27DDDC	3-23-93	90	1,202	1,130	
MI-SS-DE	21S-12W-26CC	4-15-93	90	880	820	
MI-SS-DW	21S-12W-26CC	4-15-93	96	820	770	
MI-SS-IM	21S-12W-27DACC	4-13-93	60	720	680	
MI-SS-EOS	21S-12W-26CDCC	4-15-93	100	1,370	1,320	
MI-SS-NOS	21S-12W-27ACDD	4-15-93	128	810	680	
MI-SS-P, 200 gal*	21S-12W-27DACC	4-14-93	228		55,600	
MI-SS-P, add'l 100 gal*	"	4-15-93	227.8		60,600	9.55
MI-SS-DA, 1st 200 gal*	21S-12W-27DADD	4-15-93	167.0		37,300	
MI-SS-DA, 2nd 200 gal*	"	4-15-93	167.0		38,400	7.80
MI-SS-P, gal @210 ft**	21S-12W-27DACC	6-02-93	227.8		70,800	7.85

See tables 2 and 3 and fig. 5 for well descriptions and locations.
*amount pumped before sampling
**Amount air-lifted before sampling

Table 5. Concentrations of Dissolved Constituents in Groundwater Samples Collected for the Mineral Intrusion Study in the Area of the Siefkes Irrigation Well Located at 21S-12W-27DACC. (See tables 2-4 for full location and sample descriptions)

Well	Sample date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	B mg/L	I mg/L
WOS	3-23-93							95.6	11.1	130	0.096	0.0010
S	3-23-93							238	10.1	26.6	0.860	0.0050
DE	4-15-93							116	14.5	47.9		
DW	4-15-93							126	8.0	17.4		
IM	4-13-93							90.6	9.3	107		
EOS	4-15-93							309	14.2	10.2		
NOS	4-15-93							95.0	14.4	29.8		
P	4-14-93							20,960	2,540	3.0		
P	4-15-93							25,240	2,870	1.6	3.8	
DA	4-15-93							13,620	1,500	0.9	2.1	
DA	4-15-93	347	162	8,880	<12	3.2	292	13,940	1,530	0.6	2.2	
P*	6-02-93	697	356	17,800	32	13.7	277	26,670	3,180	0.2	2.1	

*Silica (17 mg/L) was also determined in the 6-2-93 sample from the Permian observation well.

the graphs of ion ratio versus chloride in Whittemore (1993) for the mineral intrusion area of GMD5, they fall within the zone of mixing of freshwater and Permian saltwater The data indicate that essentially no oil brine (less than 2% based on the accuracy of the method) is present in the waters. Thus, the oil-brine contamination present in two of the intermediate aquifer waters listed in tables 4 and 5 appears to be from local surface sources and has not penetrated to the base of the aquifer at the observation-well locations.

The salinity increases greatly with depth at the Siefkes study site, from a chloride of near 100 mg/L at depths above 90 ft, to 13,600 mg/L at the aquifer base (157-167 ft), to at least 26,700 mg/L in the Permian bedrock (198-228 ft). The geophysical logs indicate that the salinity starts to increase at about 145 ft (see geophysical log section). The depth of the irrigation well is 120 ft or only about 25 ft above the top of the freshwater-saltwater interface. The chemistry of the irrigation well will be monitored once pumping begins for the season.

The chloride concentration in the Permian groundwater at the study site is within the range predicted from the chloride distribution map (plate 2) in Whittemore (1993). The aquifer base well is within the mapped 10,000-20,000 mg/L chloride range, but is very close to the 20,000 mg/L contour. This contour for the aquifer base salinity will be shifted slightly in subsequent map preparations to reflect these additional data from the Siefkes study site. The salinity at the base of the aquifer sands and gravels at the Siefkes subsidence site (NE sec. 3, T. 22 S., R. 12 W, about 1.3 miles south of the study site) is appreciably less than at the Siefkes study site. The highest specific conductance and chloride concentration recorded in the two monitoring wells drilled in the subsidence area were 16,500 mS/cm and 5,220 mg/L, respectively (Whittemore, 1990). However, the depths of the wells were 130-135 ft, appreciably shallower than at the Siefkes study site. The bedrock configuration map of Sophocleous et al.,(1993) shows that the bedrock surface slopes from the subsidence site towards the Mineral Intrusion study site. The map indicates a valley in the bedrock surface 2-3 miles northwest of the intrusion study site. Higher salinity water at greater depths in the bedrock valley is consistent with the observations at the two locations.

In addition to the results reported above and earlier analyses presented by Whittemore (1993), GMD5 has also had a long-term program of water-quality monitoring. A report of results to date is included as Appendix C of this report as part of the GMD5 contribution to the overall cooperative project. A search was also made of the USEPA STORET database system. Water quality data listed there for the Mineral Intrusion study area have been identified, and will be retrieved and published in a subsequent project technical report. With the inclusion of these data, this report plus the two earlier review reports (Young, 1992; Whittemore, 1993) constitute as complete a set of the geohydrologic, geologic, and geochemical information on the Mineral Intrusion study area as it is practical to assemble. These documents and data sets provide the basis for future research and reporting.

Core and drill log analysis

Drilling logs based on inspection of returned cuttings were combined with gamma logs to produce a detailed description of the formation in the vicinity of the Siefkes site deep Permian well. This composite log is shown in fig. 6. Boundaries based on cuttings are approximate since judgments are based on estimates of fluid return time and may be affected by sloughing from materials higher in the borehole.

The Permian borehole was cored for approximately 30 feet beginning approximately 10 feet below the top of the bedrock. This represents the longest and deepest Permian cored interval that has been thoroughly logged and examined. The core was described, and the descriptive log is given in table 6.

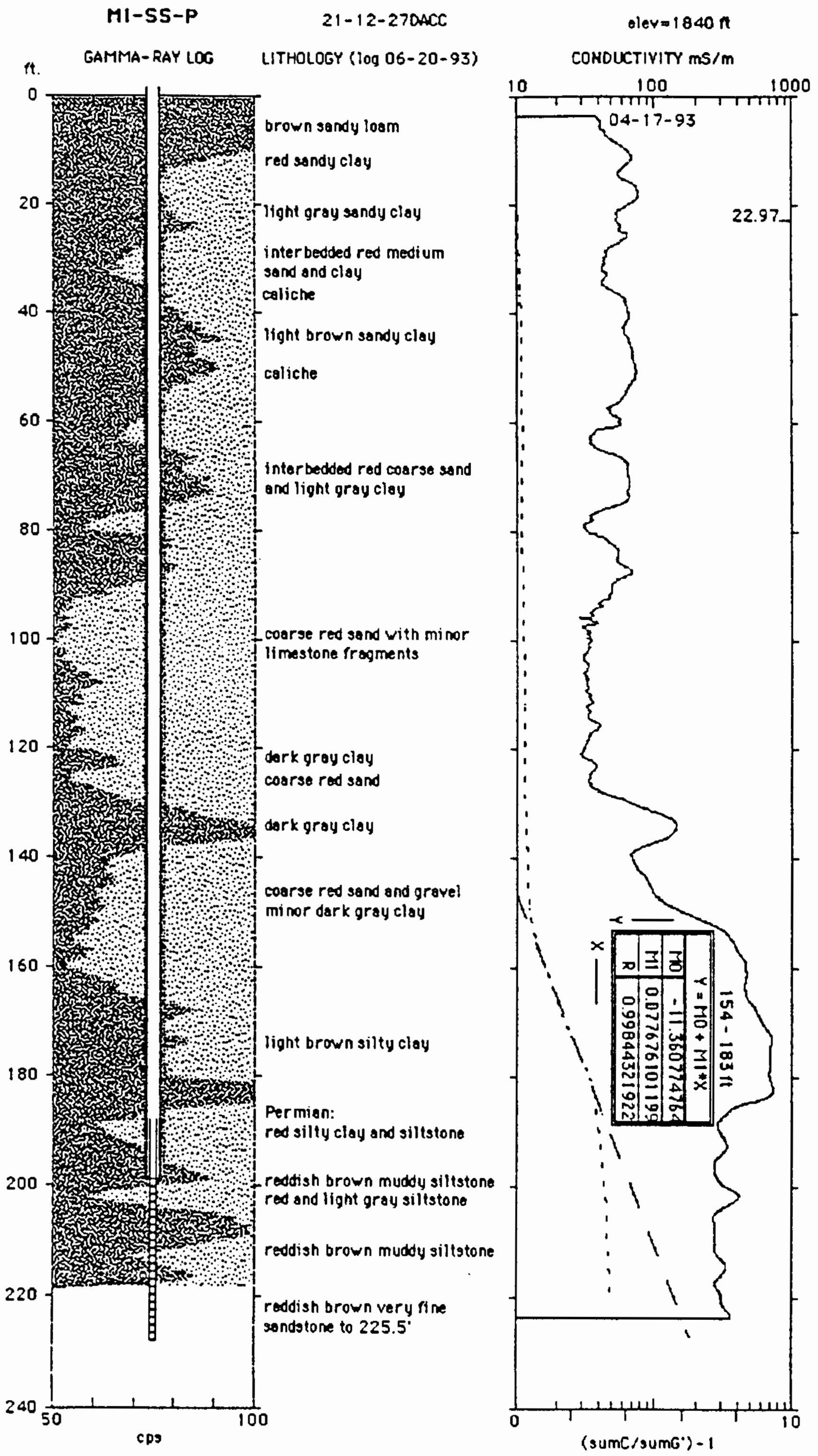


Figure 6. Gamma-ray, conductivity, and drilling log for the Permian monitoring well at the intensive study (Siefkes) site.

Table 6: Siefkes Permian Core Description

197' 10" to 200'
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted, poorly indurated, no structures.

200' to 203'
Core loss--Probably siltstone or very fine sandstone.

203' to 203' 6"
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted, poorly indurated, no structures.

203' 6" to 204'
Light-gray siltstone, well sorted, poorly indurated, no structures.

204' to 207' 6"
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted poorly indurated, no structures, slightly mottled with light gray.

207' 6" to 212' 9"
Core loss--Probably moderate-reddish-brown siltstone or very fine sandstone.

212' 9" to 217' 9"
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted, poorly indurated, no structures, light-gray mottles at 216'.

217' 9" to 223' 6"
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted, poorly indurated, no structures.

223' 6" to 225' 6"
Moderate-reddish-brown very fine sandstone (99% quartz), no $CaCO_3$, well sorted , quartz grains well rounded and Fe stained, no structures, many light-gray mottles.

225' 6" to 226' 6"
Moderate-reddish-brown muddy siltstone, no $CaCO_3$, well sorted, poorly indurated, no structures.

IV. Log Interpretation

The well logs used for this study were obtained using a logging tool that detects both the natural gamma radiation and the induced electrical conductivity of the formation surrounding the borehole.

The gamma-ray response function, measured in counts-per-second (cps), is dependent on the concentrations of the radioactive elements uranium (U), thorium (Th), and potassium (K) present in the minerals. Because clays possess higher concentrations of K than a quartz arkosic sand, the response will be generally higher in the vicinity of clay layers. An earlier study (Rosner, 1988) determined from analysis of gamma-ray logs and samples obtained from monitoring wells constructed in the Great Bend Prairie that silt-clay end-member gamma activity begins at approximately 100 cps and that the sand-gravel activity is typically 50 cps or less.

The conductivity log measures electrical-current flow capacity in millisiemens-per-meter (mS/m) as a response to an induced electromagnetic (EM) field. The conductivity response is dependent on temperature, porosity, connectivity, and ionic strength of both the media and the pore fluid. Because clay minerals possess relatively high cation exchange capacities, the response will be higher than a quartz arkosic sand saturated with a fluid of low ionic strength. However, sand saturated with a highly concentrated solution can have a conductivity response equal to or greater than that of clay or the underlying consolidated bedrock formations.

Each suite of logs has been conveniently plotted on comparable scales in Appendix A with the accompanying lithologic description log that was recorded when the wells were constructed. The introduction to the appendix contains a further description of and key to the log presentations.

The electronic log data have been processed and analyzed to determine the characteristics of the saltwater interface and transition zone. The primary purposes of this processing are to remove some of the effects of matrix (aquifer mineral) conductivity that may obscure the signal due to groundwater salinity, and to provide a quantitative, objective basis for detecting changes over time. The characteristics derived from this analysis include the elevations of the top and midpoint of the transition zone. The rate of change or slope of the line connecting these two points represents the contrast or degree of mixing between freshwater and saltwater. These initial values for the elevation and thickness of the transition zone are important in establishing a base level against which temporal variations will be compared from repeated logging and analysis of the wells.

The method presently employed for characterizing interface depth and thickness involves signal summation and correction of the EM log with the gamma log data. Although we expect that the methods will undergo further modification before the final data processing approach is adopted, we discuss the present version in some detail to illustrate the objectives, conceptual approaches, and problems. The conductivity log profile is transformed into cumulative form by progressively summing the individual conductivity data points from top to bottom of the log. This yields a plot representing the typical S-shaped interface-transition zone. Because of the inherent lithologic relationship between the gamma and EM logs discussed above, the gamma-ray log is standardized and also transformed into a cumulative form to permit its use as a correction factor for removal of the background lithologic signal from the cumulative conductivity profile. Examples of the corrected and uncorrected calculated cumulative curves for two sites are shown in fig. 7. The logs from the freshwater Monitoring Site 50 were used for the standardization, based on the excellent cross-correlation between the gamma-ray and conductivity logs (fig 8.). The basis for standardization is discussed in the introduction to Appendix A.

The ratio of the summed conductivity log to the standardized summed gamma log is calculated. For wells that exhibit a distinct transition zone, a least-squares line is fit to the segment of the derived curve spanning the region where the greatest change occurs . Figure 9 presents a comparison of the original logs, the cumulative curves, and the calculated interface characteristics obtained from duplicate successive logging runs at a single site. In spite of statistical uncertainties in the gamma records and in the correlation between lithologic and conductivity signals, this process clearly generates a much clearer picture of the saltwater interface than could be obtained from EM records alone. The reproducibility of both slope (M1) and depth intercept (-M0/M1) is encouraging, since the difference in the intercept is less than 0.2 feet, which is the expected limit of resolution for calculations based on logs sampled at 0.1-foot intervals. The intercept of this line with the depth axis is defined as the top of the transition zone; inspection of the logs suggests that this is probably a reasonably conservative practical definition of the depth at which a water

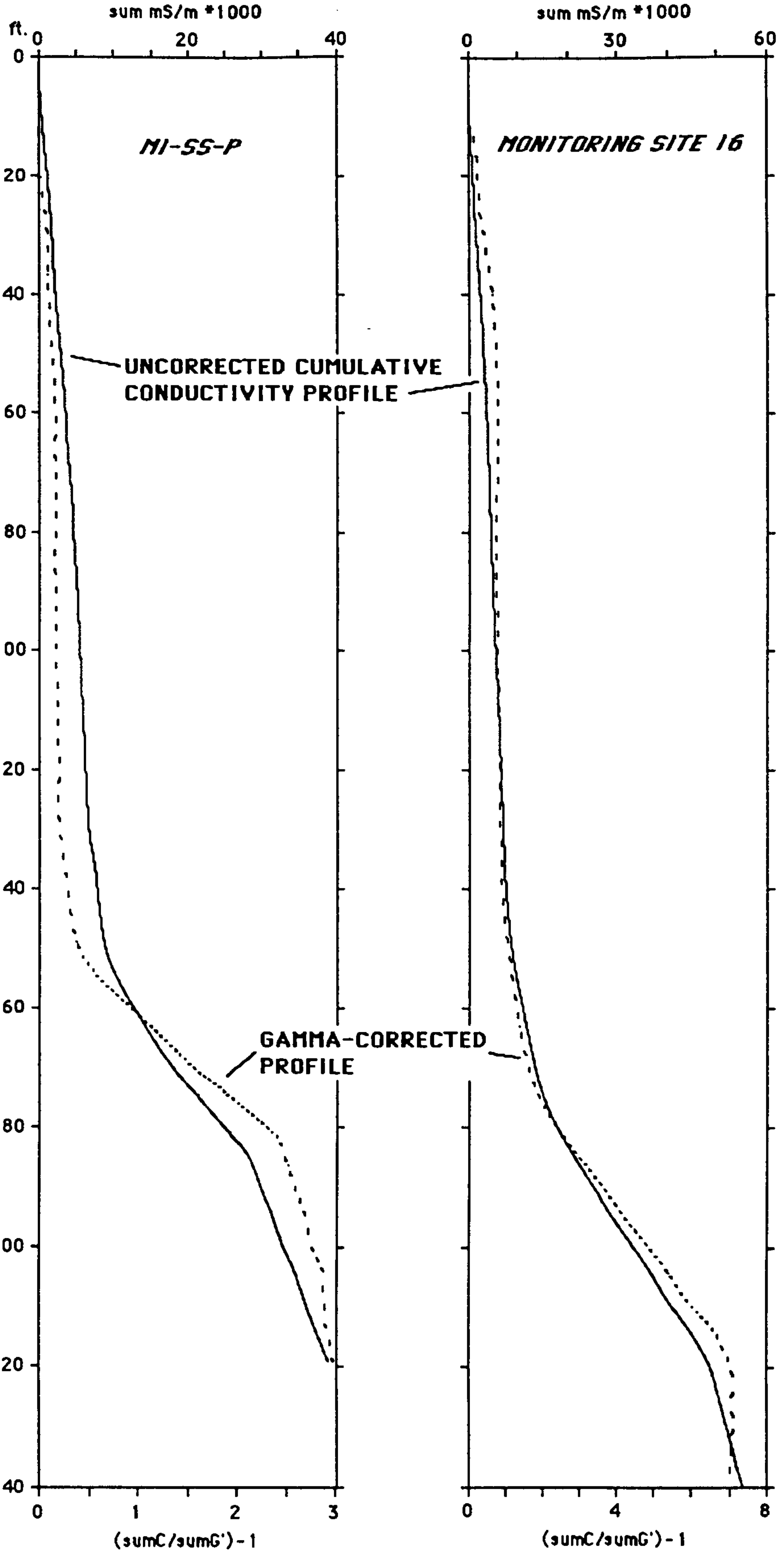


FIGURE 7. Gamma-ray log corrections applied to conductivity logs: sumC is the cumulative conductivity profile; sumG' is the cumulative standardized gamma profile.

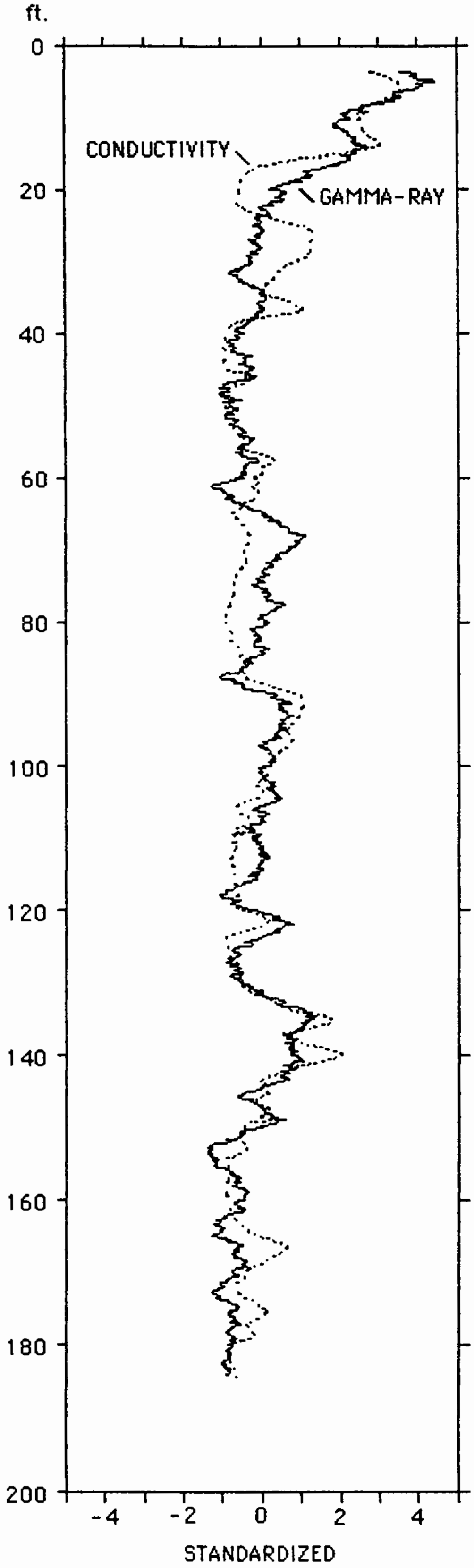


FIGURE 8. Plot of standardized gamma-ray and conductivity logs for Monitoring Site 50.

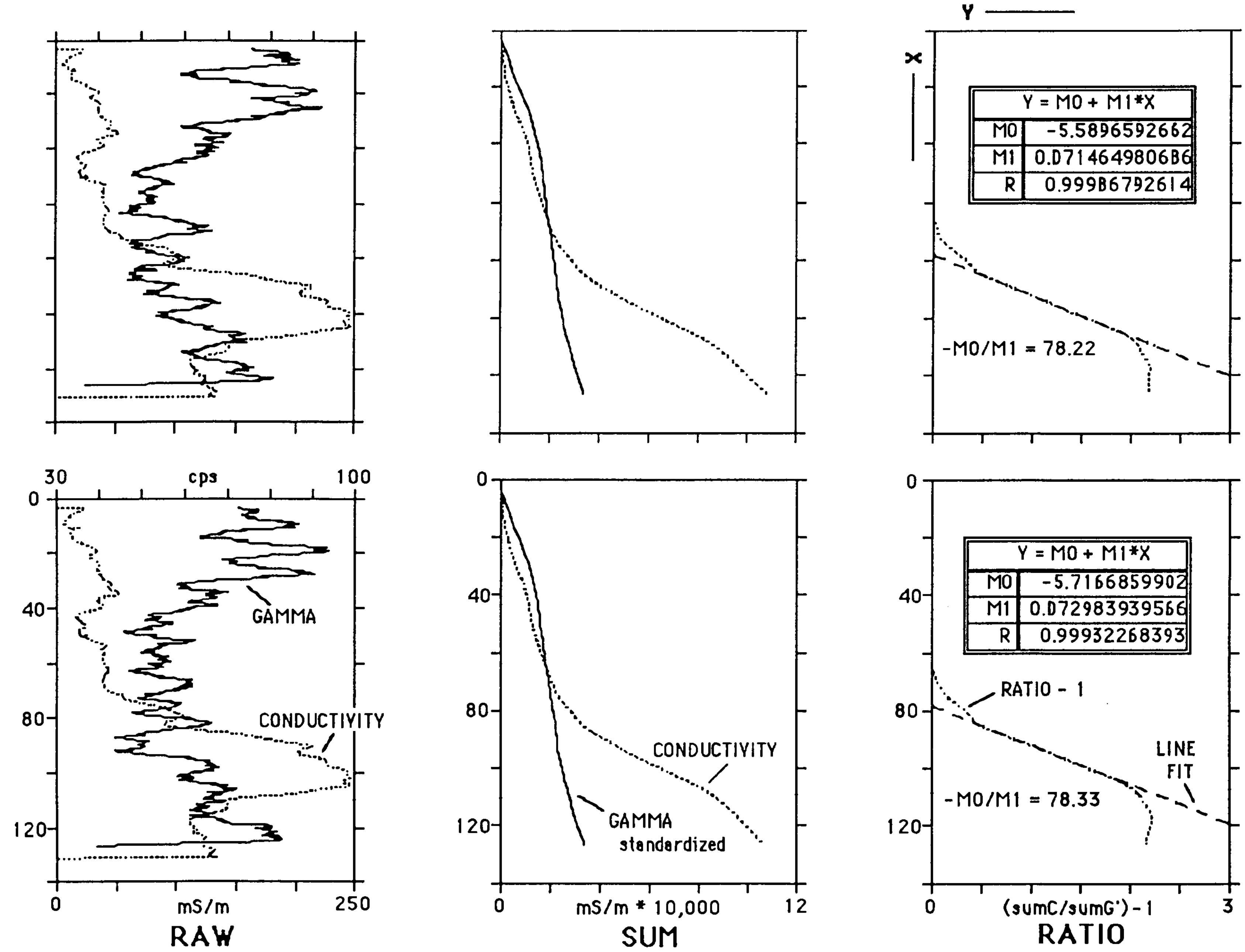


FIGURE 9. Examples of the gamma correction and curve fitting process for repeated logs of a single well. Differences are due largely to statistical variations in detection of the gamma activity.

user might expect to encounter deteriorating water quality. The slope of this line, change in conductivity with change in depth, indicates the rate of variation (or extent of mixing) between the fresh and saltwater at a particular site. The midpoint of the linear portion of the summed curve is halfway between the intercept elevation and the bedrock elevation for the logs examined to date, but this is almost certainly an artifact of the change in gross conductivity due to the low matrix conductivity of the bedrock. Research is continuing on the best method to use for detection of the true midpoint of the transition zone and its change over time.

The data inset box shown in fig. 9 contains the equation for the line with the correlation coefficient R indicating the goodness of fit. Linear dispersion functions have been similarly used to characterize the transition zone between fresh and saltwater in an unconsolidated coastal aquifer (Schmorak and Mercado, 1969). This method allows analysis of logs that span the transition zone as well as logs that only partially span it, with the assumption that the function remains constant until the bedrock is encountered. For this reason, and as another test of the sensitivity of this method, logs from the other monitoring wells at sites with a shallow transition zone were processed and compared to those from the bedrock wells. Table 7 presents a summary of the differences in calculated interface characteristics between these adjacent wells. The largest differences appear to be related to differences between the gamma logs (see Appendix A).

Log analysis results are plotted in Appendix A for each well logged so far, with the results of the linear analysis described above included for wells that have a well-defined transition zone. Some wells indicate elevated levels of conductivity but lack a well-defined transition zone, while others show no excess conductivity. Criteria for selection, processing, and presentation of these data are discussed in the introduction to Appendix A

Research is continuing on further improvements in approaches to interface detection and characterization. The geochemical calibration of these curves will be attempted once the method has been further refined and assessed, and when appropriate water samples have been collected and analyzed. An ultimate goal is to be able to translate the corrected EM data into some variant of pore-water salinity such as total dissolved solids, chloride concentration, or specific conductivity on a quantitative predictive basis. However, the curve is useful in its present form for the determination of the physical characteristics of the interface and transition zone, and can be used to deduce approximate salinities.

Table 7. Differences between interface characteristics determined from measurements on pairs of wells at the same site.

	Deep Aquifer-Bedrock		Shallow Aquifer-Bedrock	
WELL ID	dTOP	dSLOPE	dTOP	dSLOPE
MS16	0.42	0.005		
MS17	4.95	-0.003		
MS18	-2.47	0.005		
MS22	-0.26	0.012		
MS25	0.68	-0.114	0.46	0.004
MS26	-0.97	-0.004		
MS36	4.13	0.024		

dTOP = Change (in feet of elevation) of top of interface ($-M_o/M_1$).
dSLOPE = Change in slope (M_1) of line fitted to transition zone.

V. Saltwater Distribution

Values for calculated elevations of interface top and midpoint are tabulated in table 8. Saturated thicknesses for both fresh and saltwater are also tabulated from measurements of water-table elevations during log collection. The fraction of total saturated thickness that is saltwater rather than fresh is given in the final column; it can be seen that a serious overestimate of available freshwater resources will result if bedrock rather than the saltwater interface is used to define the bottom of the usable aquifer. Further analysis of the relationship between the elevations of the transition zone will be carried out to extend estimates of the saltwater-saturated thickness to areas between the wells where there is reason to believe that a distinct transition zone exists.

The present methods used to separate the influence of matrix conductivity from groundwater salinity introduce some uncertainty as a result of statistical uncertainties in any individual gamma ray log and of short-range variations in lithology. Table 7 (discussed above) shows the differences in intercept elevations and slopes calculated from different wells at the same monitoring site. Minor differences, such as a fraction of a foot in elevation, may be due to local variations in unsurveyed well elevations or actual short-range variability in the interface. However, differences of several feet are probably largely artifacts of the correction approach. Table 7 gives a rough idea of the absolute accuracy of individual interface determinations; research is continuing in order to understand and reduce these apparent differences in interface detection.

An example of the use of calculated interface characteristics to monitor changes in individual wells is shown in table 9, which compares the results of logs taken approximately one month apart and again approximately 1.5 months apart at several of the transect wells. As long as the same gamma ray log is used for the scorrection, there should be no additional relative uncertainty introduced into repeat measurements fo the same well, and differences should reflect change in the saltwater interface. Because of an unusually wet winter and spring the water table was rising over this period, and this may not represent "normal" conditions for this time of year. However, the tabulated comparisons show that some (but not all) wells showed changes in the intercept of the fitted curve that were considerably greater than the replicate-measurement uncertainty illustrated in fig. 9.

Table 8. Saltwater interface elevations and characteristics at Mineral Intrusion monitoring wells.

Well ID	GRDel	TOPel	MIDel	BRel	SLOPE	FRESH	SALT	WLel	SALTfr
MI-SS-DA"	1840.000	1695.820	.	.	0.051	128.880	.	1825.000*	.
MI-SS-P"	1840.000	1693.780	1673.890	1654.000	0.078	131.220	39.780	1825.000*	0.228
MS1"	1827.000	1719.890	1700.450	1681.000	0.111	101.820	38.890	1821.710	0.276
MS3"	1898.000	1768.600	1768.300	1768.000	0.029	103.670	0.600	1872.270	0.006
MS4"	1912.000	1809.040	1796.020	1783.000	0.051	94.290	26.040	1903.330	0.216
MS6"	1950.000	1808.860	1805.430	1802.000	0.039	127.360	6.860	1936.660	0.051
MS8"	1848.000	1760.080	1745.540	1731.000	0.021	79.160	29.080	1839.240	0.269
MS9"	1755.000	1685.340	1676.670	1668.000	0.129	61.000	17.340	1746.340	0.221
MS11"	1763.000	1658.930	1606.970	1555.000	0.022	90.530	103.930	1749.460	0.535
MS16"	1872.000	1709.990	1681.500	1653.000	0.160	150.020	57.990	1860.010	0.279
MS17"	1804.000	1725.790	1703.400	1681.000	0.072	66.610	35.790	1792.400	0.350
MS18"	1810.000	1676.690	1636.350	1596.000	0.045	100.810	80.690	1777.500**	0.445
MS21"	1801.000	1682.640	1673.320	1664.000	0.117	96.790	18.640	1779.430	0.162
MS22"	1855.000	1677.250	1658.630	1640.000	0.080	161.640	37.250	1838.890	0.187
MS25"	1780.000	1755.830	1712.920	1670.000	0.469	17.840	85.830	1773.670	0.828
MS26"	1738.000	1658.760	1609.880	1561.000	0.062	72.390	97.760	1731.150	0.575
MS29"	1731.000	1580.890	1581.000	1581.000	0.044	111.560	0.000	1692.450	0.000
MS35"	1760.000	1609.180	1608.090	1607.000	0.021	131.770	2.180	1740.950	0.016
MS36"	1892.000	1726.360	1711.680	1697.000	0.076	139.610	29.360	1865.970	0.174
MS38"	1844.000	1709.870	1682.440	1655.000	0.020	108.210	54.870	1818.080	0.337
MS43"	1872.000	1825.510	1816.260	1807.000	0.063	41.500	18.510	1867.010	0.309

*water level from well id MI-SS-IM
**water level from deep aquifer well

GRDel = Ground elevation (feet above MSL).
TOPel = Elevation of top of salt transition zone (line intercept–M_o/M_1).
MIDel = Elevation of middle of salt transition zone.
BRel = Elevation of top of bedrock.
SLOPE = Slope of line fitted to transition zone (M_1).
FRESH = Saturated thickness of fresh-water in aquifer (ft).
SALT = Saturated thickness of salt water in aquifer (ft).
WLel = Elevation of water table
SALTfr = Fraction of total saturated thickness occupied by salt water.

Table 9. Changes in interface characteristics at selected wells between April and May 1993 and between May and July 1993.

	May-Apr			Jul-May		
WELL ID	dTOP	dSLOPE	dWL	dTOP	dSLOPE	dWL
MI-SS-DA	0.11	0.006	1.9	-1.33	0.003	2.1
MI-SS-P	0.14	0.000	1.0	0.18	0.000	1.3
MS11	-3.82	0.002	1.4	-2.26	-0.002	1.0
MS16	-0.84	-0.001	2.4	0.76	-0.001	1.9
MS17	-2.52	0.003	1.0	-0.80	0.001	0.6
MS18	-2.51	0.002	2.2	-0.61	0.001	1.2
MS22	-0.69	0.004	1.3	-0.03	-0.002	1.1

dTOP = Change (in feet of elevation) of top of interface ($-M_o/M_1$).

dSLOPE = Change in slope (M_1) of line fitted to transition zone.

dWL = Change (in feet) of elevation of water level.

VI. Water-level History

Changes in water level have the potential to affect the position and characteristics of the saltwater interface, both through changes in relative head and preferred flow direction, and through changes in the dynamic effects of groundwater flow. Correlation of head, water elevation, and interface characteristics will be a major effort during the coming year. This section presents a summary overview of the nature, range, and distribution of water table elevation changes in GMD5.

Figure 10 presents a broad-scale picture of changes since the predevelopment period (composite pre-1960 water levels) to January, 1991. This represents the status of knowledge at the beginning of the Mineral Intrusion Project. Water levels have generally increased since that time because of the high rainfall of 1992-93, but it will be some time before the rapid changes have equilibrated to the point where an equilibrium water table map can be reliably created.

Some general patterns can be seen in fig. 10. Areas of relatively high decline are generally limited to the western half of GMD5 above the extreme southern portion. Water table increases are observed in the south and southeast of the district, and in the north-central and eastern portions of the district (the region of greatest concern from the mineral intrusion standpoint) declines are relatively small. This may be the result of relatively low rates of witdrawal, especially in the areas of high salinity, or of the fact that the eastern part of the district is a natural discharge zone for both fresh and saltwater.

Within each of the general regions described, detailed local behavior of the water table shows significant variation. Figures 11-13 show long-term water level records as detailed examples of the behavior over time. All of the graphs have the same horizontal (time) axis, and the same range of vertical scale (30 ft) even though the absolute values vary. Well IDs based on the legal descriptions are included so that locations can be esitmated from the township grids in fig. 1 or fig. 10. The wells have different frequencies of measurement, which leads to different appearances of the records. A well that is only measured annually will show a much smoother pattern than one that is measured often enough to record seasonal as well as annual variations.

Figure 11 shows hydrographs from the wells along the northwest boundary of the study area and in the west-central portion. To varying degrees, these wells show the effects of floods (1973) or wet years (1987); however, the longer records indicate that these increases were superimposed on a sustained declining trend. Figure 11 depicts trends in the north-central portion of the study area. Here declines are not as great, as indicated by the contours of fig. 10, and the two middle panels of fig. 12 show little if any evidence of sustained decline. However, the hydrographs at the top and bottom of the page rather clearly show declines, although they are not as substantial as those farther west. Figure 13 shows patterns common in the eastern and southeastern part of the study area, where there is no evidence for systematic decline.

Although there are general trends and patterns identifiable, the absolute amounts and detailed patterns of water level changes show substantial variation even within a limited area. This means that it will be critical to determine, either experimentally or by simulation, the effects of head and head differences on the saltwater interface. Records of head changes in the different wells at the monitoring sites show complex variations over time (see, for example, fig. 6 in Buddemeier et al., 1992). These data, and their possible relationship to interface characteristics, are presently being analyzed and will be reported in a subsequent publication.

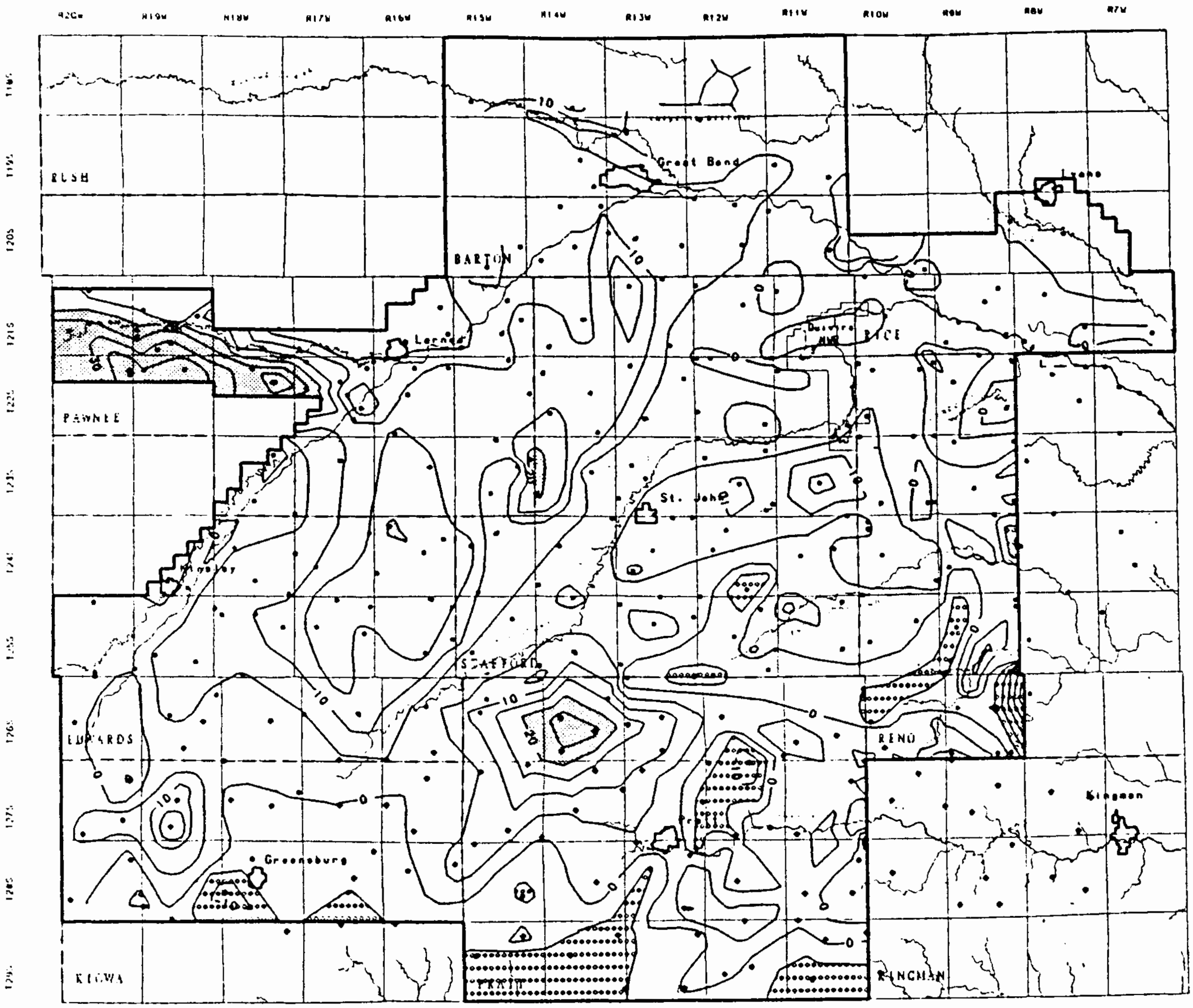


Figure 10. Contour map of the change in water level between the predevelopment period (pre-1960) and January 1991 in the area of GMD5. Contour intervals are five feet of water elevation, and the dots represent observation wells (data points). Contours filled with diamonds are regions of increase in water elevation; saded contour intervals represent decreases greater than 20 feet. Map preparation by Marios Sophocleous and Alan Stern.

Well ID = 22S15W13DCA + 01

Well ID = 23S14W30BBB + 01

Well ID = 26S14W17DCB + 01

Well ID = 25S13W16AAC + 01

Well ID = 27S14W12DDD + 01

Well ID = 26S13W34BCB + 01

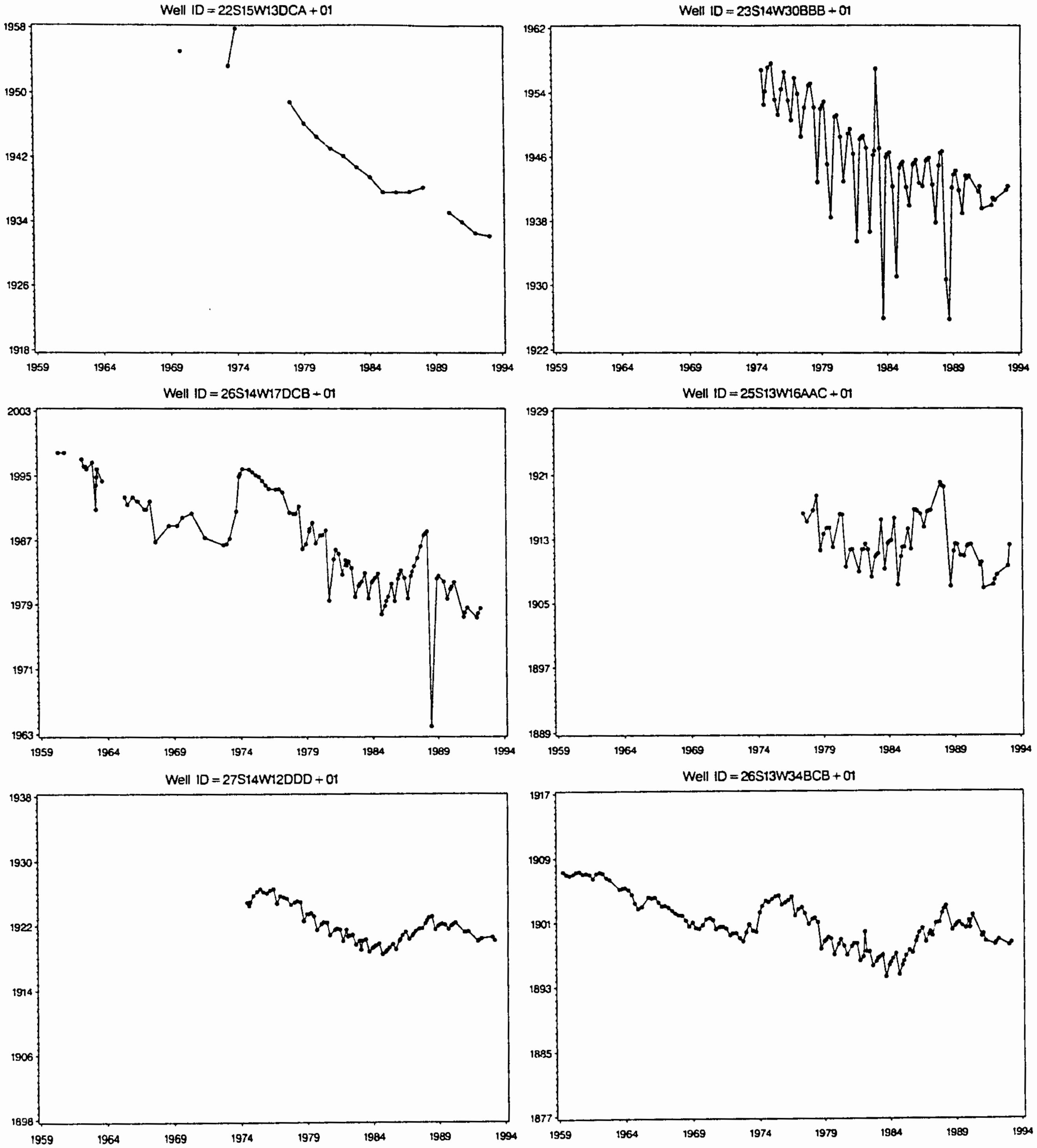
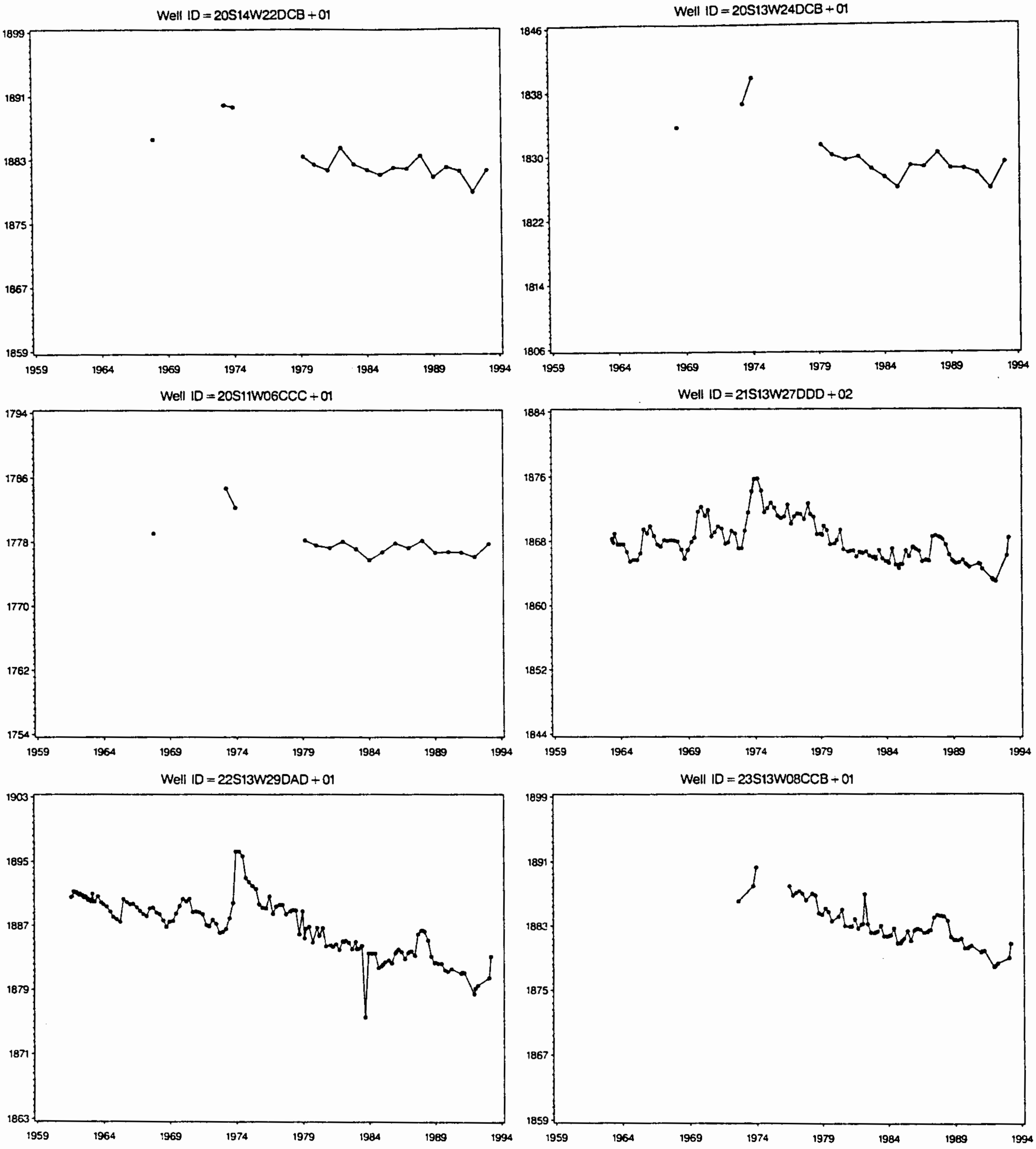


Figure 11. Water elevation hydrographs from long-term observation wells along the western boundary and in the southwestern portion of the Mineral Intrusion Study area. Vertical axes are water table elevation in feet above mean sea level; horizontal axes are dates. See text for discussion.


Well ID = 20S14W22DCB + 01

Well ID = 20S13W24DCB + 01

Well ID = 20S11W06CCC + 01

Well ID = 21S13W27DDD + 02

Well ID = 22S13W29DAD + 01

Well ID = 23S13W08CCB + 01

Figure 12. Water elevation hydrographs from long-term observation wells in the north-western portion of Mineral Intrusion Study area. Vertical axes are water table elevation in feet above mean sea level; horizontal axes are dates. See text for discussion.

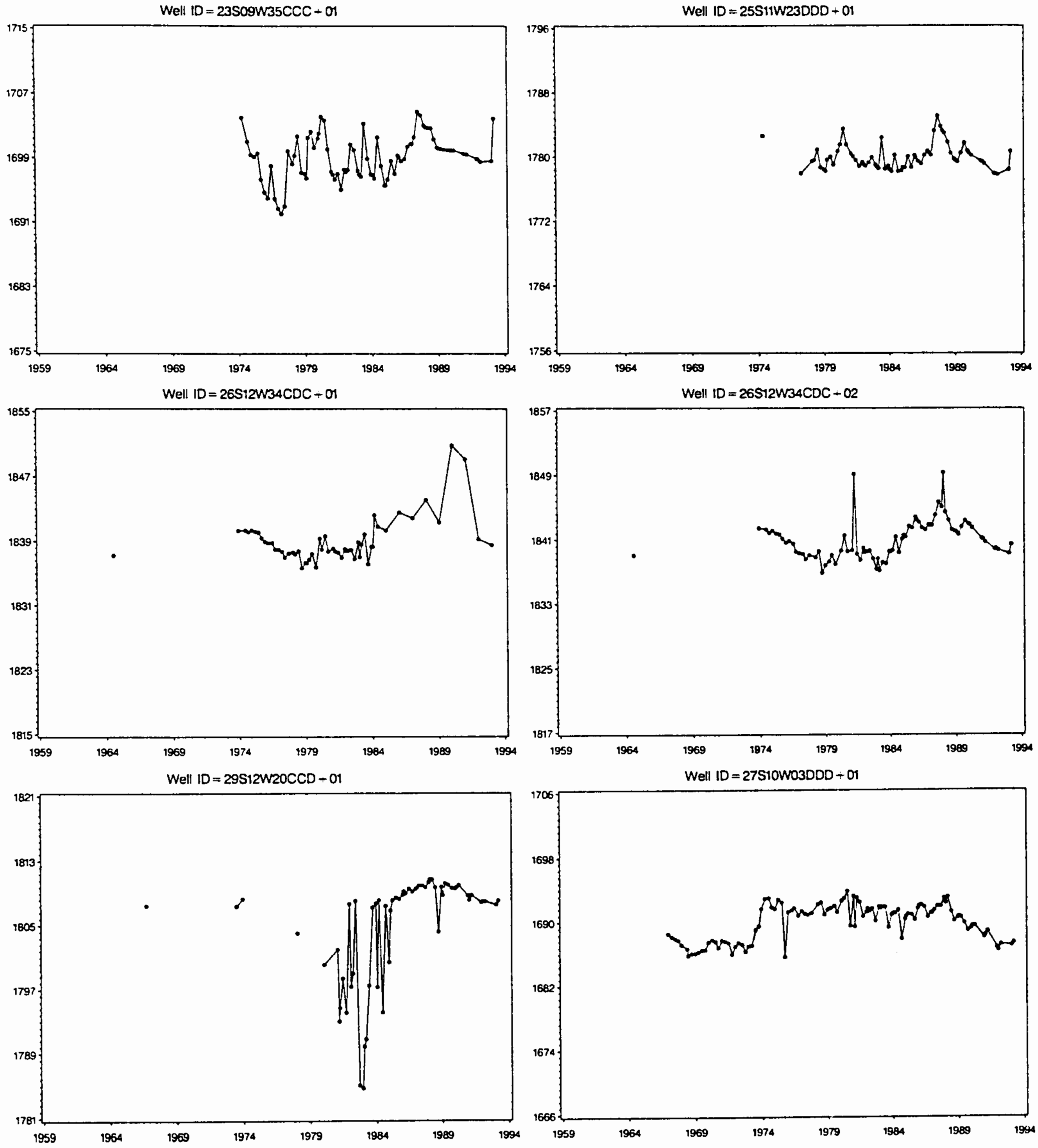


Figure 13. Water elevation hydrographs from long-term observation wells in the southeastern portion of the Mineral Intrusion Study area. Vertical axes are water table elevation in feet above mean sea level; horizontal axes are dates. See text for discussion.

VII. Model-development Progress

Preliminary modeling tests

One of the main objectives of investigations in the eastern Great Bend Prairie aquifer is to determine the present conditions and trends of saltwater-freshwater interface subject to variations in climatic conditions or local pumping stresses. The purpose of modeling the transport of solutes in groundwater flow systems is to obtain an understanding of how the sources and sinks, the boundary conditions, and the aquifer parameters interact to cause groundwater flow patterns and consequent solute concentration movement in the system under investigation. In addition, because the aquifer is heterogeneous and anisotropic and the salt is dissolved and enters the groundwater flow from the underlying Permian strata, the development of the groundwater velocity field and contours of concentrations are of interest.

Initial investigations were undertaken using the SUTRA two-dimensional model (described below). The results of these investigations are being prepared and will be issued as a separate technical report (Sophocleous and Chung, 1993). Efforts focused on simulating possible aquifer scenariaos in the vicinity of the intensive study site (described above). It proved possible to develop credible models of saline water upconing in response to pumping, and to investigate the effects on upconing of continuous and discontinuous clay "confining" layers above the saltwater interface. However, the two-dimensional character of the SUTRA model proved to be a major obstacle to expanding its use to wider areas and a broader range of aquifer and pumping conditions. We have therefore decided that although we will continue to use simple analytical and numerical models to test and predict local observations, application of a three-dimensional solute transport model will be required to meet the needs of the larger program.

3-D solute transport models for modeling saltwater intrusion

Several 3-D solute transport models were investigated for their suitability to the Mineral Intrusion Study, and the most appropriate one (SWIFT-II) was chosen for modeling saltwater intrusion in the study area. The following summarizes the models considered and their characteristics.

Model applications and field/laboratory validations

1. HST3D: Heat and Solute Transport in 3-D Groundwater Flow Systems (Kipp,1987)

The HST3D is based on the finite difference technique; this model calculates heat and solute transport in three-dimensional saturated groundwater flow systems; it can be applied to the study of waste injection into saline aquifers, landfill-contaminant movement, sea water intrusion in coastal regions, brine disposal, freshwater storage in saline aquifers, heat storage in aquifers, and liquid-phase geothermal systems. This model has been verified against eight analytical solutions for fluid flow, heat, and solute transport and has also been compared to the finite element transport code SUTRA. This model seems appropriate one for this study, and the source code which was originally on Prime 9950 computer has already been downloaded to PC-formatted file; however, the source code has not yet been modified to make it workable on 486-based PC systems.

2. SUTRA: Saturated-Unsaturated Transport Model (Voss, 1984)

SUTRA simulation is based on hybridization of finite element and integrated finite difference methods, and it can calculate fluid density-dependent flow with heat or chemically reactive single-species solute transport and has been verified by comparisons to four analytical solutions, several other codes, and a field experiment. It has applications to saltwater intrusion, thermal pollution of aquifers, and groundwater contamination studies. This model is primarily for two-dimensional simulations; the thickness of the model grid can be specified from cell to cell to represent a three-dimensional model, but it is not quite appropriate for this study due to its pseudo three-dimensional ability.

3. FE3DGW: Finite Element Three-dimensional Groundwater Flow Model (Gupta et al., 1984)

FE3DGW is a finite element model and is developed for analyzing flow through large, multilayered, complex ground-water systems with varying number of layers, varying thickness, and constant or time-dependent source/sink terms. This model has been applied to several field problems, some of which are:

A. Sutter Basin, California, to define the flow field in a multilayered system with volcanic rock outcrop and fault zone (Gupta and Tanji, 1976).

B. Multilayered ground-water system, Long Island, New York, to evaluate alternative schemes for water supply and waste-water treatment (Gupta and Pinder, 1978).

C. Drawdown and pumping requirements for a purposed uranium mine in Sweden (Carlson and Carlstedt, 1980).

This model calculates hydraulic head values, but does not account for density variations; therefore, it is not an appropriate model for this study. Its upgraded version, CFEST, can be used for coupled flow, energy, and solute transport. However, the CFEST code is proprietary.

4. SWIFT-II: Sandia Waste-isolation Flow and Transport Model (Reeves et al., 1986)

The SWIFT-II model is based on the finite-difference technique and is a fully-coupled, transient, three-dimensional model. This code has been verified against eight analytical solutions for heat flow and solute transport, and also against laboratory results. In addition, it has been applied in studies of nuclear-waste isolation, deep injection (Ward et al., 1987), and mineral-intrusion problems (Butow and Holzhecher, 1987).

The SWIFT-II documentation is complete, and the source code (originally on a CDC computer) has been successfully downloaded to a PC-formatted file and modified as a PC-workable model. This model has been tentatively selected to simulate themineral intrusion problems, and some simple example problems provided by the original code have already been tested., A simplified mineral-intrusion problem will be tested soon, and if the results are satisfactory then this model will be applied to the Great Bend Prairie aquifer for the simulation of present conditions and trends of the saltwater interface.

VII. Summary of Accomplishments, Interim Conclusions, and Future Directions

Since this is primarily a report of progress and a compilation of data, detailed interpretation will be reserved for subsequent publications. However, a number of achievements and observations deserve mention.

During its first year, the project has carried out a comprehensive review and compilation of data relating to the issue of mineral intrusion in GMD5, and has significantly added to that data base by additional field observations. Essentially all of the goals and schedules outlined by Buddemeier et al (1992) for the first year of the project have been achieved.

The major accomplishment of the first year of the project has been the development and demonstration of techniques to sensitively detect the elevation and characteristics of the saltwater interface, and to measure its changes over time. These methods have been used to survey interface characteristics in all accessible deep monitoring wells in the study area and to develop the first regional inventory of the saturated thickness of freshwater (as opposed to total saturated thickness) in the eastern portion of the Great Bend Prairie Aquifer. These accomplishements bode well for our ability to measure and model the regional characteristics of the saltwater interface in the future.

An intensive study site has been established to monitor the local effects of seasonal recharge and pumping and how these are controlled by aquifer geology. A 30-foot core of Permian bedrock in this location shows that it is made up of alternating layers of siltstone and sandstone. This observation may help explain the extreme variability of formation hydraulic conductivities observed in shorter intervals tested by the monitoring-well network (Young 1992). If this layered structure is a general feature of the Permian formation, it may possible to treat it as a homogeneous hydrologic unit at scales enough to average out local spatial variability in the hydrologic connection of the Great Bend Prairie aquifer with the various bedrock strata.

Although these results are encouraging in terms of developing a good general understanding of the system, other initial results from the intensive study site highlight the complexity of the problems remaining to be solved. First, we have found that some (but not all) of the elevated salinity in the intensive study area is due to previously unrecognized oil-brine pollution. This will necessitate careful chemical analysis to permit interpretation of observations of change in salinity of the various water sources. This presents somewhat of an operational dilemma, since this was not included in the original project design, and may necessitate reductions in some of the originally proposed activities to make resources available. Second, drilling with a well spacing of several hundred yards has shown that an apparently substantial clay stratum that might have the capability to act as a confining layer for underlying saltwater is locally discontinuous. This indicates that it may be difficult to make explicit predictions of local and subregional behavior on the basis of the density of well logs available, and that a geostatistical approach will be required. Finally, substantial but spatially variable recharge has been observed as a result of the unusually wet season, and in some wells the change in the water table appears to have been accompanied by a significant change in the saltwater interface. This natural variability will require close attention to methods for defining our experimental baseline and for assessing the effects of local and regional groundwater withdrawal.

Activities for the second year of the project will continue along the general lines laid out by Buddemeier et al (1992). Experimental activities will include continued monitoring and assessment of the the saltwater interface, a limited program of testing the hydrologic characteristics of the Permian aquifer, and sampling and analysis as needed to determine water-quality trends and to distinguish between natural brine and oil-field contamination. Data interpretation will focus on the relationships between the saltwater interface and the bedrock topography, and between hydraulic heads in different parts of the hydrologic system, geologic features, and the relative movement of fresh and saltwater. Considerable attention will be devoted to developing and testing computer models of interface behavior, both to understand the system and to define additional data that may be needed to complete the project.

We will continue to seek the guidance of our Public Advisory Committee and Technical Advisory Committee, and to respond in any way practical to the information needs for water management of GMD5 and the Division of Water Resources.

Acknowledgments

We gratefully acknowledge the cooperation of the Board, Manager, and technical staff of Big Bend Groundwater Management District Number 5. The progress reported would not have been possible without their assistance, support, and local expertise. At KGS, the project has benefited from the secretarial support of Anna Kraxner, graphic art support by Mark Schoneweis, and administrative support by Frank Cherry. The KGS drilling crew, Joe Anderson and Dave Dettman, successfully performed the field installations, often under difficult circumstances. Larry Hathaway assisted with chemical analyses, S. Ravikumar assisted with field work and logistic assistance, and Geographic Information System assistance was provided by Rod Bassler, Deb Kirshen, and Jian Fan. J. E. Mitchell retrieved well hydrographs from the water level database.

We are grateful for the advice and interest of the Lower Arkansas Basin Advisory Committee, and the Technical Advisory Committee and Public Advisory Committee of the Mineral Intrusion Project. The study would not have been possible without the support and advice of the staff of the Kansas Water Office.

References

Buddemeier, R. W., M. A. Sophocleous, and D. O. Whittemore, 1992, Mineral Intrusion: Investigation of Salt Contamination of Ground Water in the Eastern Great Bend Prairie Aquifer. Kansas Geolgical Survey, Open-File Report 92-25, 45 pp.

Butow, E., and E. Holzbecher, 1987, "On the modeling of ground-water flow under the influence of salinity," Ground water contamination : Use of models in decision making, Kluwer Academic Publishers, p. 263-271.

Carlsson, L., and A. Carlstedt, 1980, "Hydrogeologiska synpunkter PA planerad uranbrytning vid pleutajokk," Arjeplogs Kommun, Sveriges Geologiska Undersokning, Luossavaara-Kiirunavaara AB, March.

Gupta, S. K., C. R. Cole, F. W. Bond, and A. M. Monti, 1984, "Finite-element three-dimensional ground-water (FE3DGW) flow model: Formulation, Computer source listings, and User's manual," Technical Report, BMI/ONWI-548, Office of Nuclear Waste Isolation, Battelle Memorial Institute, October.

Gupta, S. K., and G. F. Pinder, 1978, "Three-dimensional finite element model for multilayered ground-water reservoir of Long Island, New York," Department of Civil Engineering, Princeton University, Princeton, NJ.

Gupta, S. K., and K. K. Tanji, 1976, "A three-dimensional finite element ground-water model," Contribution #152, pg. 199, California Water Resource Center, Univ. of California, Davis, CA.

Kipp, K. L. Jr., 1987, "HST3D: A computer code for simulation of heat and solute transport in three dimensional ground-water systems", U.S. Geological Survey, Water Resource Investigations, 86-4095,.

Mitchell, J. E., Woods, J., McClain, T. J., and Buddemeier, R. W., 1993. Jauary 1992 Kansas Water Levels and Data Related to Water-level Changes. Technical Series 3, Kansas Geological Survey, Lawrence, KS.

Reeves, M., D. S. Ward, P. A. Davis, and E. J. Bonano, 1986, "Theory and implementation for SWIFT-II, Release 4.84," Rep. NUREG/CR-3328 and SAND84-1159, Sandia Natl. Lab., Albuquerque, N.M.

Rosner, M. L., 1988, The stratigraphy of the Quaternary alluvium in the Great Bend Prairie, Kansas. M.S. Thesis, Dept. of Geology, Univ. of Kansas, Kansas Geological Survey, Open-file Report 88-183 pp.

Schmorak S., and A. Mercado, 1969, Upconing of freshwater-sea water interface below pumping wells, field study. Water Resources Reserve v. 5 no. 3 6 pp. 1290-1311.

Sophocleous, M.A., B. Arnold, T. McClain, and A. Stern, 1993, Configuration of the pre-Cenozoic bedrock surface of the Great Bend Prairie region of Kansas: Plate 1, Kansas Geological Survey, Open-File Report 93-3.

Sophocleous, M. A., and Stern, A., 1993, Fifteen GIS hydrologic maps of the Big Bend Ground-water Management District No. 5 (GMD5, Kansas Geological Survey, Open-file Report 93-3, 8 p. plus 15 plates.

Sophocleous, M. A., and C. Chung, 1993, Conceptual simulations of saltwater upconing with the USGS SUTRA model, Kansas Geological Survey, Open-file Report 93-29, 55 p.

Voss, C. I., 1984, "Saturated-unsaturated transport (SUTRA)," U.S. Geological Survey, Water Resource, Investigations., 84-4369.

Ward, D.S., D. R. Buss, D. W. Morganwalp, and T. D. Wadsworth, 1987, "Waste confinement performance of deep injection wells, paper presented at solving ground water problems with models," National Water Well Association, Denver, Colo., Feb. 10-12.

Whittemore, D.O., 1990, Geochemical identification of saltwater contamination at the Siefkes subsidence site: Report for Kansas Corporation Commission, 6 p.

Whittemore, D.O., 1993, Ground-water geochemistry in the mineral intrusion area of Groundwater Management District No. 5, south-central Kansas, Kansas Geological Survey, Open-File Report 93-2.

Young, D. P., 1992, Mineral Intrusion: Geohydrology of Permian Bedrock Underlying the Great Bend Prairie Aquifer in South-Central Kansas. Kansas Geological Survey, Open-file Report 92-44, 47 pp.

APPENDIX A. Well Data Sheets, Geophysical Logs, and Log Processing

This appendix contains plots of the well logs recorded and processed for each of the Monitoring Well Sites (deepest well and next deepest well with a transition zone) and each of the other available wells discussed in Section II. Figure A-1 is a key to the interpretation of the contents of each log diagram. An outline of the systematic processing steps performed on each set of logs follows this introduction.

For each log data set there is a 4.4 ft offset between the start and end of the raw gamma-ray and conductivity logs due to the corresponding offset between the detectors on the sonde. The processed records are limited to that part of the log depth range for which both types of data exist and are therefore slightly shorter than the raw logs. This range limits interface detection and characterization to the depth reached by the gamma-ray detector, which is located above the conductivity sensor. However, other approaches using the unstandardized conductivity log can be used in situations where the bottom 4-5 ft of the log contains important conductivity information.

The standardization process, discussed in Section IV., provides an approximate correction of the processed conductivity profiles for the effects of the lithologic conductivity component. The logs from Monitoring Site 50, recorded in April, were used for the standardization of the relationship between the gamma-ray response and lithologic conductivity. Monitoring Site 50 is located on the western edge of the Transect with ground-water specific conductivity values at the low end of the range for this area (Whittemore, 1993). Therefore, the measured conductivity is assumed to represent a background level dominated by lithologic effects similar to those present in all other logs. Removal of this background level is accomplished by standardizing and rescaling the gamma-ray log to match the conductivity log at this Site. The gamma-ray log is also smoothed using a 35-sample moving-average filter to reduce the characteristic of large sample-to-sample variations and to broaden major amplitude changes to better match those of the conductivity log. This smoothing process results in the loss of an additional

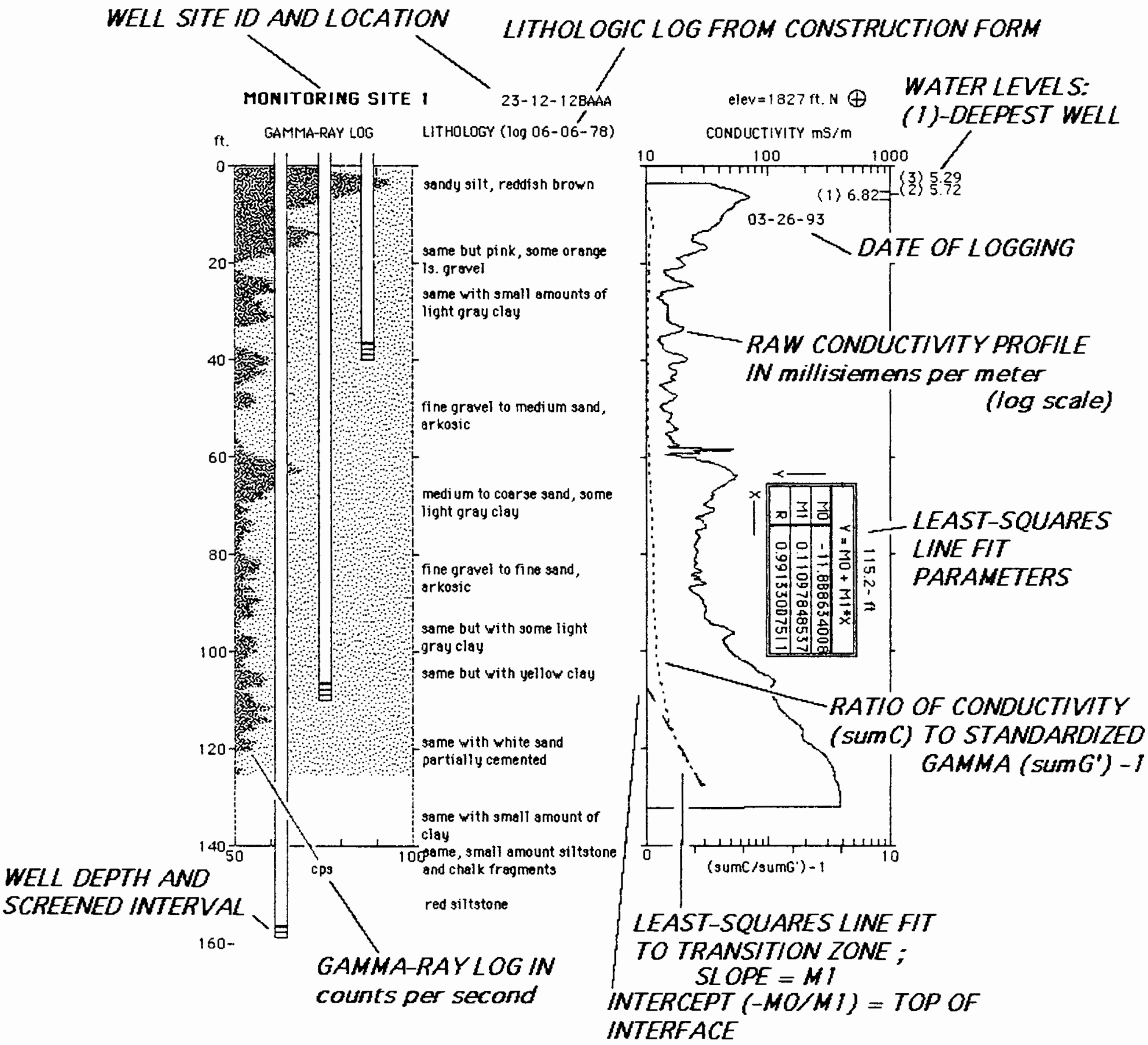


FIGURE A-1. Key to the interpretation of the contents of the log diagrams.

1.7 ft of data at the end of the processed log record, for a total of 6.1 ft of final processed data loss at the bottom of the well. The ratio of the cumulative filtered, standardized, and rescaled gamma-ray log to the cumulative conductivity log is calculated, resulting in a unitless, backround-corrected conductivity profile (see figs. 7, 8, 9, and A-1).

Repeated logging of Monitoring Site 50 will maintain a background-level reference for tracking and correction of any changes due to instrument response. Such a change is detectable as a positive offset between conductivity logs recorded in April and July at Monitoring Site 50. This offset is also consistently discernable on the log plots for other wells logged during these times. This offset was subtracted from the later conductivity logs and then the result ratioed with the gamma-ray logs using the same standardization and rescaling parameters. Logs recorded during May, also showing an offset, were adjusted by interpolation, assuming a constant linear drift in the instrument response with time.

The result of the above processing generates conductivity profiles that can be described in three categories: one that includes wells that exhibit no excess conductivity above that of the background level determined at Monitoring Site 50; one that includes wells that have excess conductivity but do not have a region with a sustained rate of conductivity increase (a slope greater than 0.02 for at least 5 ft) on the processed profile; and one that includes wells that have both excess conductivity and a sustained slope greater than 0.02. Some wells have been included in the third category because of the indication of a sustained slope in the unprocessed conductivity log even though the standardized record is truncated due to the 4.4 ft detector offset mentioned above.

Well sites that fall into the first category can be distinguished by the lack of a scale on the lower axis of the figures, since processed conductivity values are less than zero. Well sites in the second category have values above zero but lack indication of a line fit by not having an inset table containing the line-fit variables. The third category profiles have the inset that contains the line equation offset (MO) and slope (M1) with the correlation coefficient (R) indicating the goodness-of-fit. With depth on the x-axis and conductivity on the y-axis, the depth intercept point of the line can be calculated (-M0/M1). The depth range used for the line fit calculation is given by the values near the table in each plot. The range was selected by visually inspecting each processed conductivity profile and selecting endpoints that delimit the linear section of the profile. The range was further limited by rounding the depth of the shallow point to the next deeper foot and rounding the depth of the deepest point to the next shaller foot unless the conductivity log appeared to be truncated above the bottom of the transitions zone.

For well sites in the third category, initial evidence of changes caused by freshwater-saltwater movements will be detected by systematic changes in the slope and depth intercept point of the fitted line. For well sites in the other two categories, changes in area beneath the processed profiles or change from one category to another can provide evidence of changes in the freshwater-saltwater regime.

STEPS IN WELL LOG ANALYSIS

The following steps are written specifically in terms of the software and hardware systems actually used, but can be adapted to other systems in a relatively straightforward fashion.

I. Transcribe binary log data into ASCII text file via Personal CompuLog (PCL) utility to floppy disk.

II. Transfer ASCII file into Macintosh via Apple File Exchange utility.

IIb. If multiple files transcribed, copy out individual logs with MS WORD or other text editor.

III. Import and process log in KaleidaGraph.

  A. Import settings:

    1. Space delimeter.

    2. No. of spaces > 1.

3. Skip 87 lines.
4. Read titles.

B. Process steps: (Cn = column n)

1. SMOOTH (35-sample moving-average filter) gamma log (C2) into C0.
2. Select and MASK all rows with zero values in C0 AND C3 (conductivity) at top AND bottom of file i.e. disable all non-overlapping log values.
3. Standardize and rescale filtered gamma log -

   C4=((C0-gmean)/gstd)*cstd+cmean

   where: gmean and gstd are the filtered gamma log mean and standard deviation and cmean and cstd are the conductivity log mean and tandard deviation of the April Monitoring Site 50 data set.
4. Cumulative sum of conductivity log -

   RUNSUM(C3-offset,C5)

   where: offset is the difference between the current cmean at Monitoring Site 50 and the cmean of April Monitoring Site 50. (or interpolated value for an intermediate time).
5. Cumulative sum of the filtered, standardized, and rescaled gamma log

   RUNSUM(C4,C6)
6. Ratio of cumulative summed logs minus 1 -

   C7=(C5/C6)-1
7. Plot resulting ratio vs. depth (C1); select depth range of transition zone, if present.
8. MASK ratio values below and above selected depth range -

   MASK(C1 < lower,C7)

   MASK(C1 > upper,C7) - only if upper limit exists.

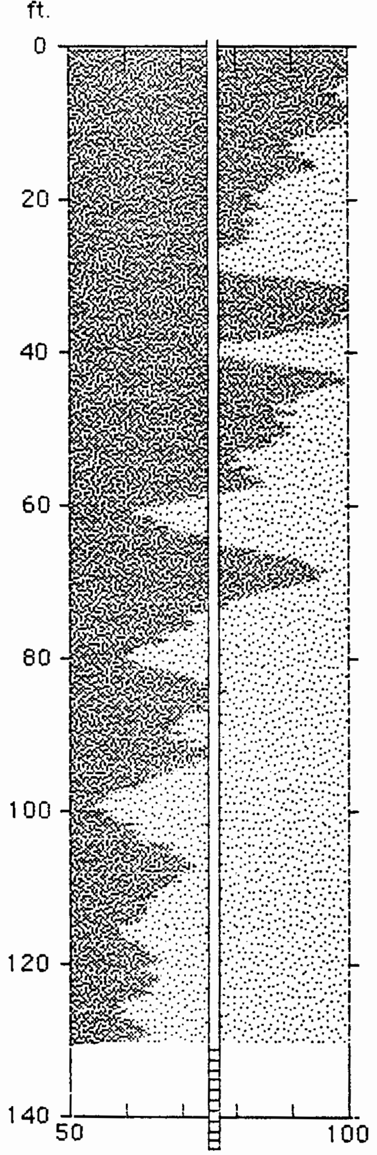
9. Replot ratio vs. depth; select linear curve fit; view fit result table; copy result table to calculator and clipboard; paste result table into plot; save document for incorporation into log appendix.
10. Calculate fitted line -

    C8=M0+M1*C1
11. UNMASK C0, C1, C3, and C7.
12. Plot C0 vs. C1; save document for log appendix.
13. Plot C3 and C7, C8 vs. C1 (double y-axis); save document for log appendix.

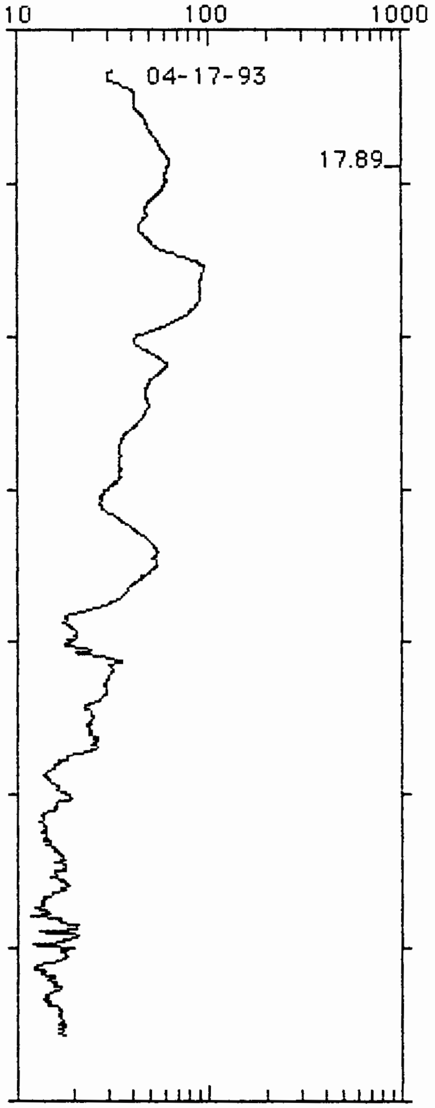
CLARKE 1-X

SE/4 SW/4 NE/4 Sec. 34 T21S R12W elev= ft

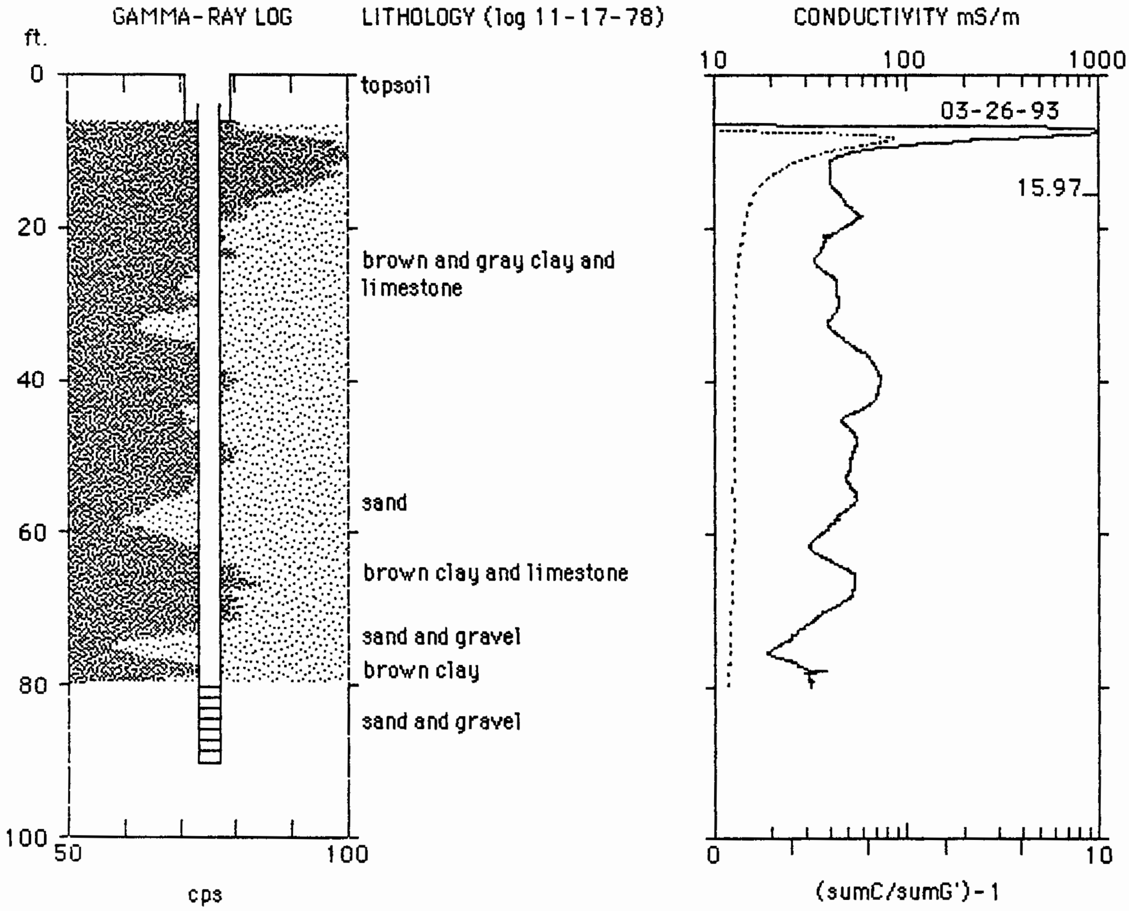
GAMMA-RAY LOG



CONDUCTIVITY mS/m



MI-SS-S 21-12-27DDDC elev= 1836ft



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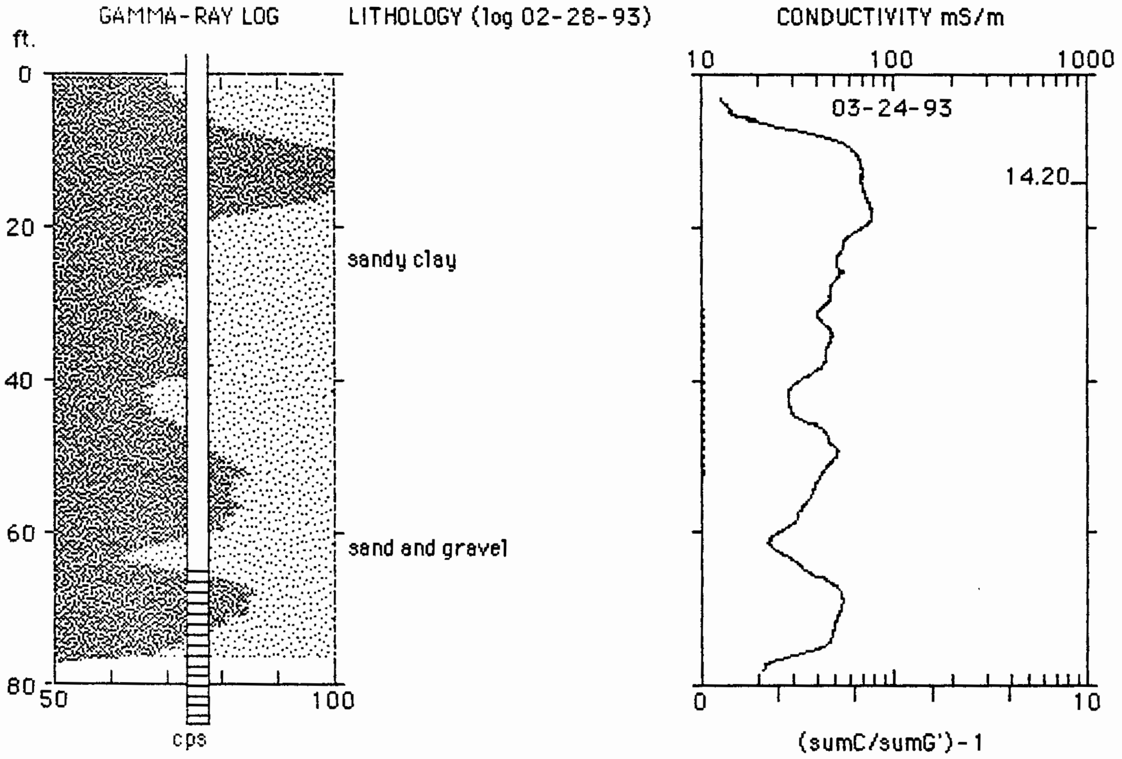
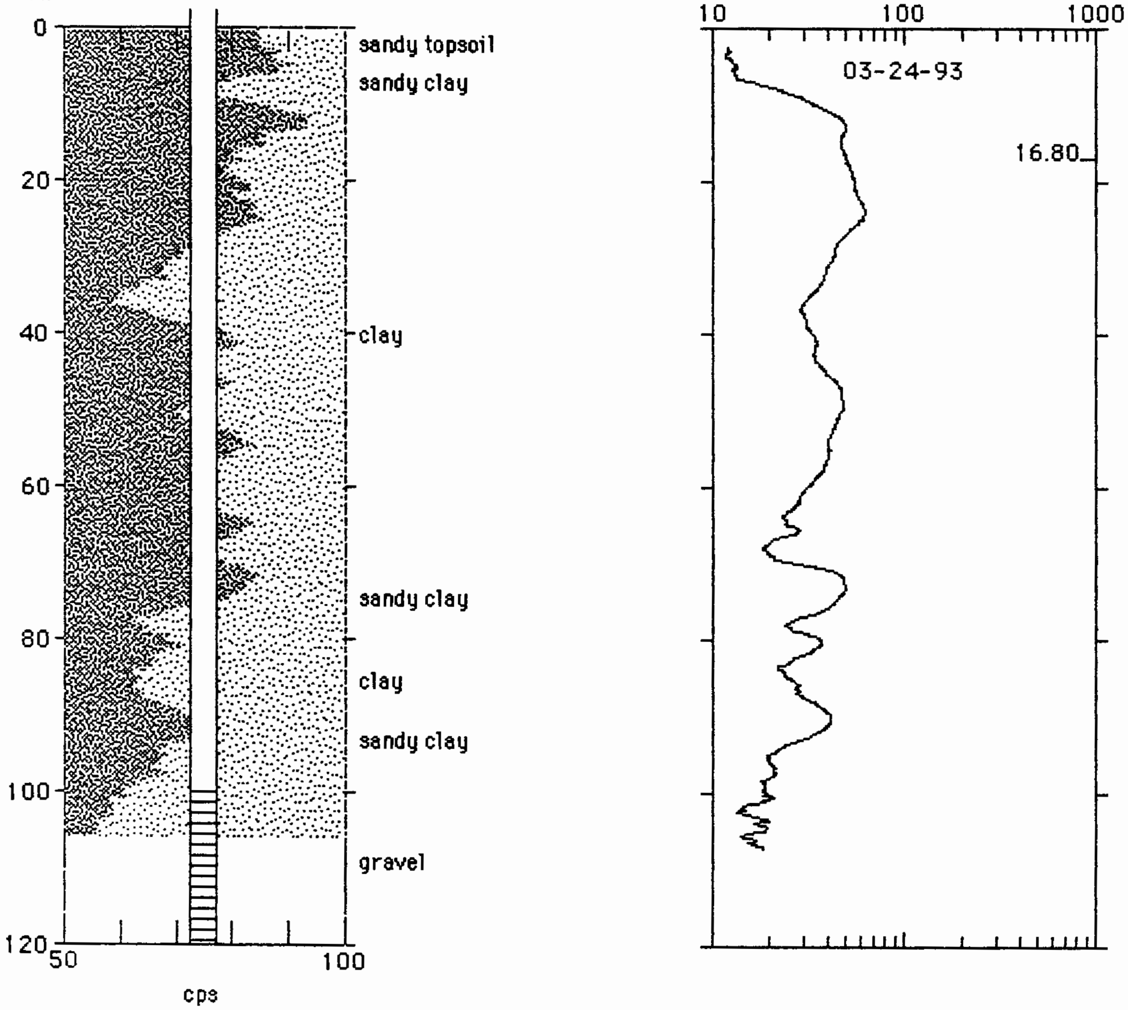


MI-SS-NOS 21-12-27ACDD elev= 1839 ft

GAMMA-RAY LOG LITHOLOGY (log 05-09-85) CONDUCTIVITY mS/m



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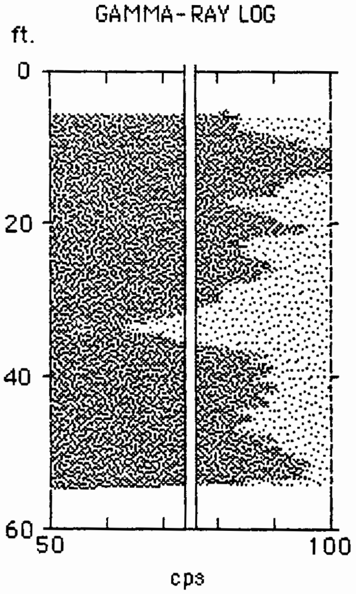
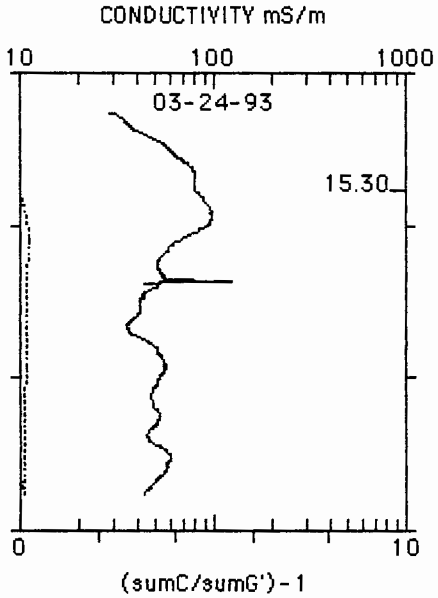
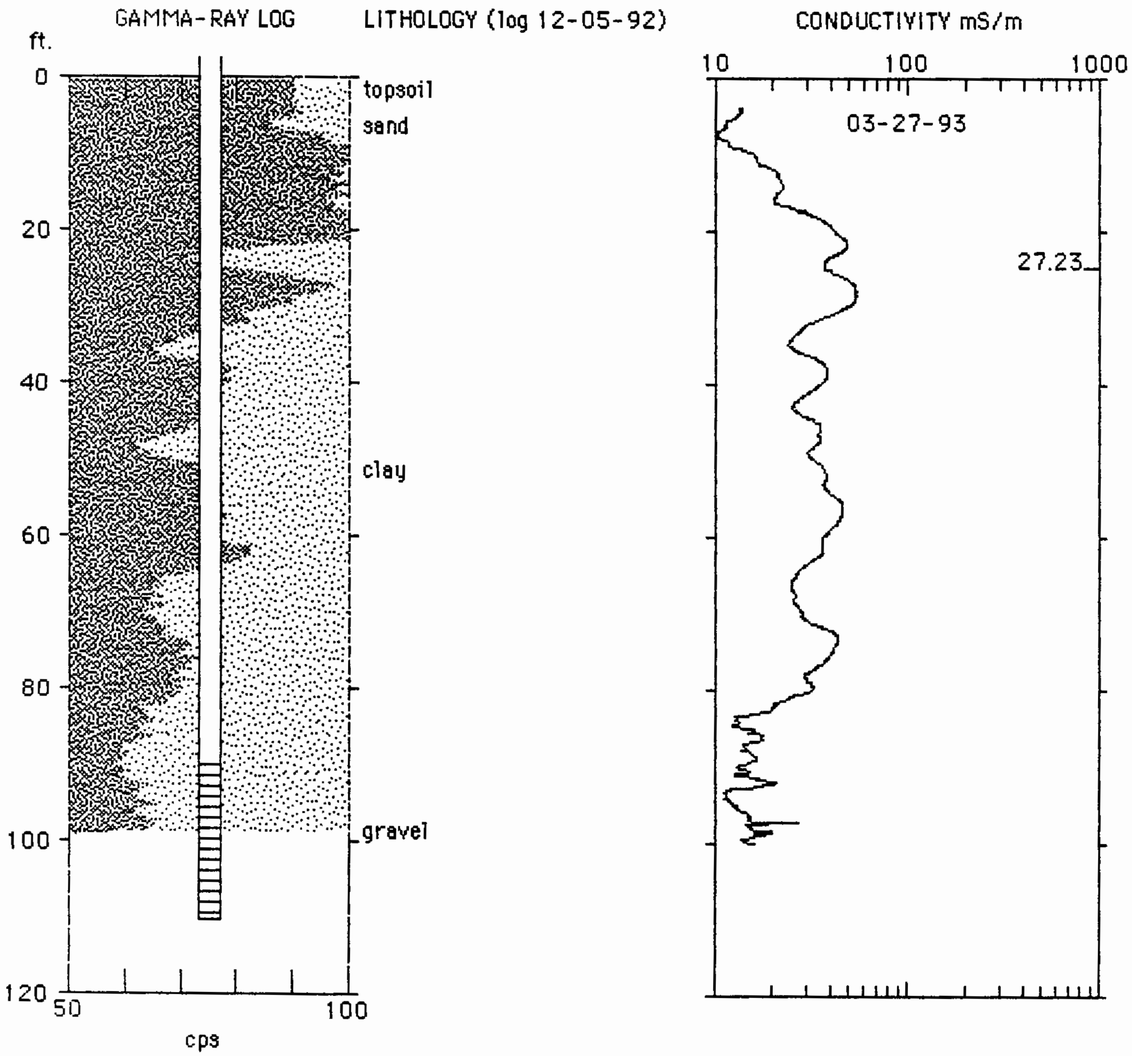




MI-SS-NEO 21-12-26BDB elev= 1840ft



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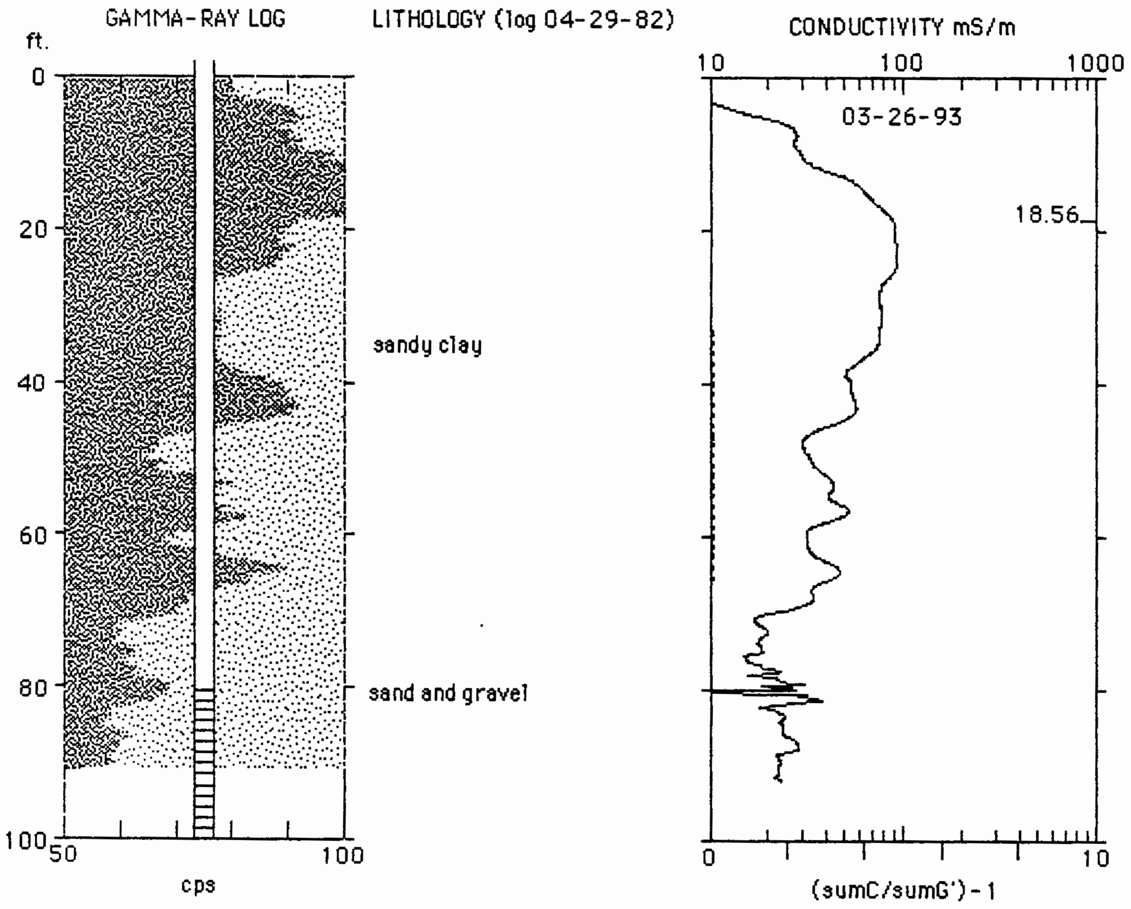
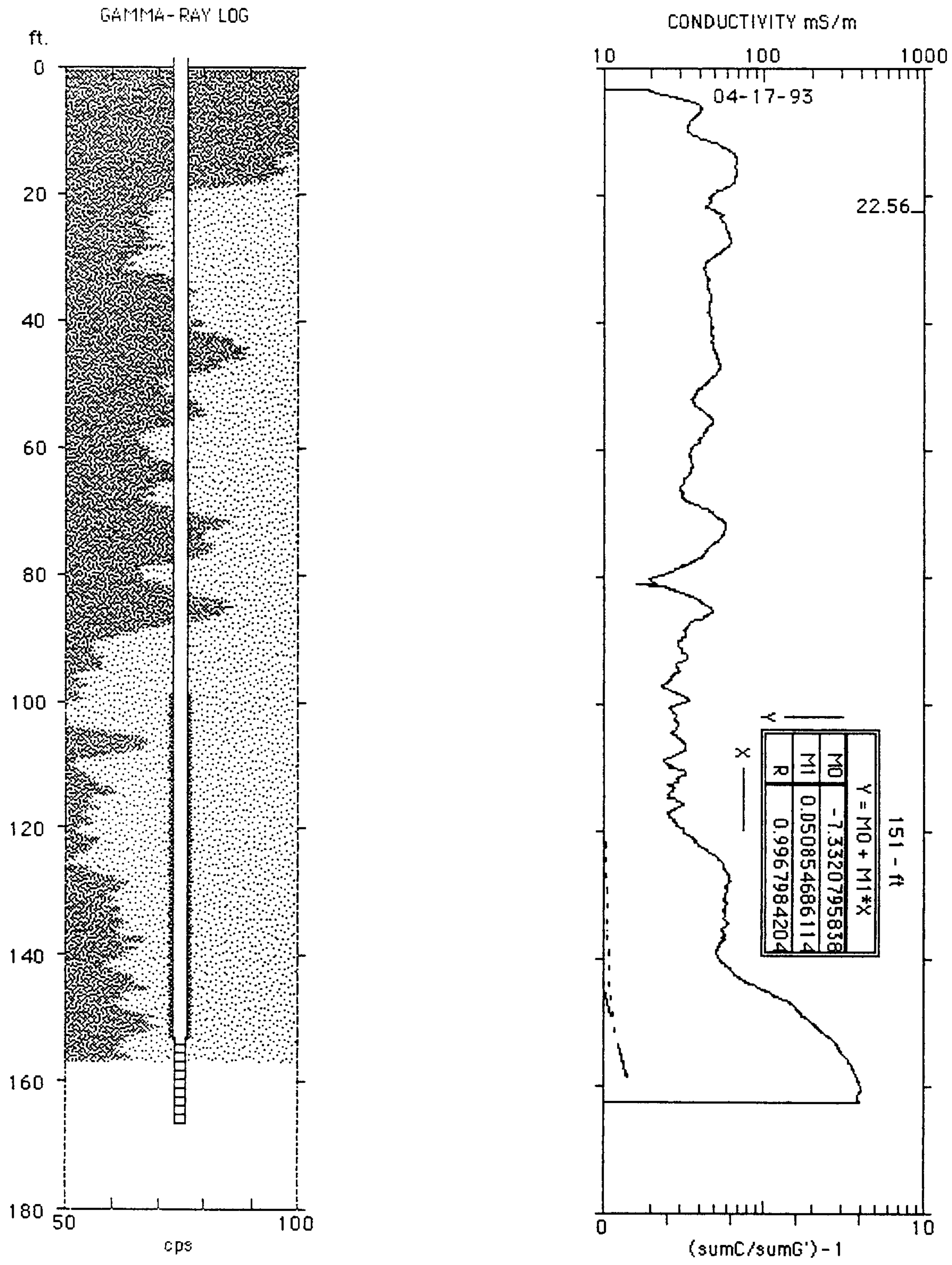


MI-SS-DA

21-12-27DADD elev=1840ft



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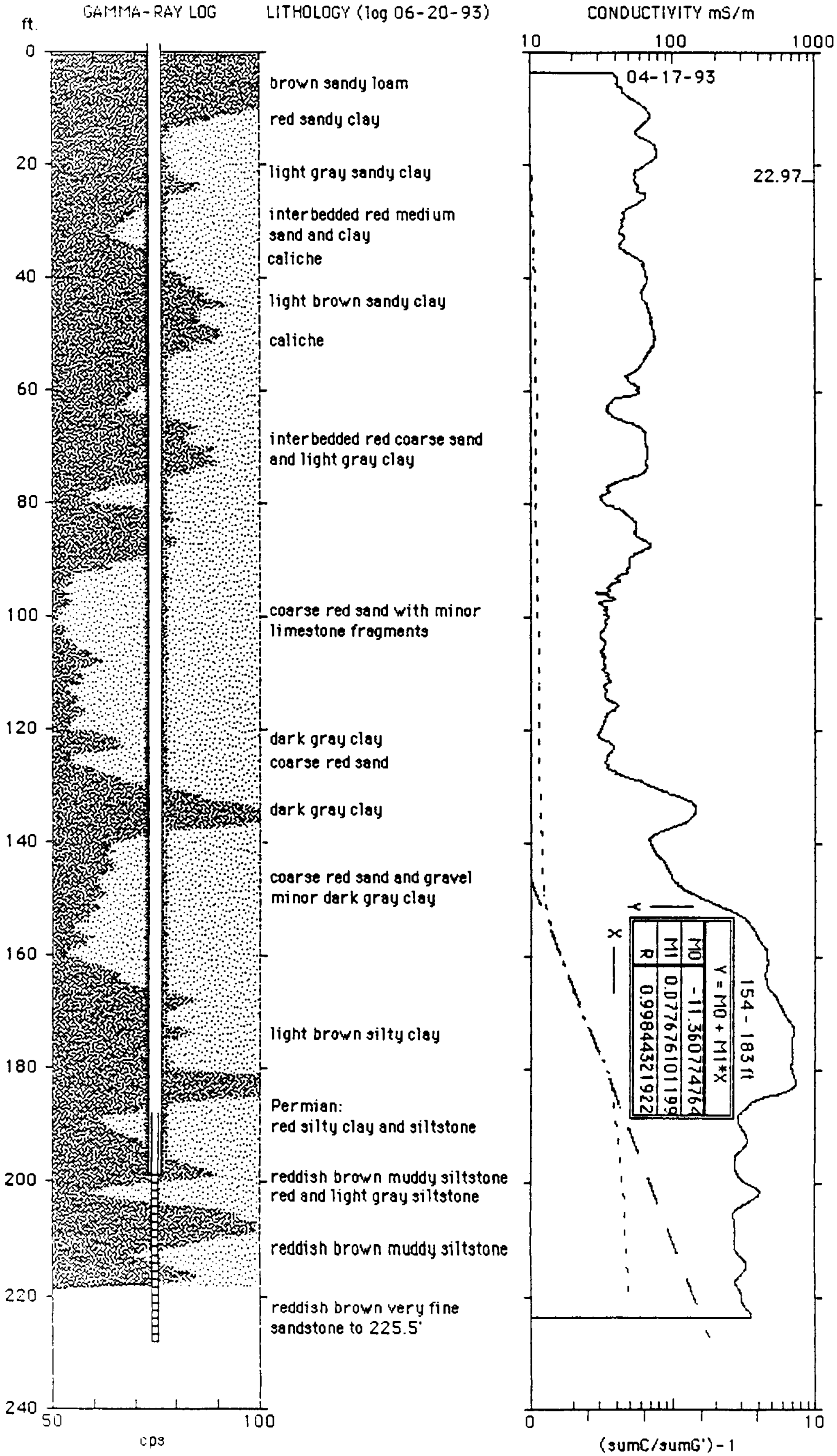
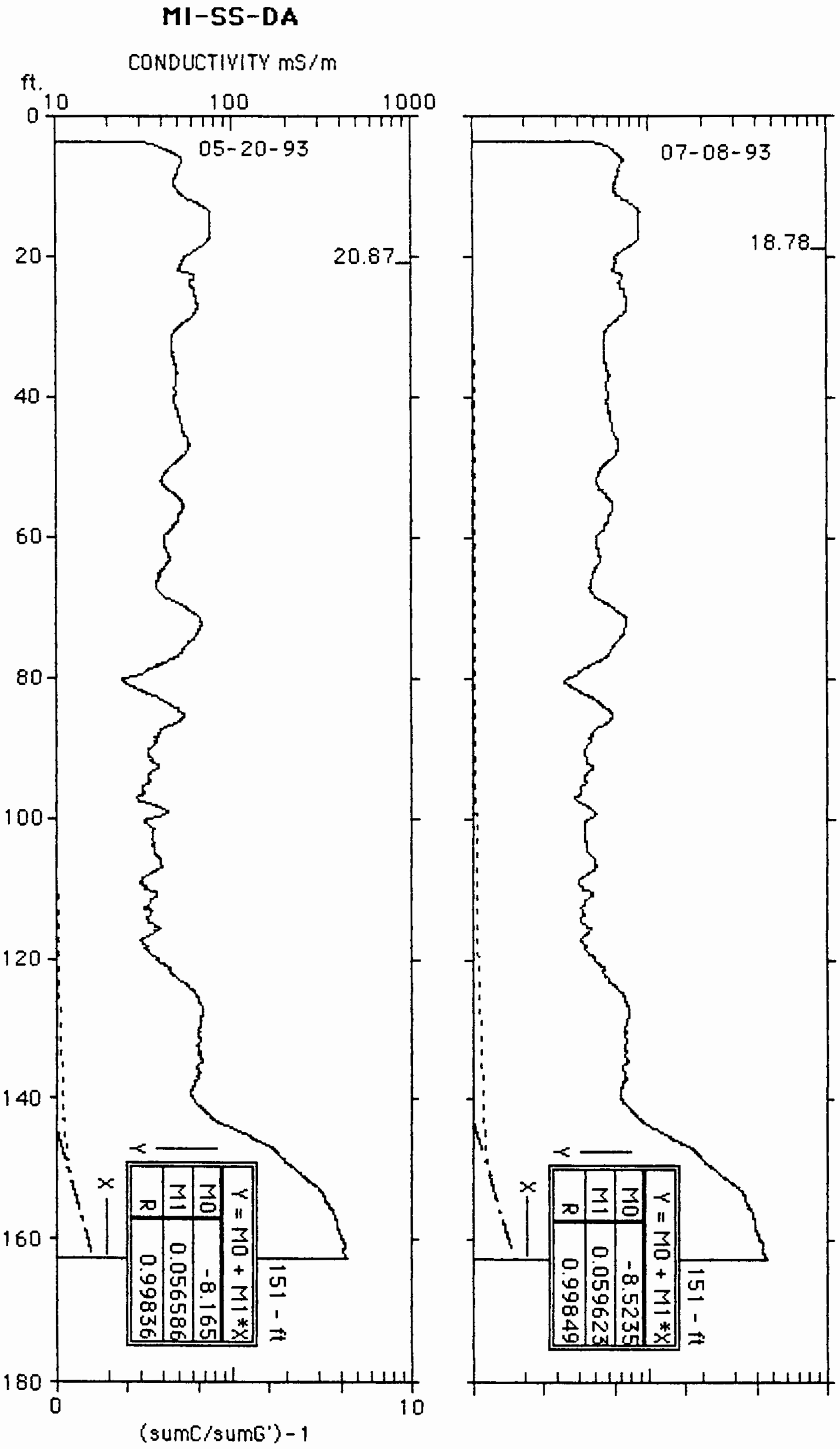
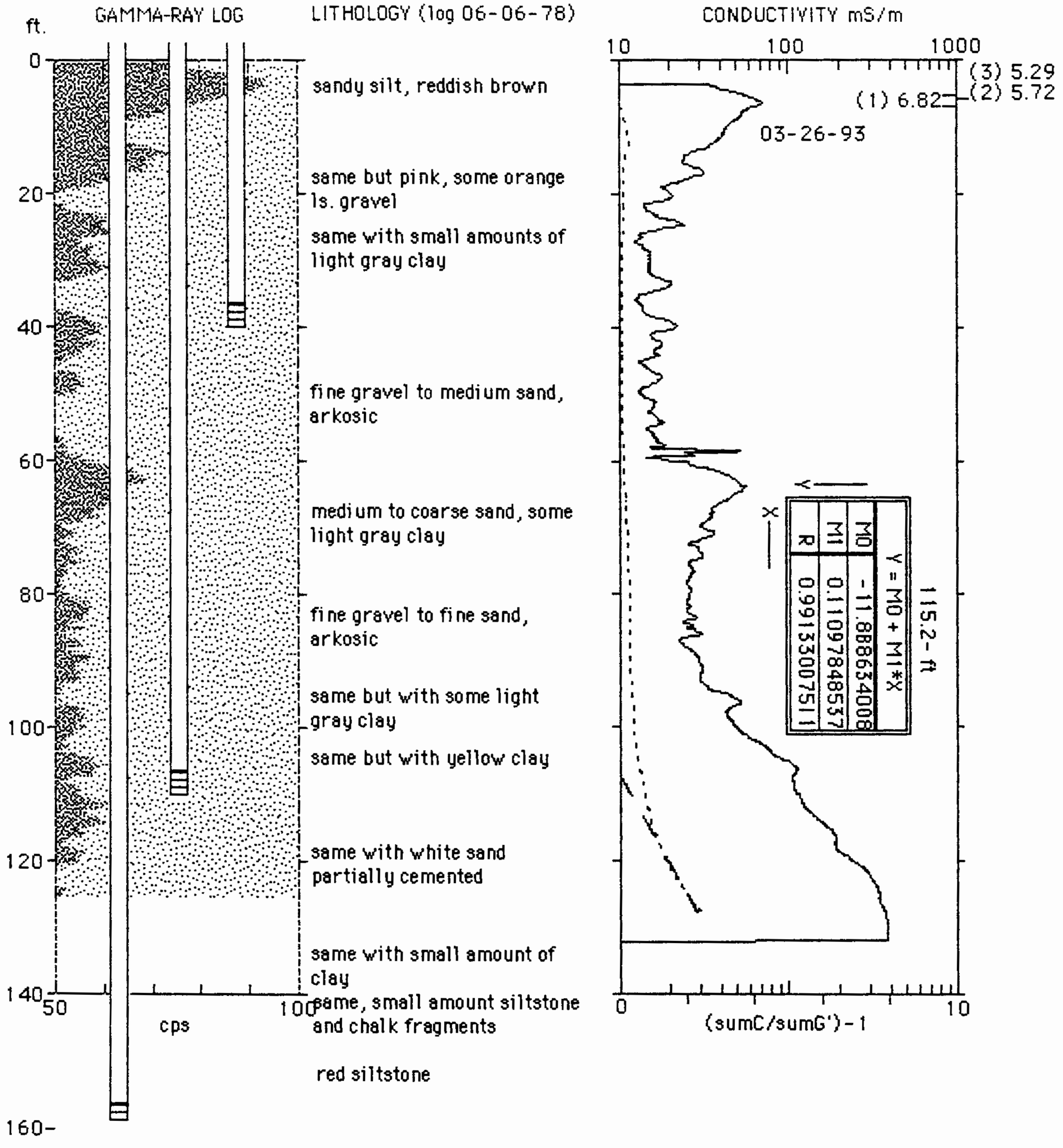



MI-SS-DA
CONDUCTIVITY mS/m
ft.
10
100
1000
0
20
40
60
80
100
120
140
160
180
05-20-93
20.87
07-08-93
18.78
Y
X
Y = M0 + M1*X
M0 -8.165
M1 0.056586
R 0.99836
151 - ft
Y = M0 + M1*X
M0 -8.5235
M1 0.059623
R 0.99849
151 - ft
0
10
(sumC/sumG')-1

MONITORING SITE 1 23-12-12BAAA elev=1827 ft. N ⊕



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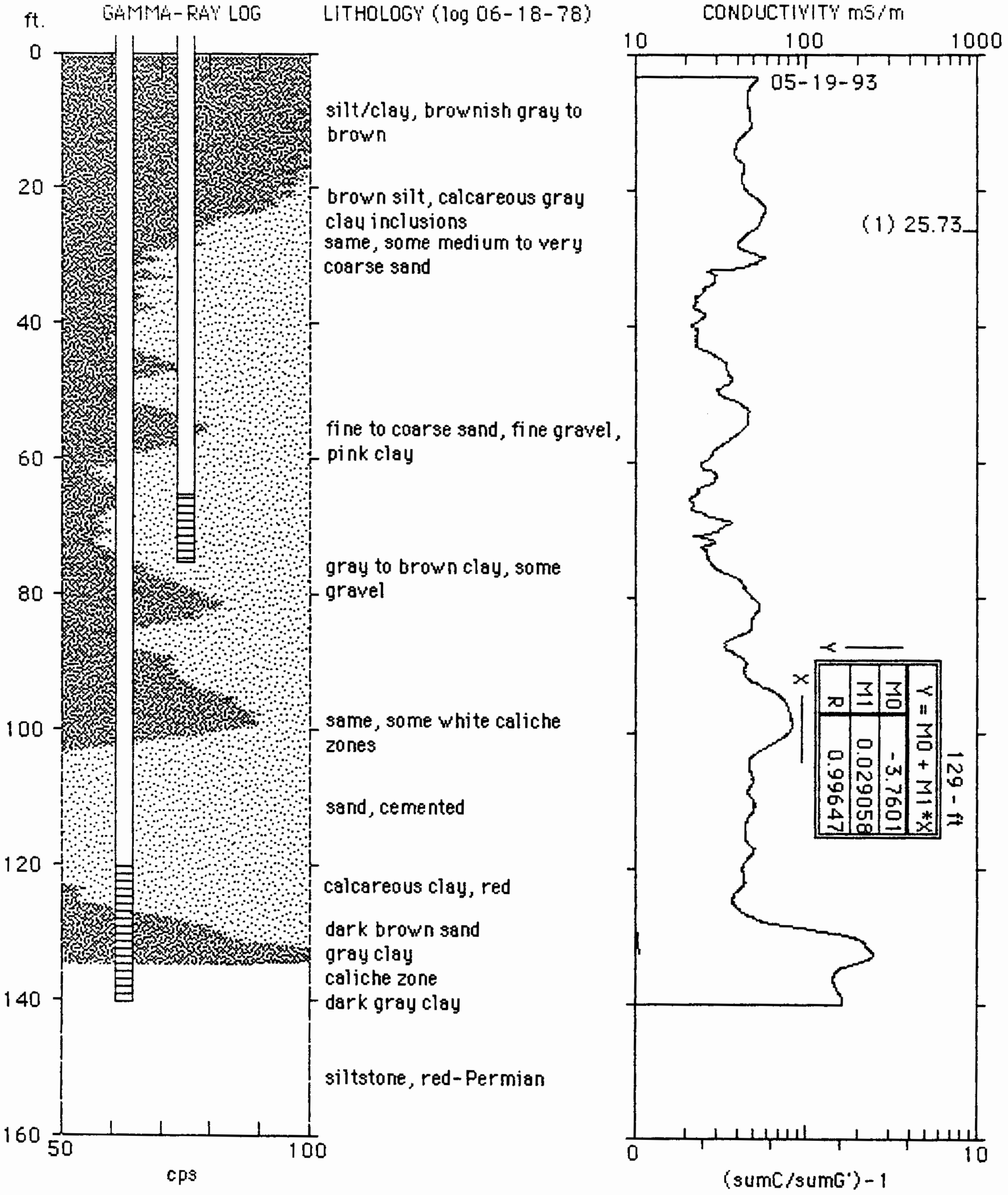

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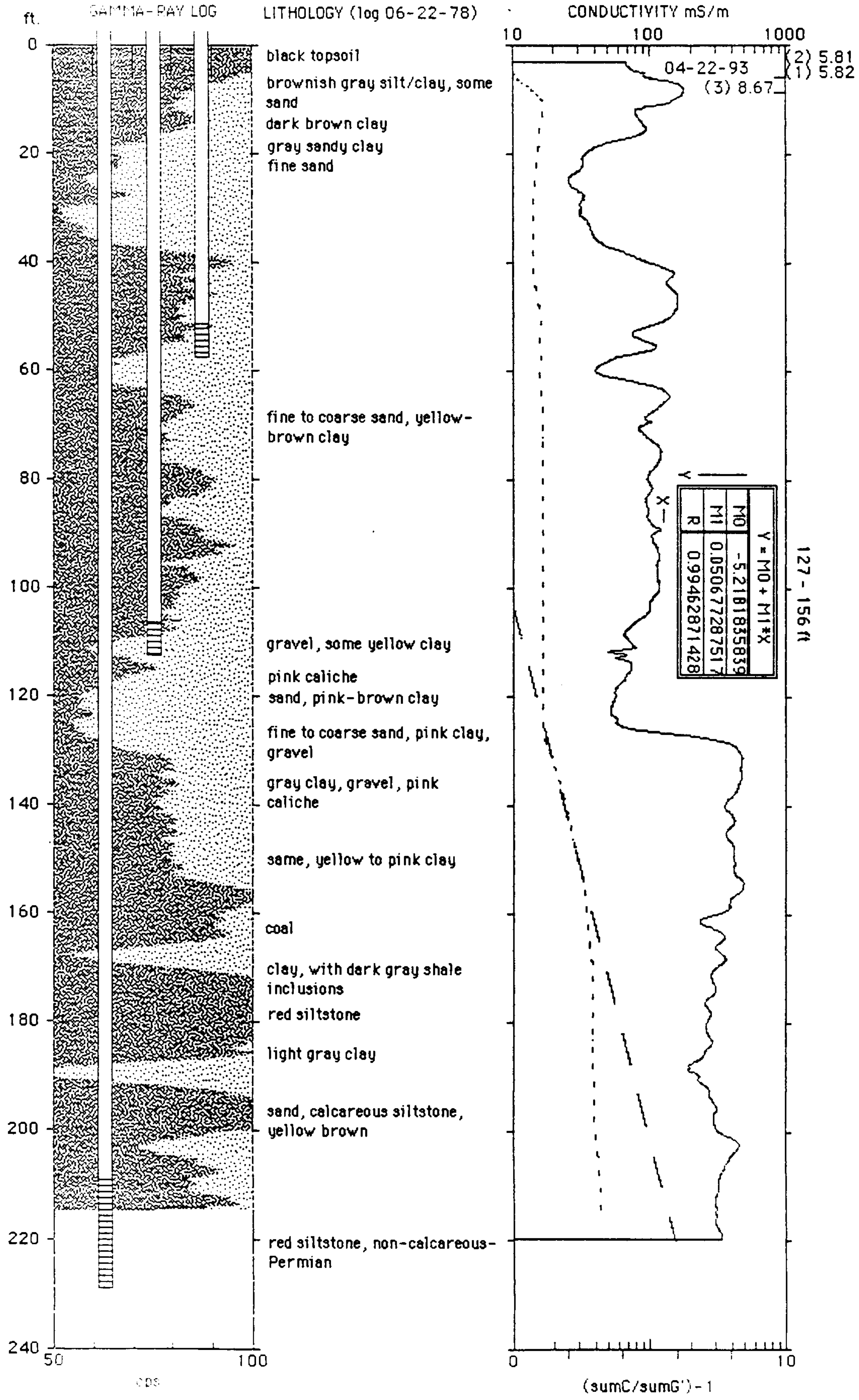

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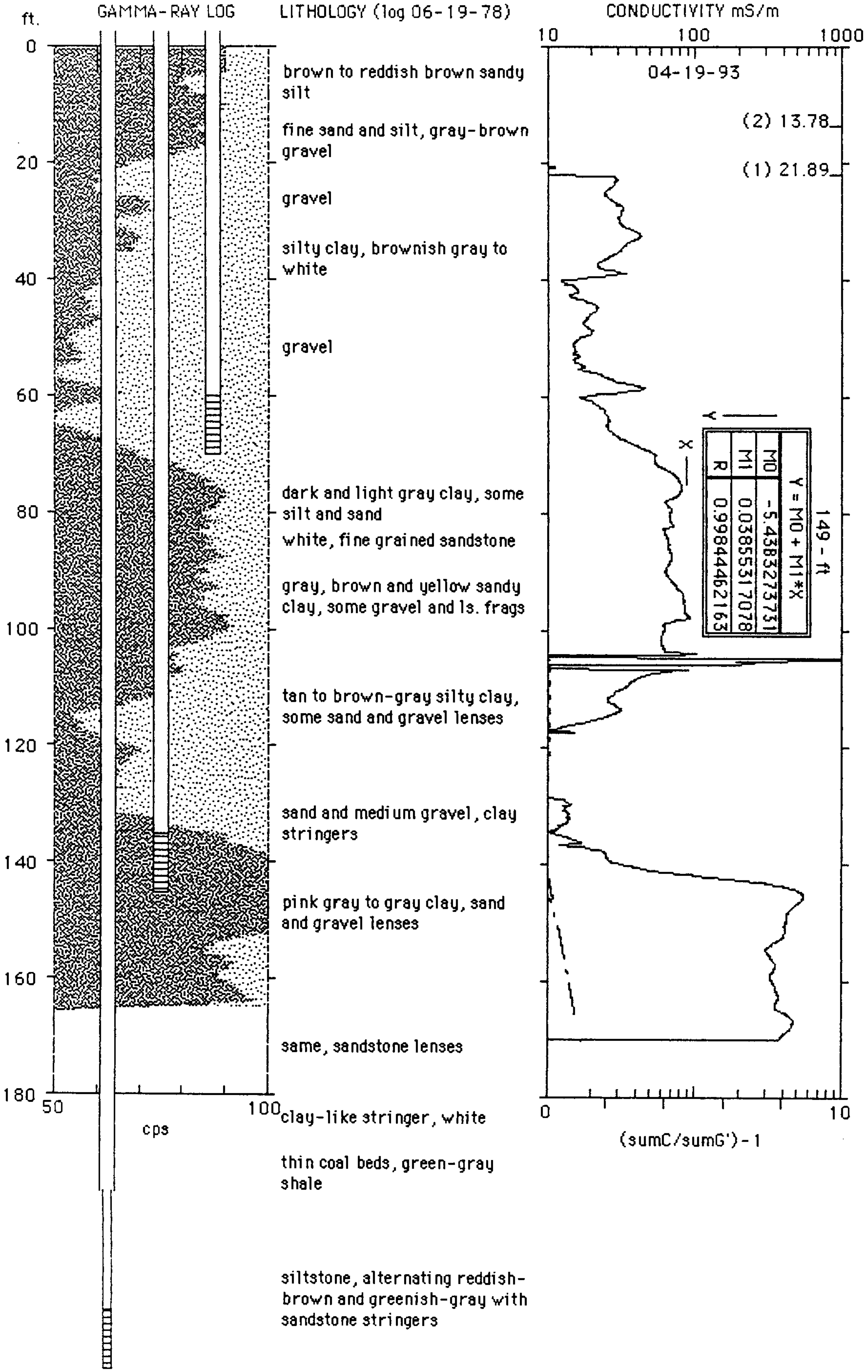

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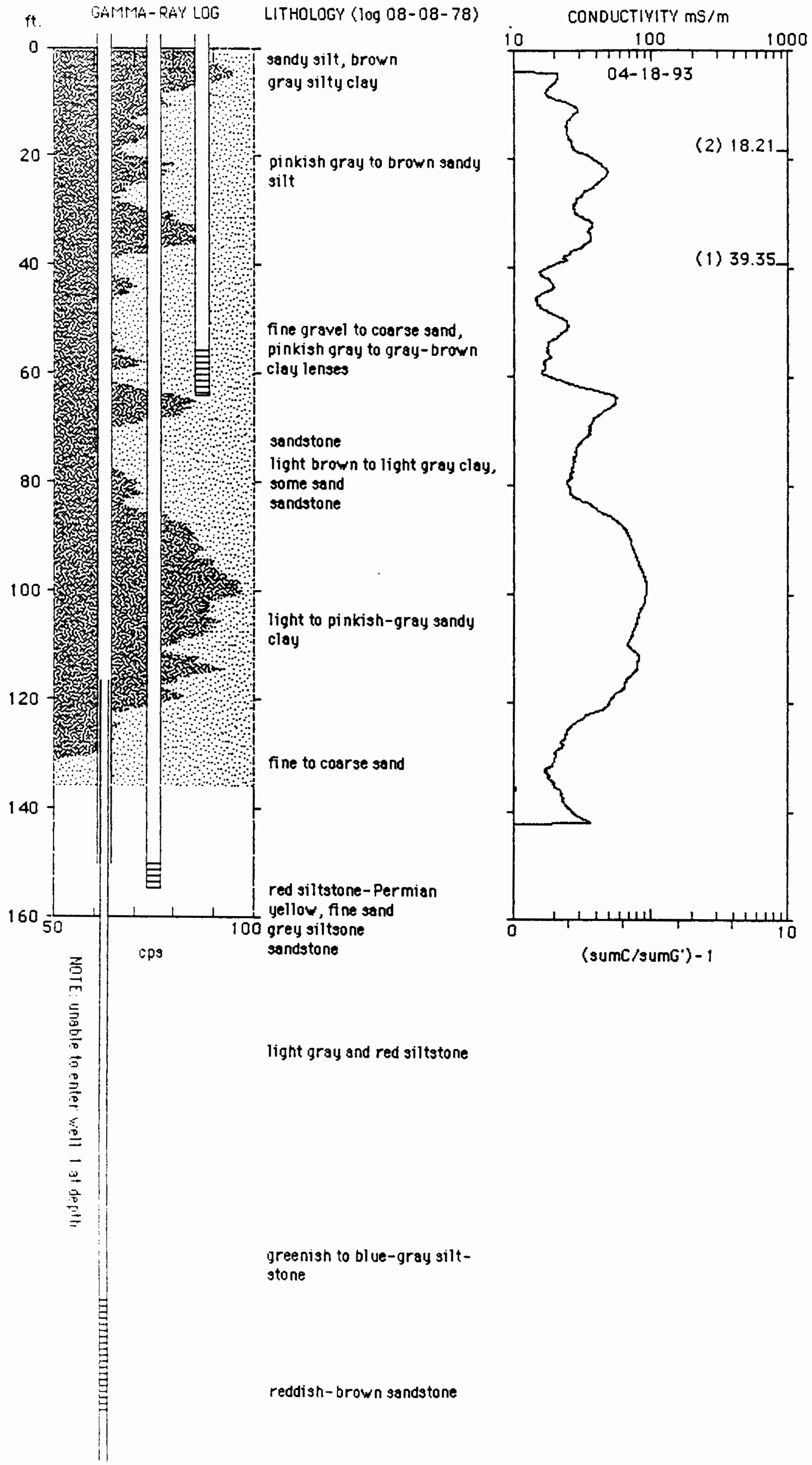

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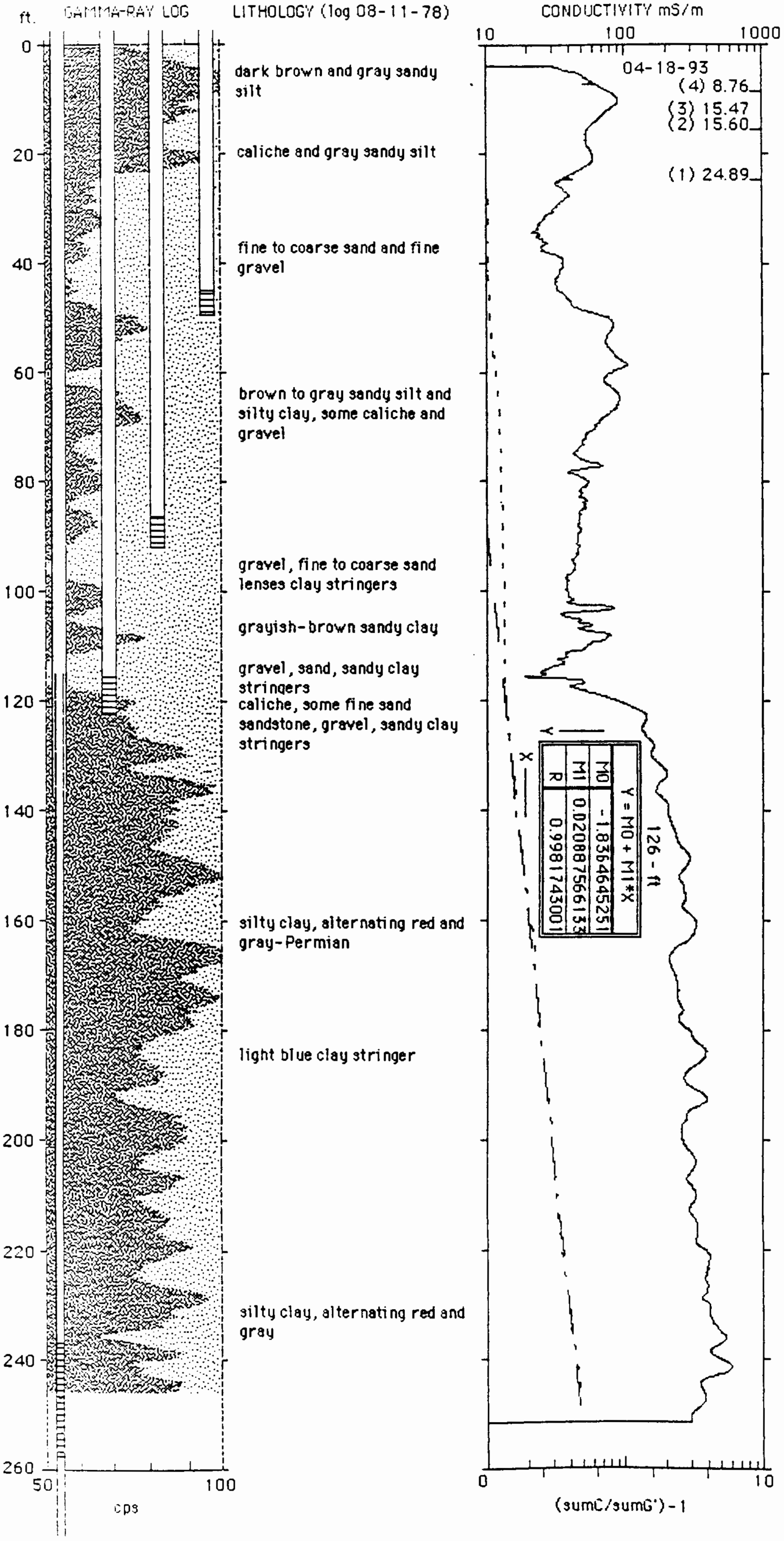
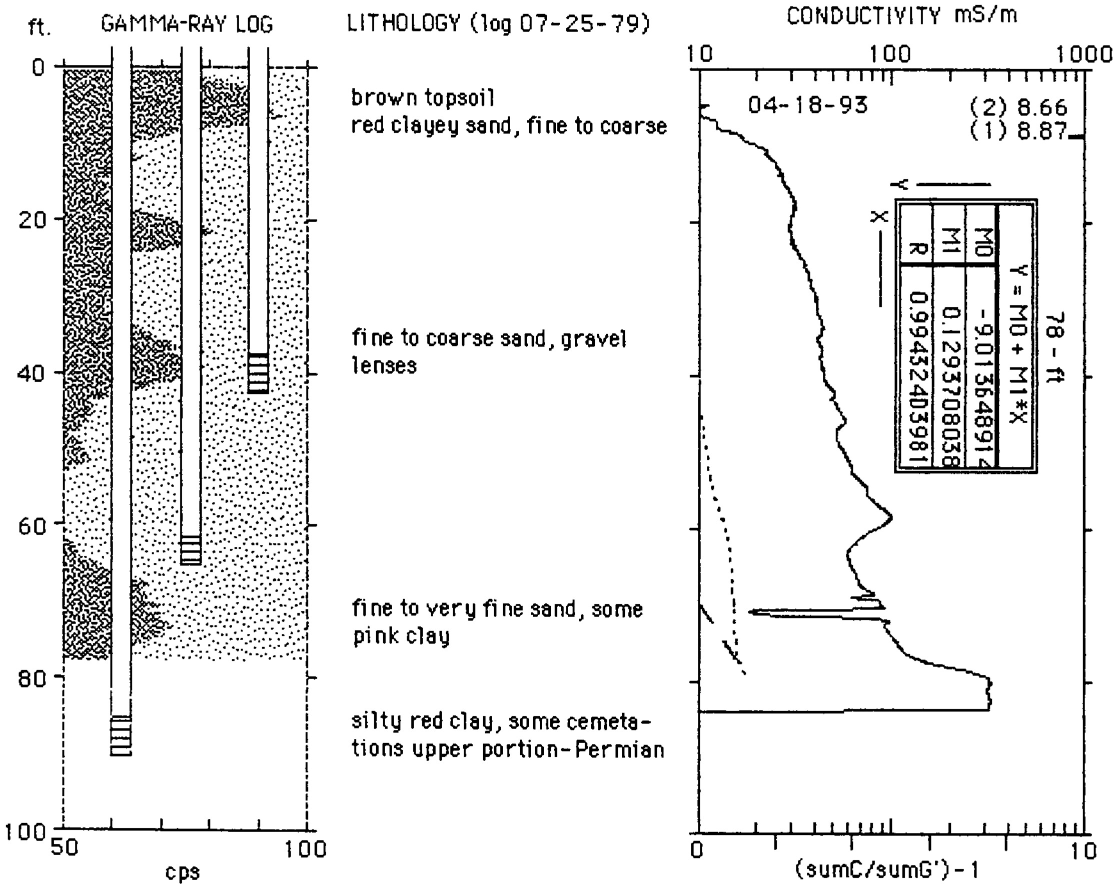


MONITORING SITE 9

24-10-31CBCB elev=1755 ft. N →



MONITORING SITE 10

24-10-06DCCC

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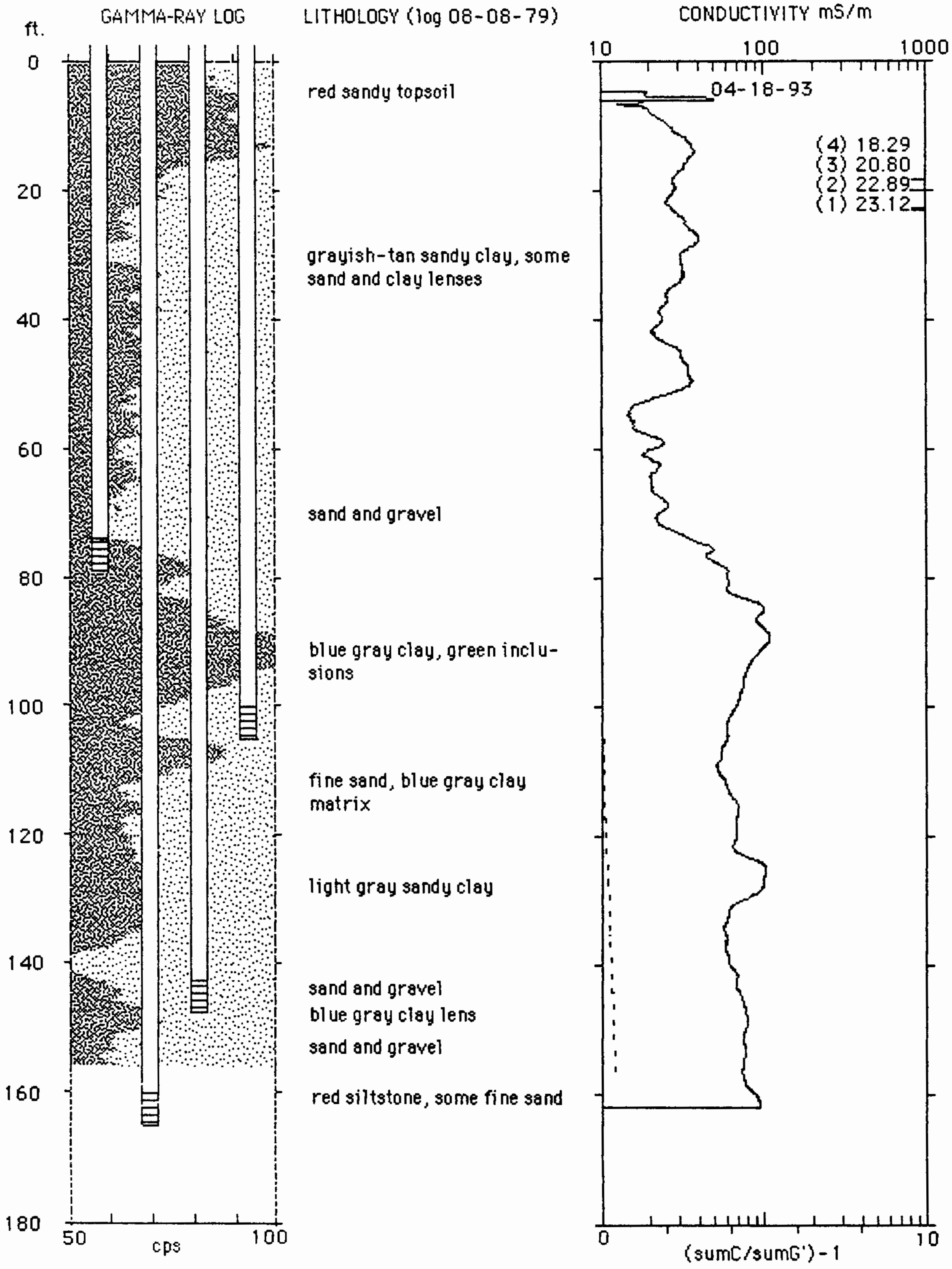

MONITORING SITE 11

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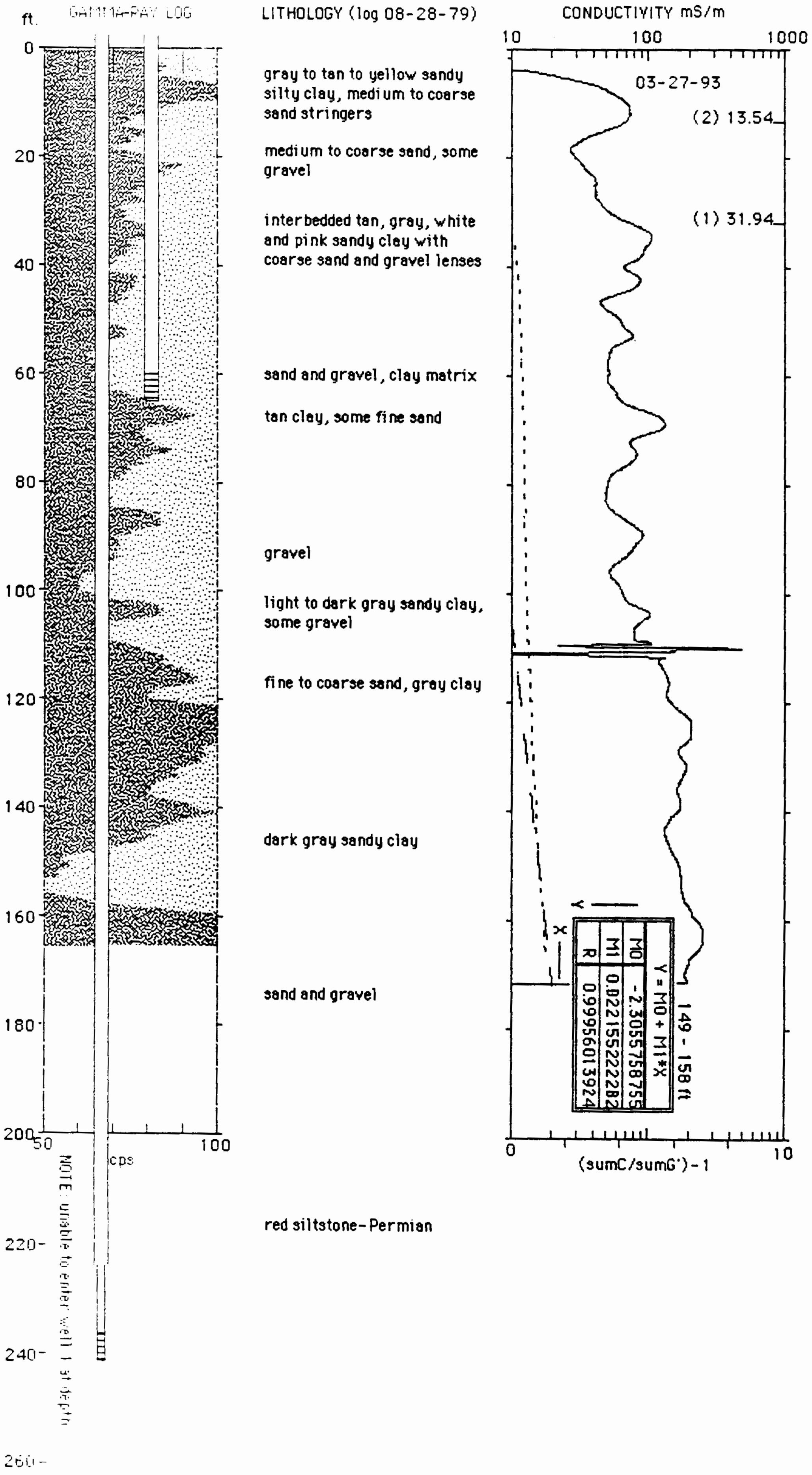
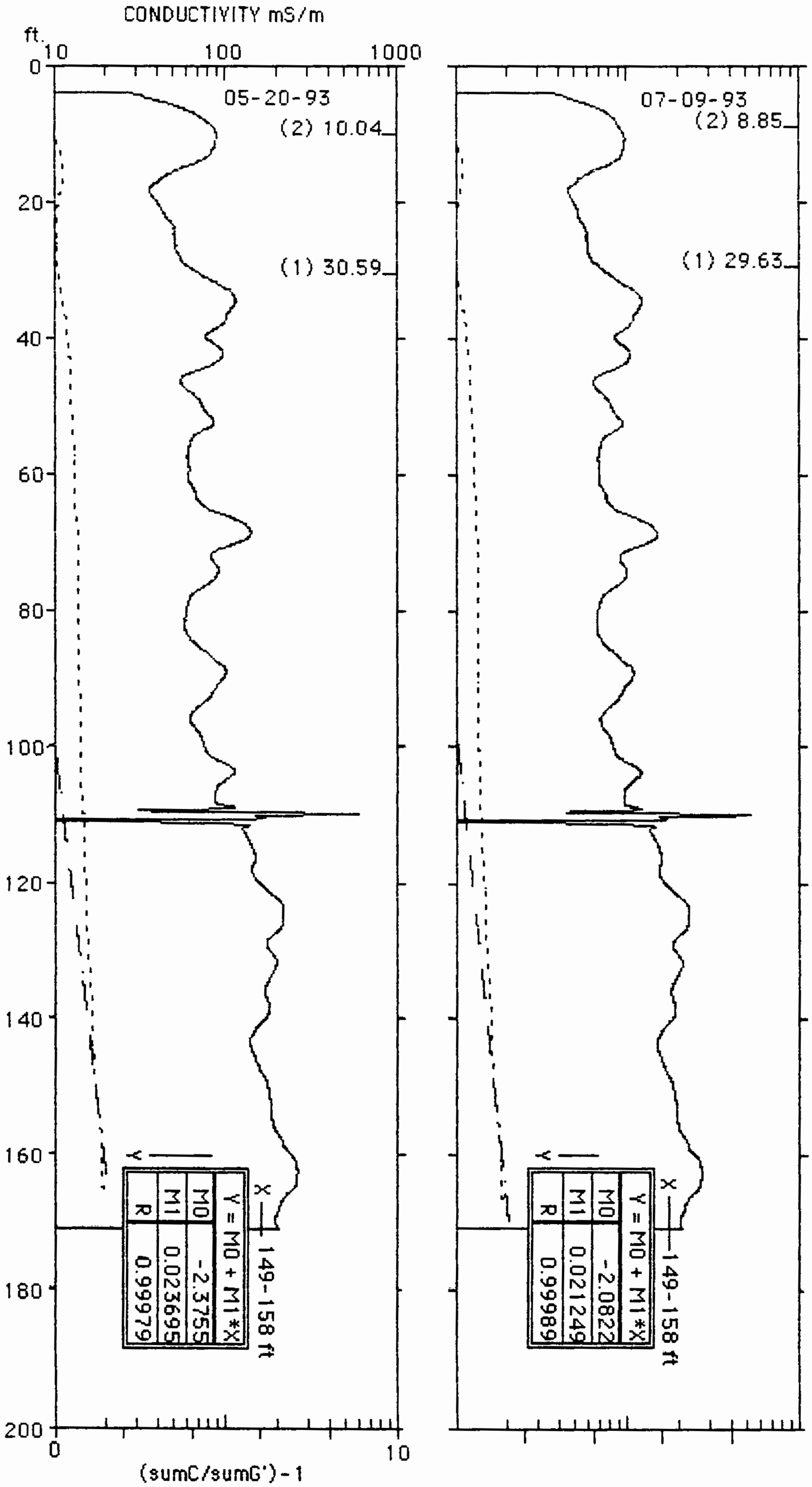


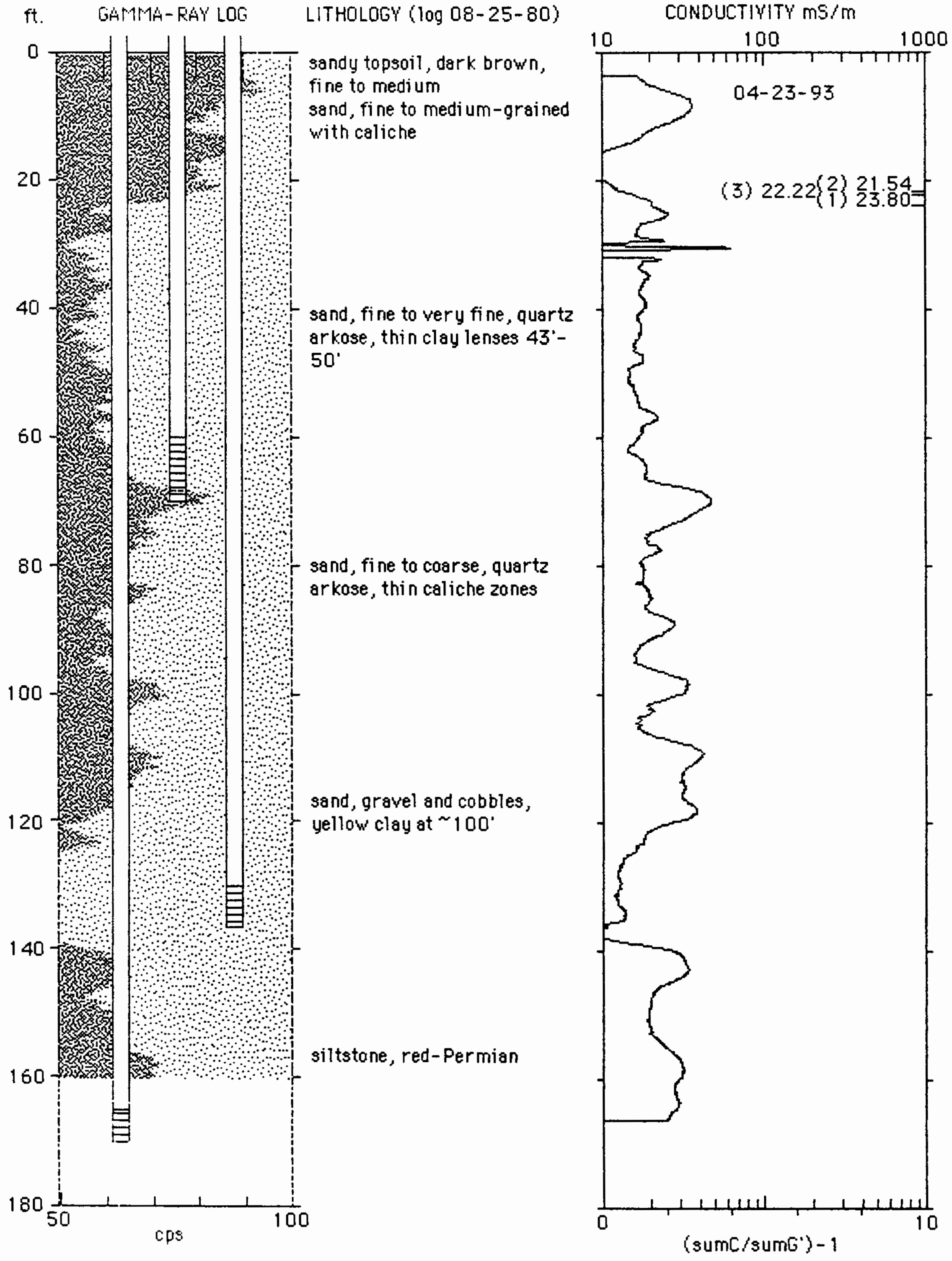
MONITORING SITE 11



MONITORING SITE 12

29-11-36ACCC

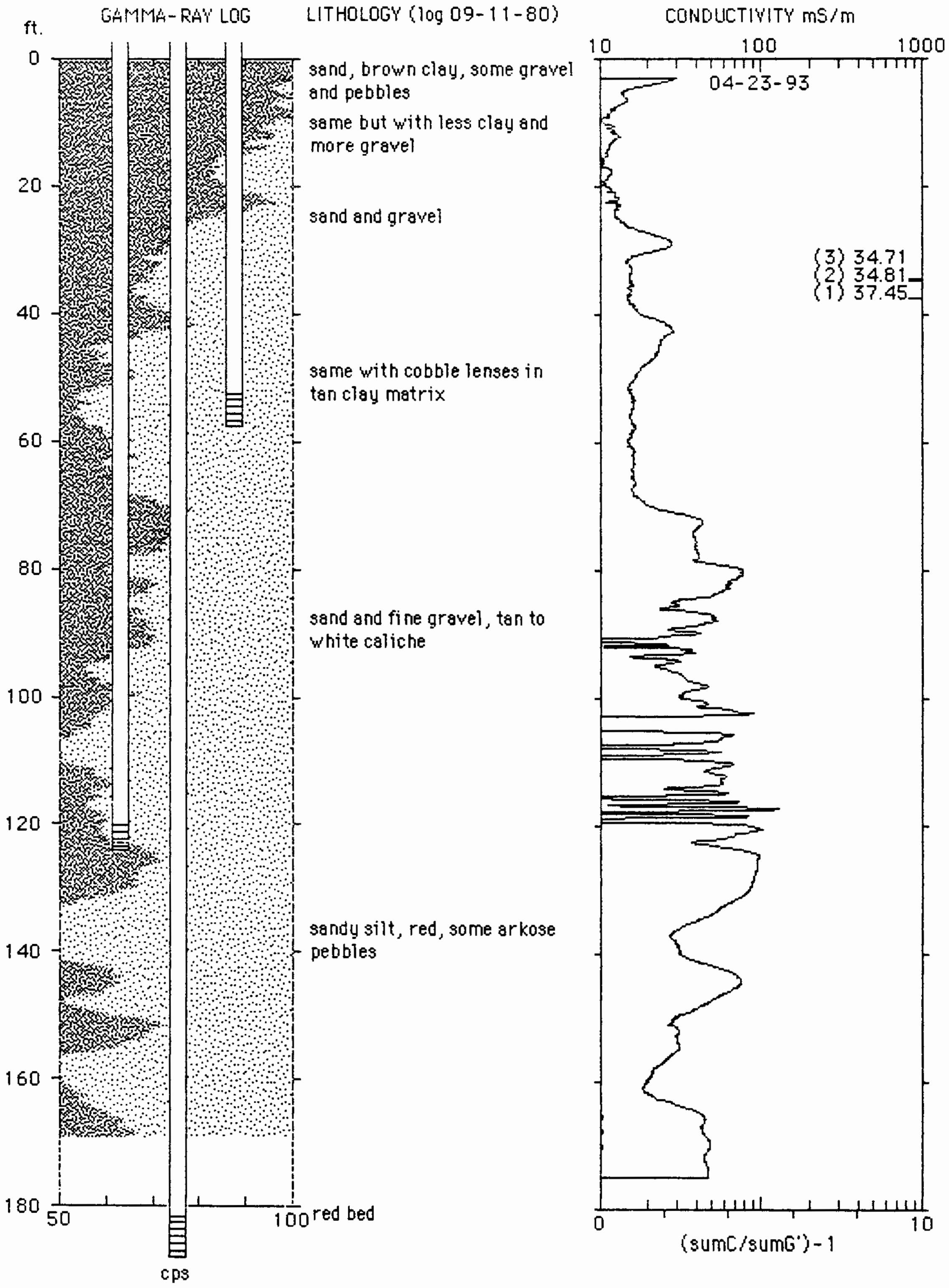
elev=1770 ft. N ⊕



MONITORING SITE 13

29-14-36AAAD

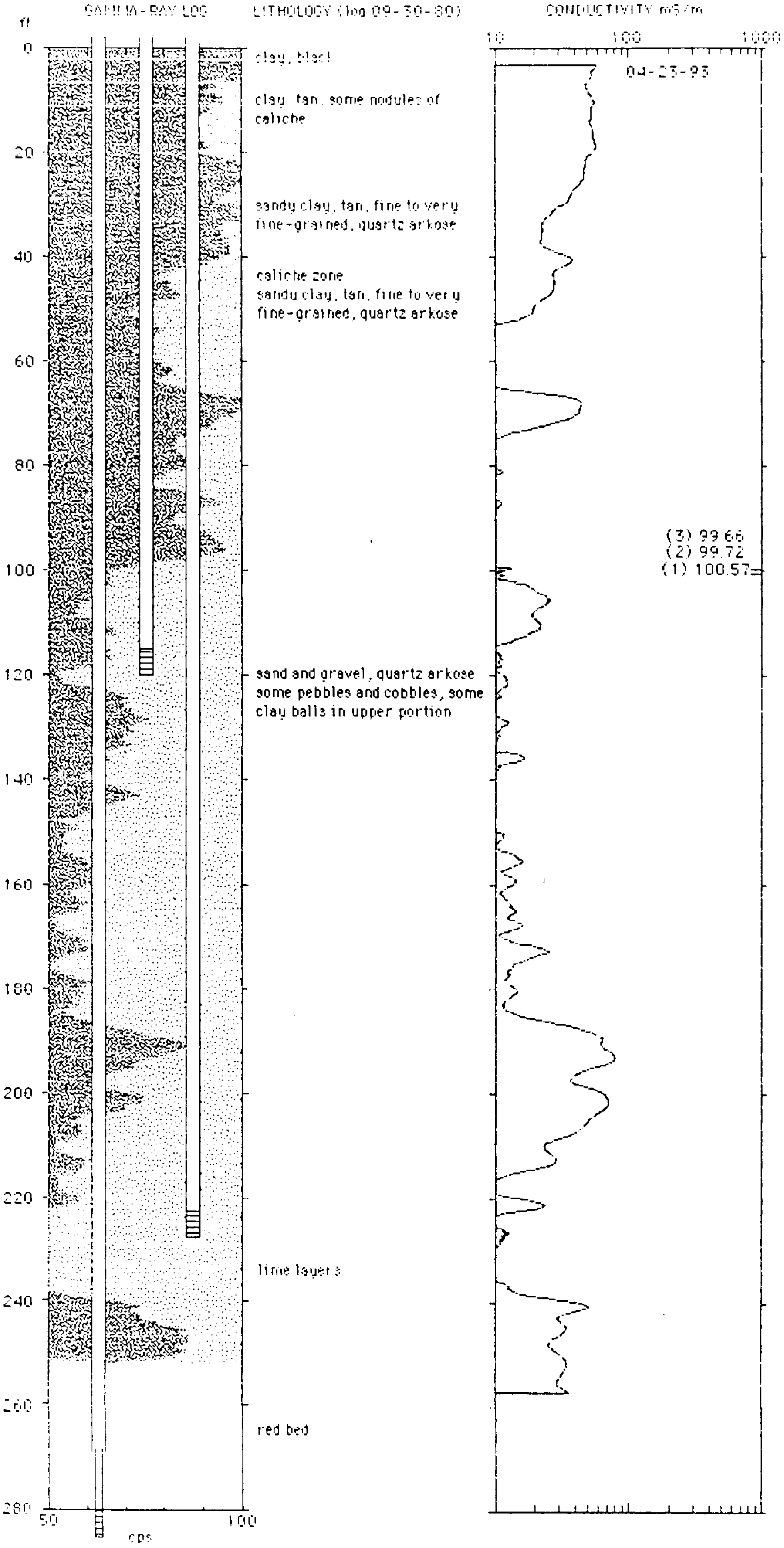
elev= 1905 ft. N



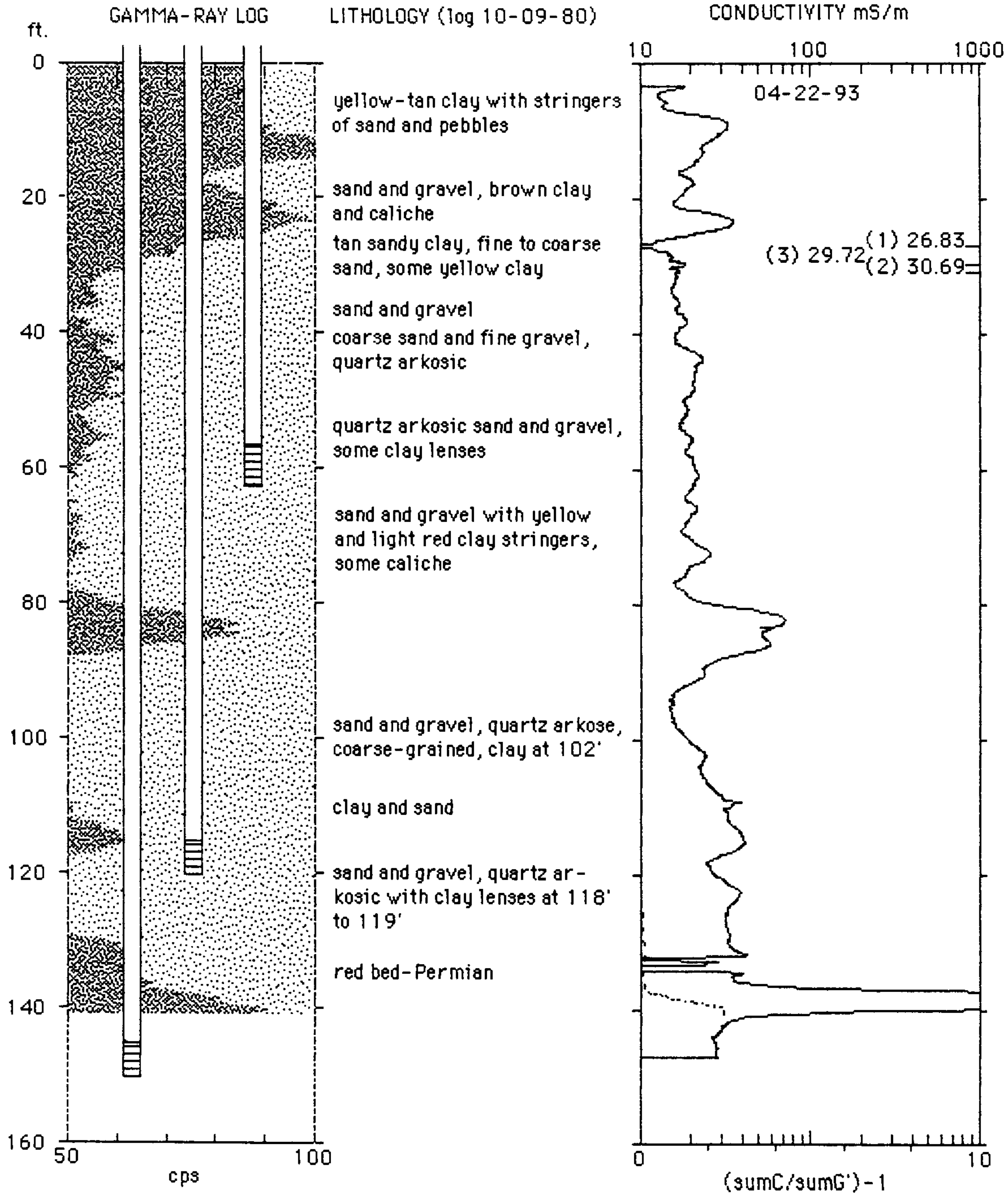
MONITORING SITE 14

29-14-12ABBB

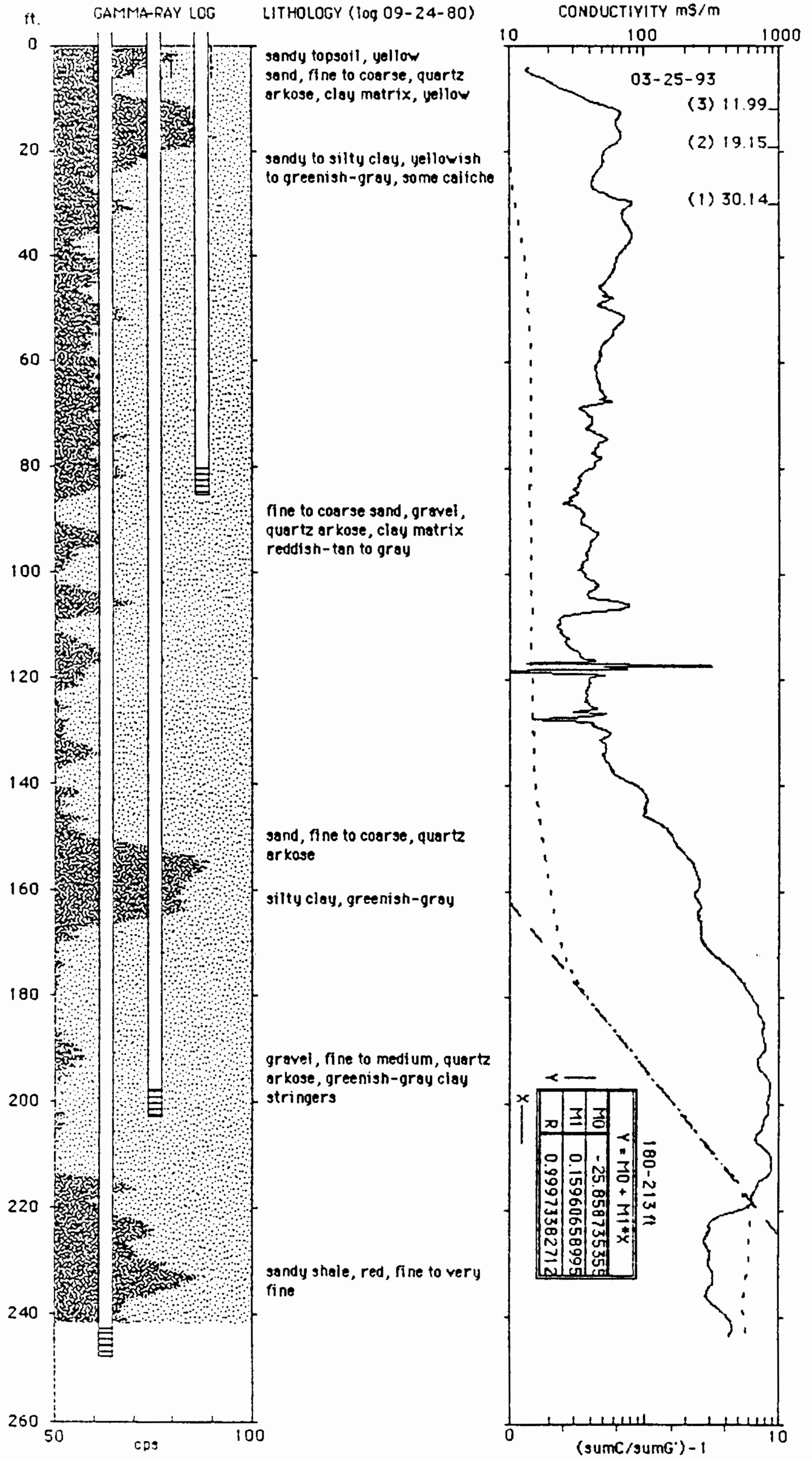
elev= 1909 ft N ⊕



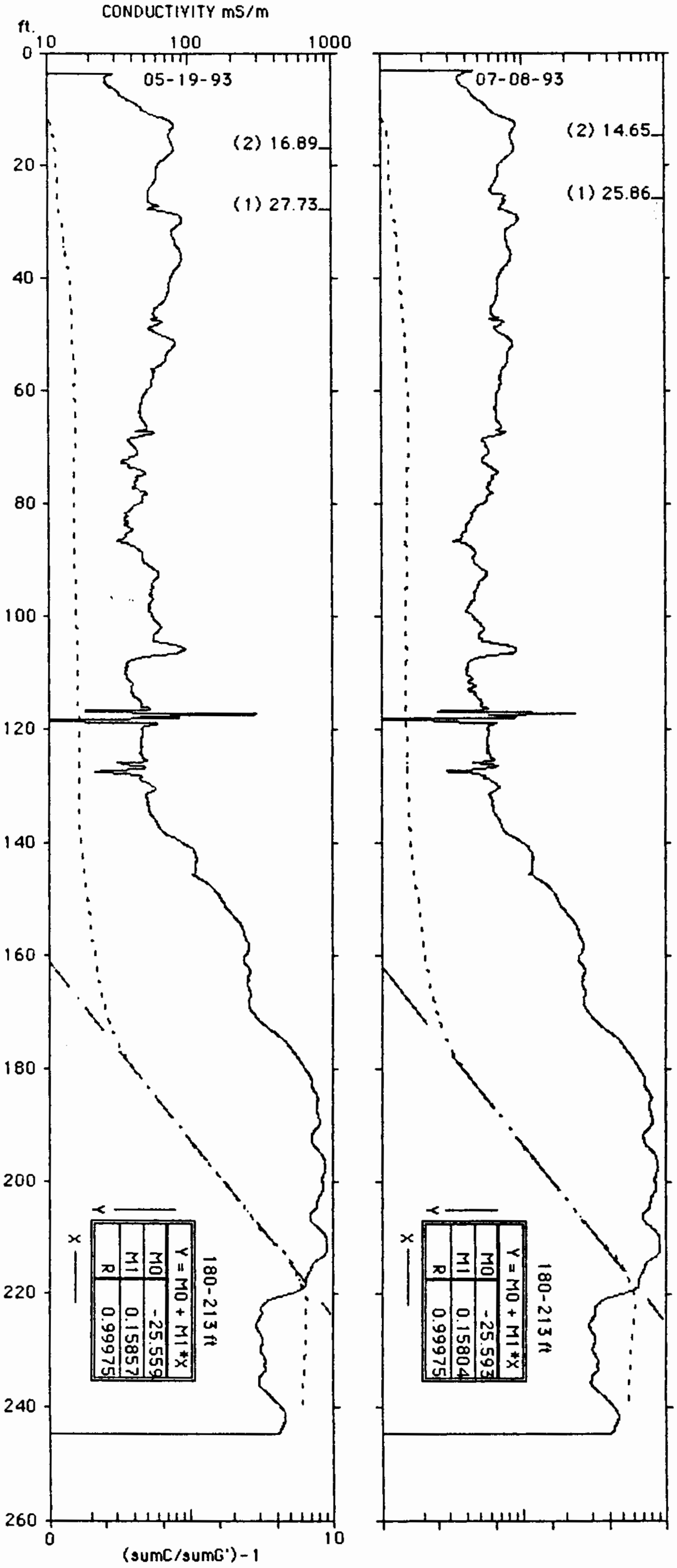
MONITORING SITE 15 28-11-01AAAD elev=1725 ft. N ◄—

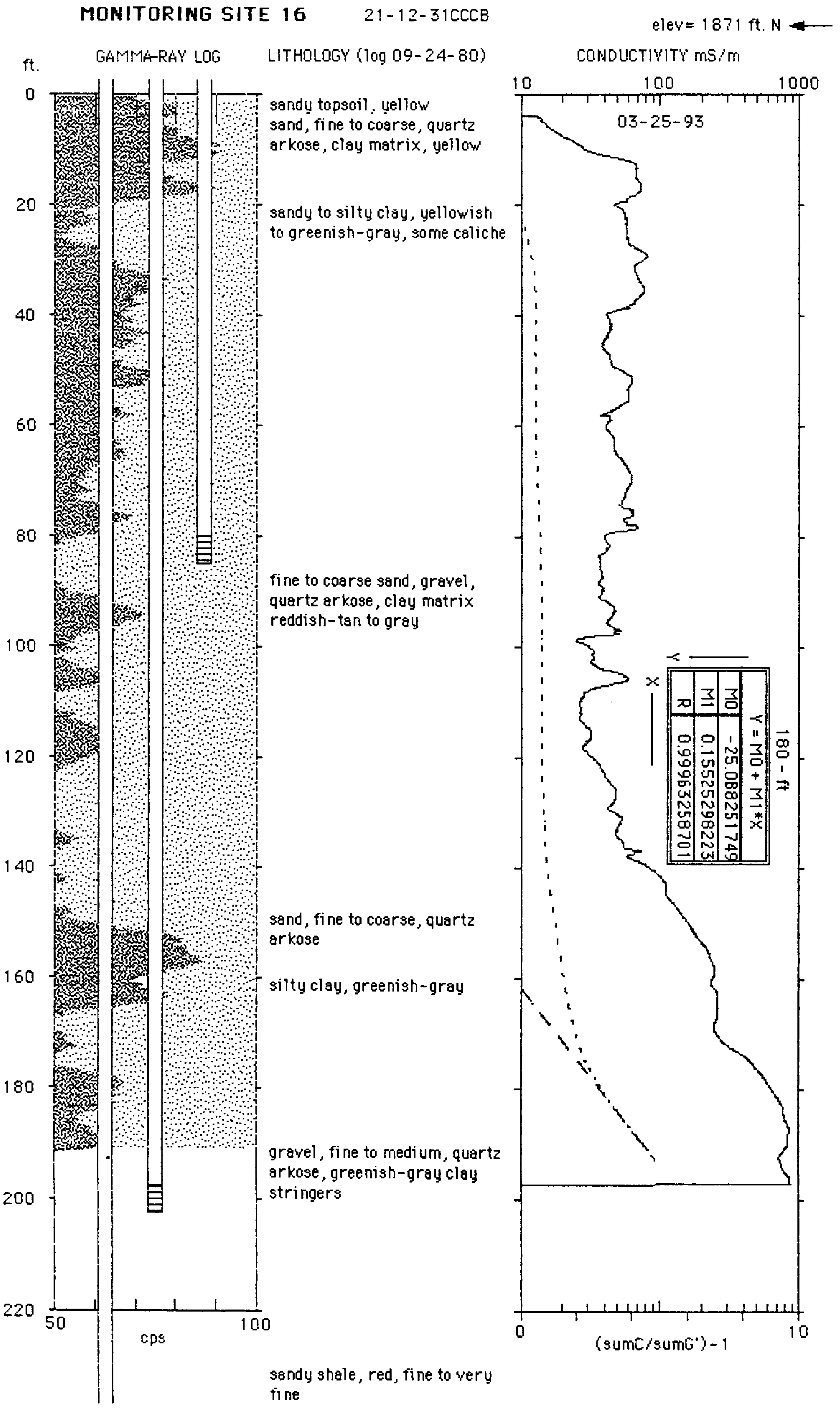


MONITORING SITE 16 21-12-31CCCB



MONITORING SITE 16

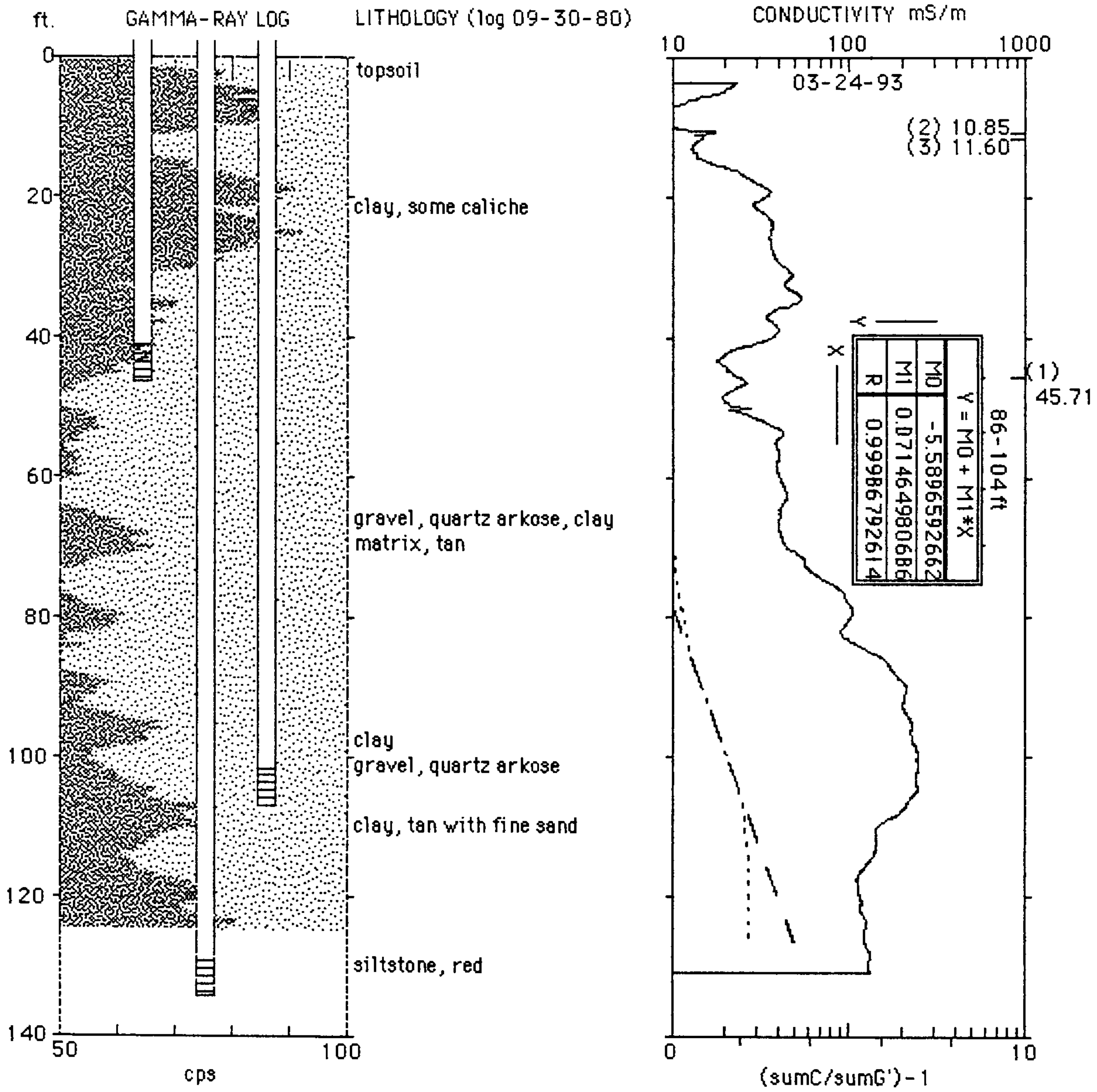



MONITORING SITE 16
21-12-31CCCB
elev= 1871 ft. N
GAMMA-RAY LOG
LITHOLOGY (log 09-24-80)
CONDUCTIVITY mS/m
ft.
0
20
40
60
80
100
120
140
160
180
200
220
50
cps
100
10
100
1000
03-25-93
sandy topsoil, yellow
sand, fine to coarse, quartz arkose, clay matrix, yellow
sandy to silty clay, yellowish to greenish-gray, some caliche
fine to coarse sand, gravel, quartz arkose, clay matrix reddish-tan to gray
sand, fine to coarse, quartz arkose
silty clay, greenish-gray
gravel, fine to medium, quartz arkose, greenish-gray clay stringers
sandy shale, red, fine to very fine
180 - ft
Y = M0 + M1*X
M0
-25.088251749
M1
0.15525298223
R
0.99963258701
Y
X
0
10
(sumC/sumG')-1

MONITORING SITE 17

21-12-36DDCC

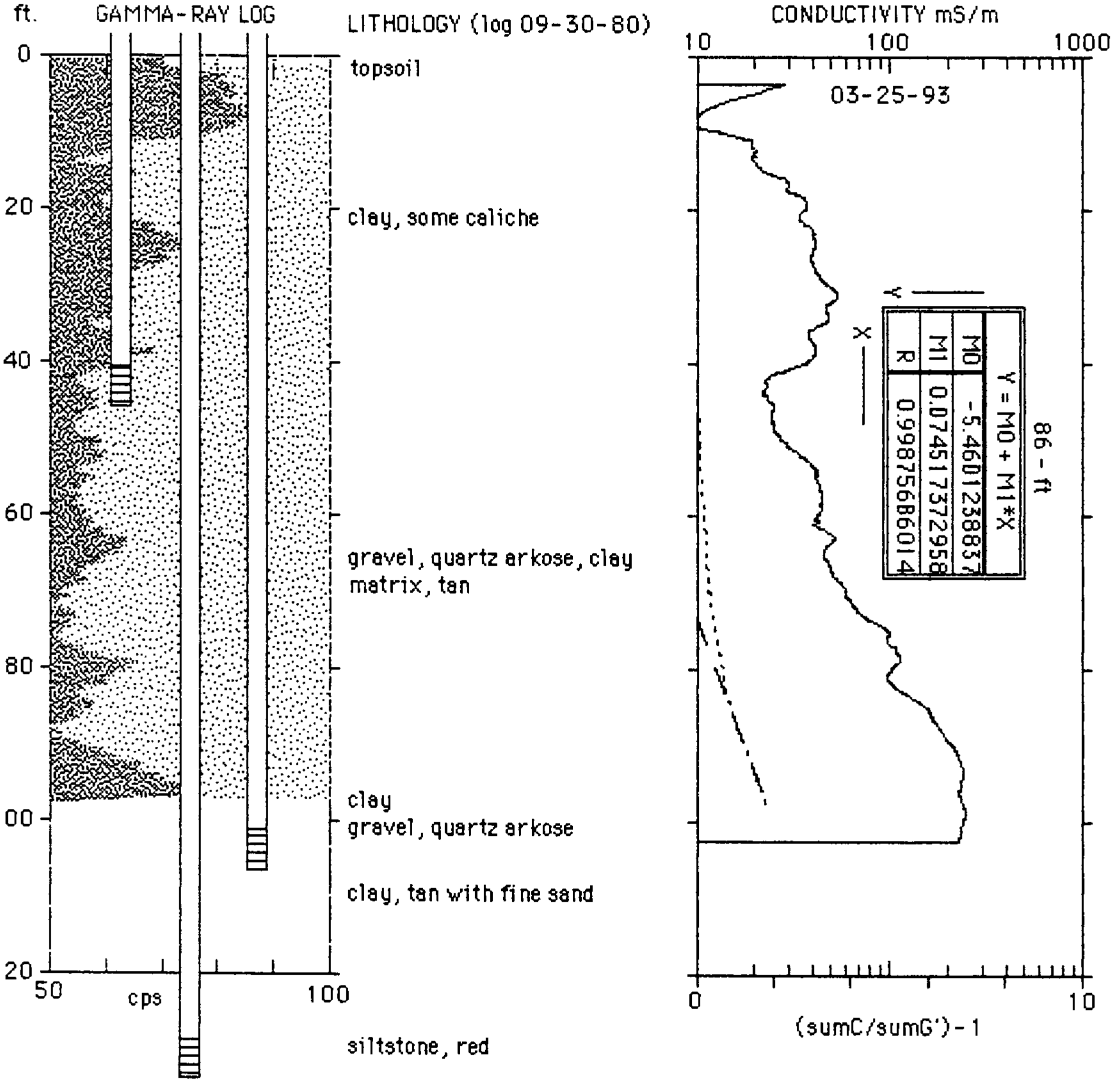
elev=1804ft. N ⊕

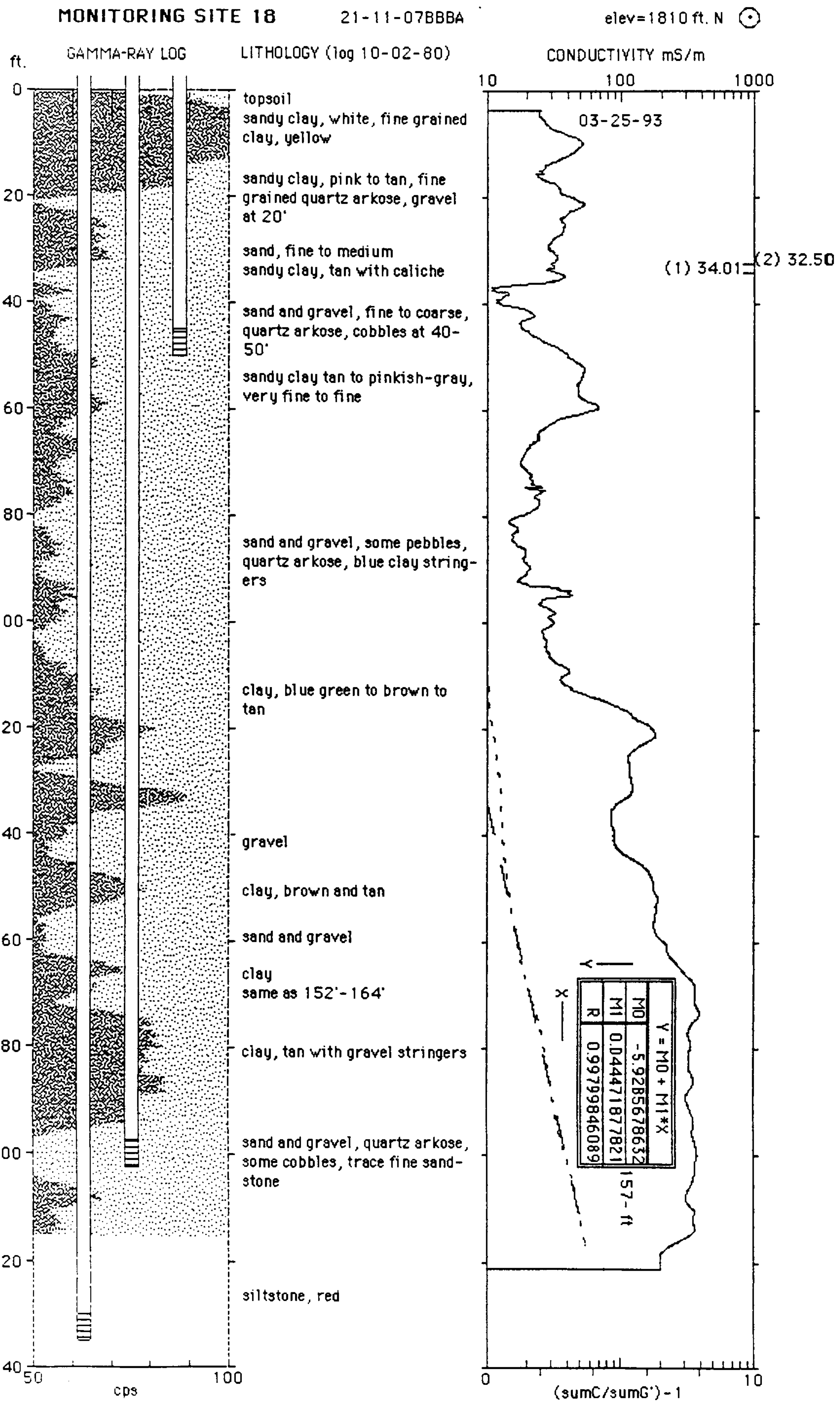


MONITORING SITE 17

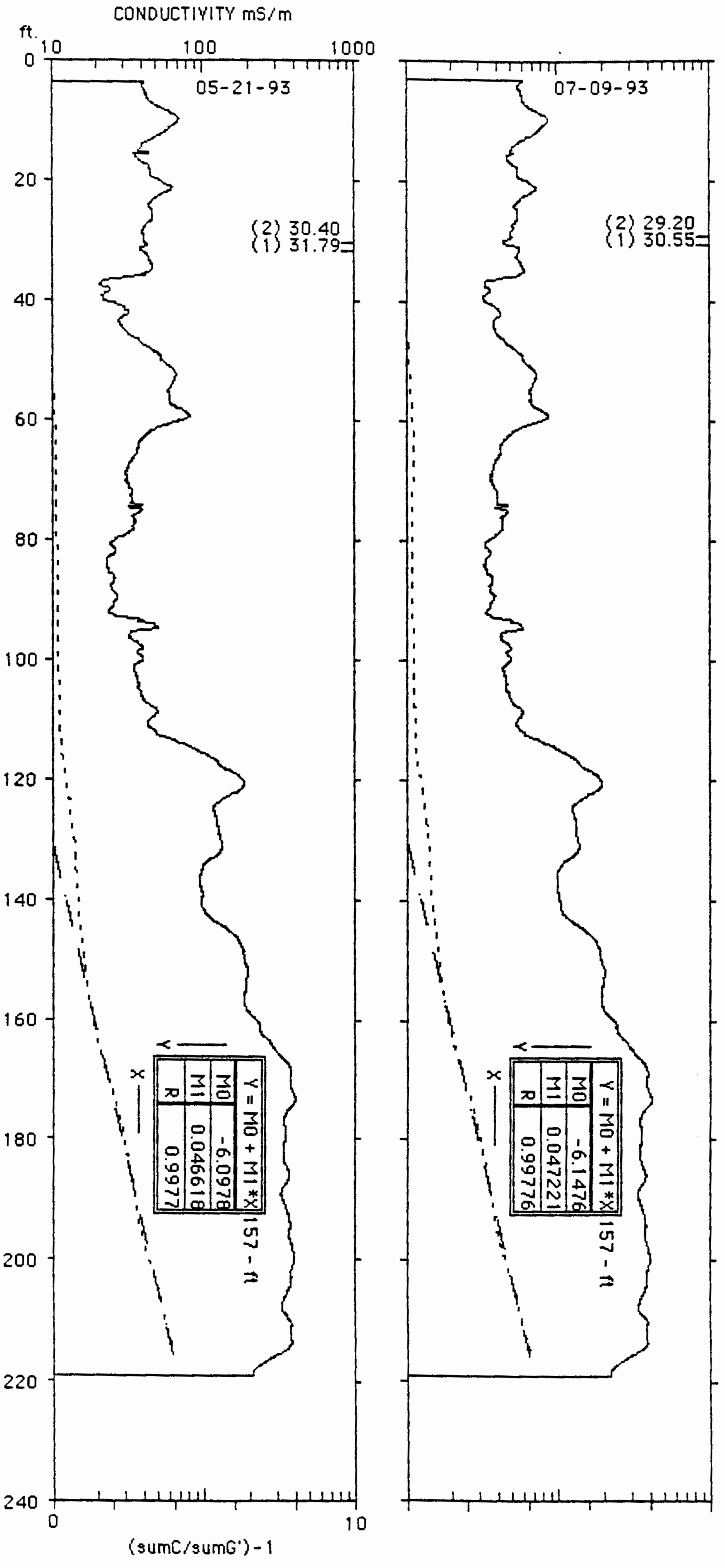
21-12-36DDCC

elev=1804ft. N

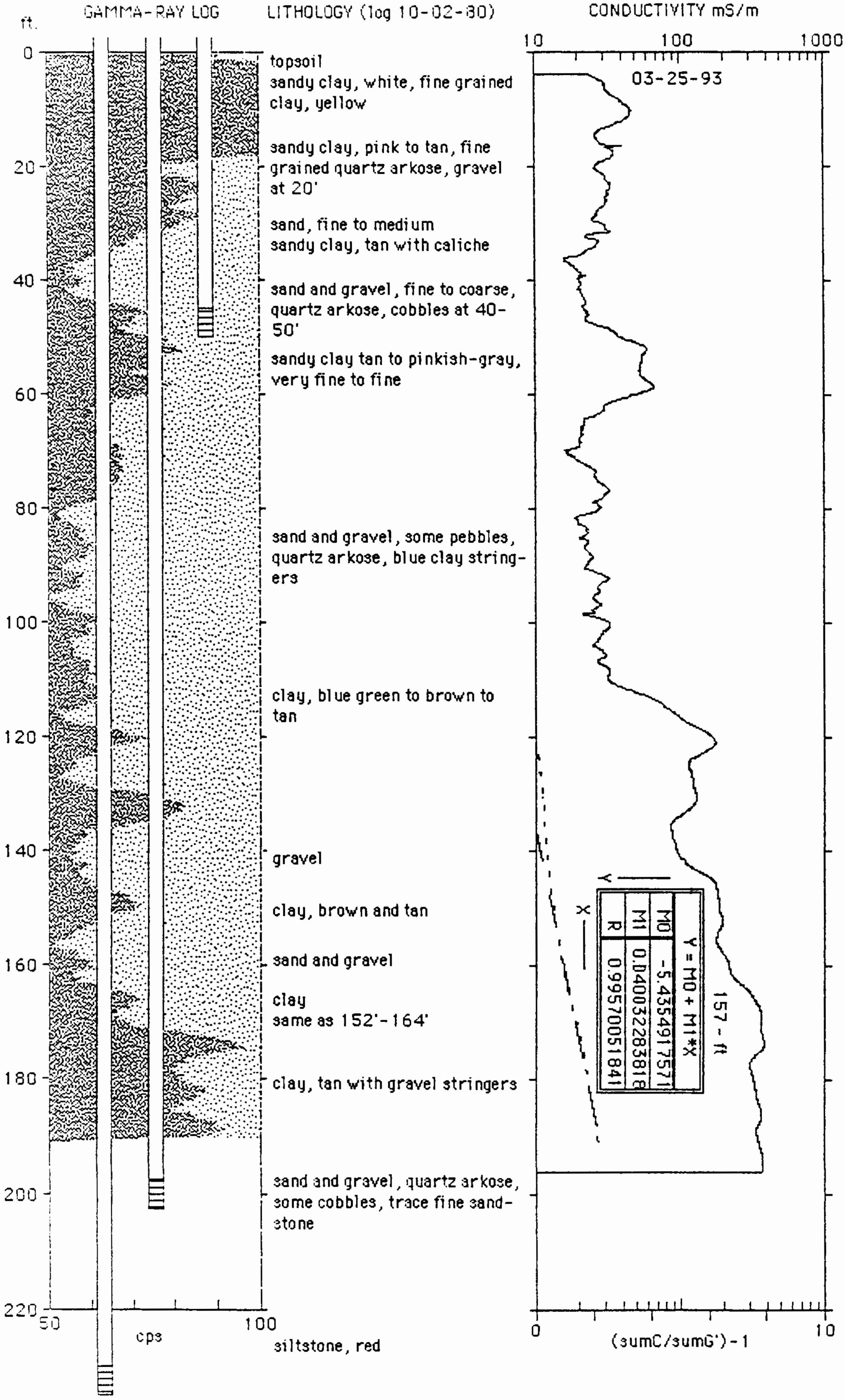



MONITORING SITE 18
21-11-07BBBA
elev=1810 ft. N
GAMMA-RAY LOG
LITHOLOGY (log 10-02-80)
CONDUCTIVITY mS/m
ft.
0
20
40
60
80
100
120
140
160
180
200
220
240
50
cps
100
topsoil
sandy clay, white, fine grained
clay, yellow
sandy clay, pink to tan, fine grained quartz arkose, gravel at 20'
sand, fine to medium
sandy clay, tan with caliche
sand and gravel, fine to coarse, quartz arkose, cobbles at 40-50'
sandy clay tan to pinkish-gray, very fine to fine
sand and gravel, some pebbles, quartz arkose, blue clay stringers
clay, blue green to brown to tan
gravel
clay, brown and tan
sand and gravel
clay
same as 152'-164'
clay, tan with gravel stringers
sand and gravel, quartz arkose, some cobbles, trace fine sandstone
siltstone, red
10
100
1000
03-25-93
(1) 34.01
(2) 32.50
Y
X
Y = M0 + M1*X
M0 -5.92856786632
M1 0.044471877821
R 0.997998460089
157- ft
0
(sumC/sumG')-1
10

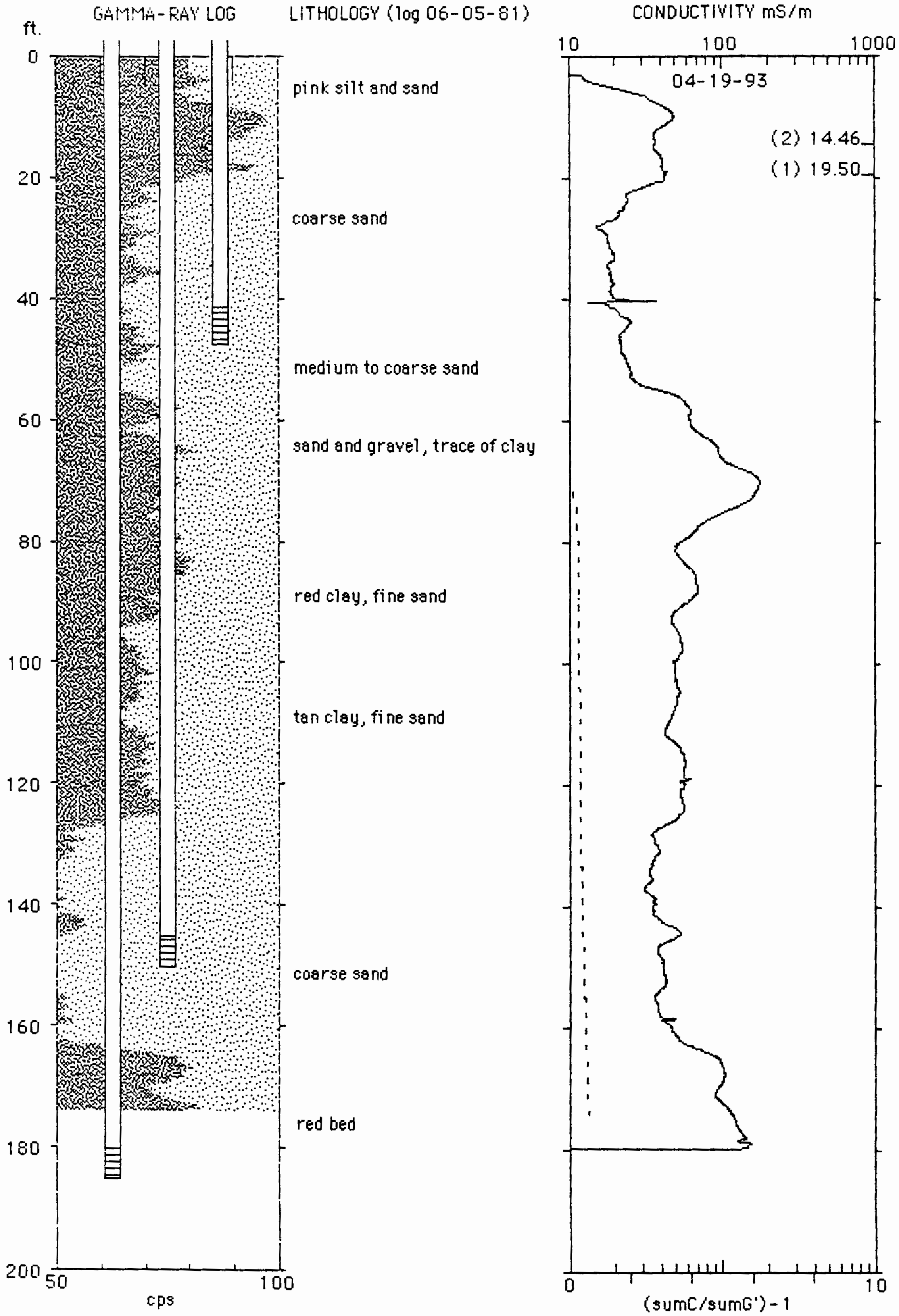
MONITORING SITE 18



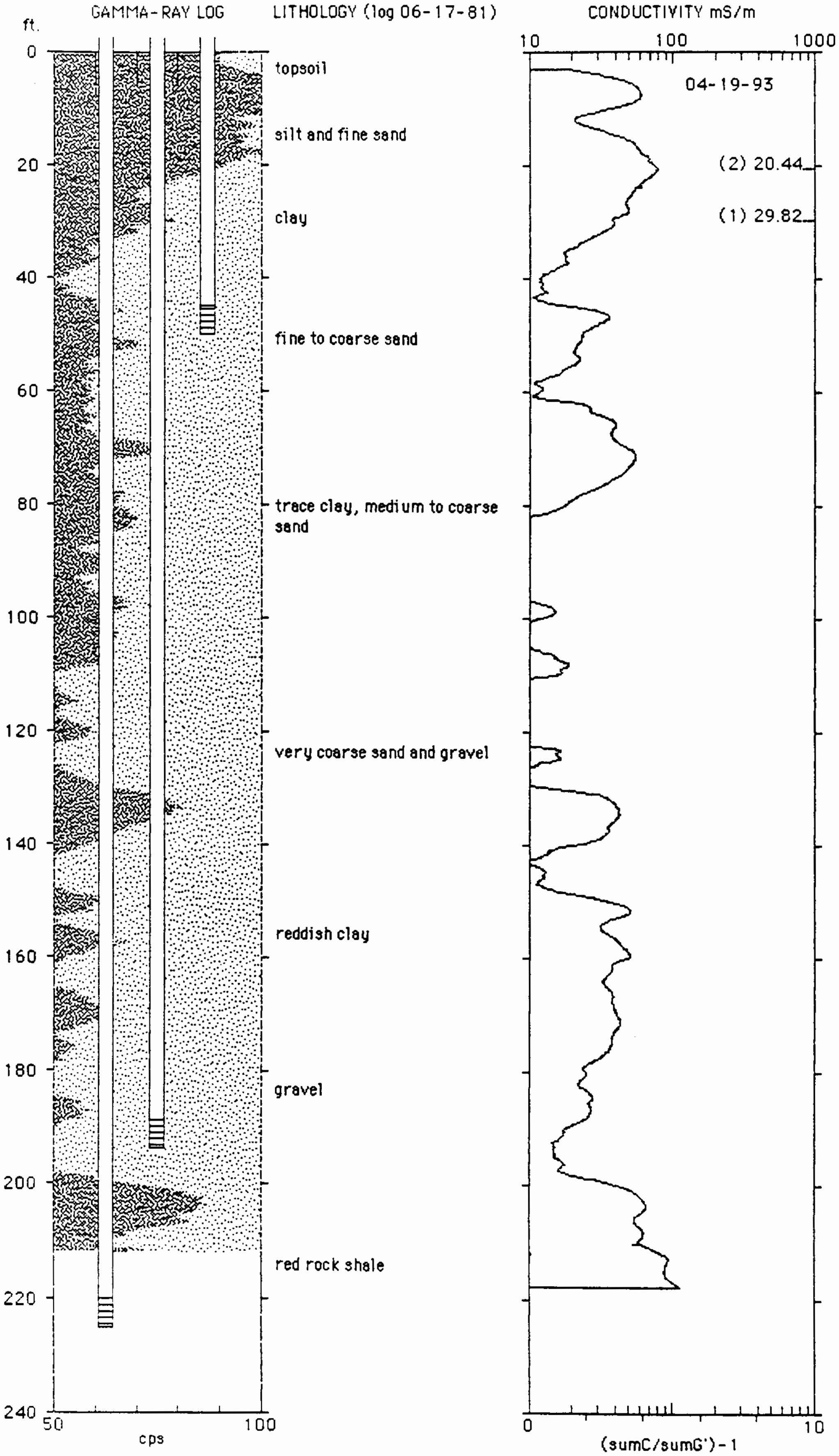
MONITORING SITE 18 21-11-07BBBA elev=1810 ft. N



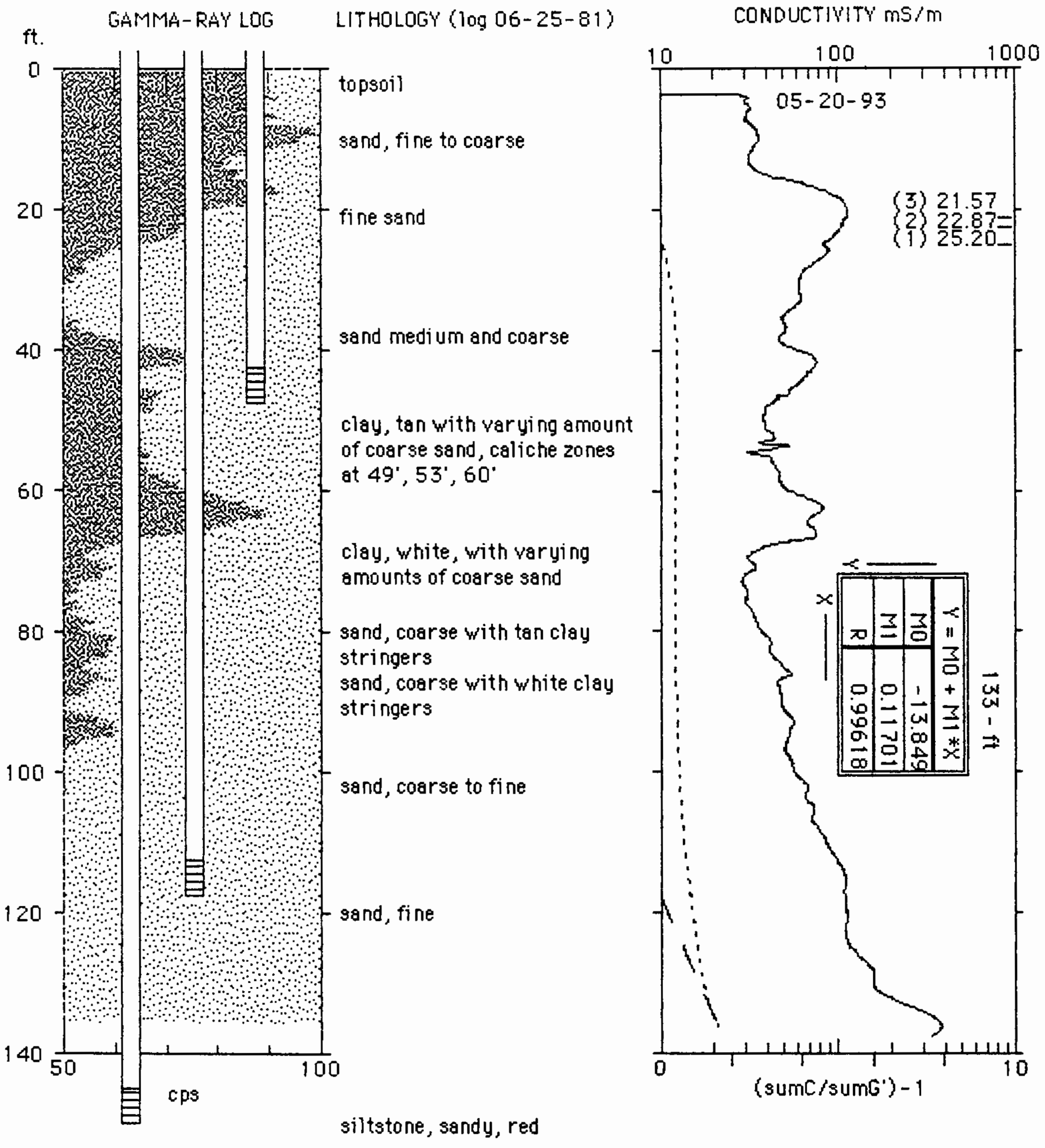
MONITORING SITE 19 25-13-36DCCC elev= 1902 ft. N ⊙



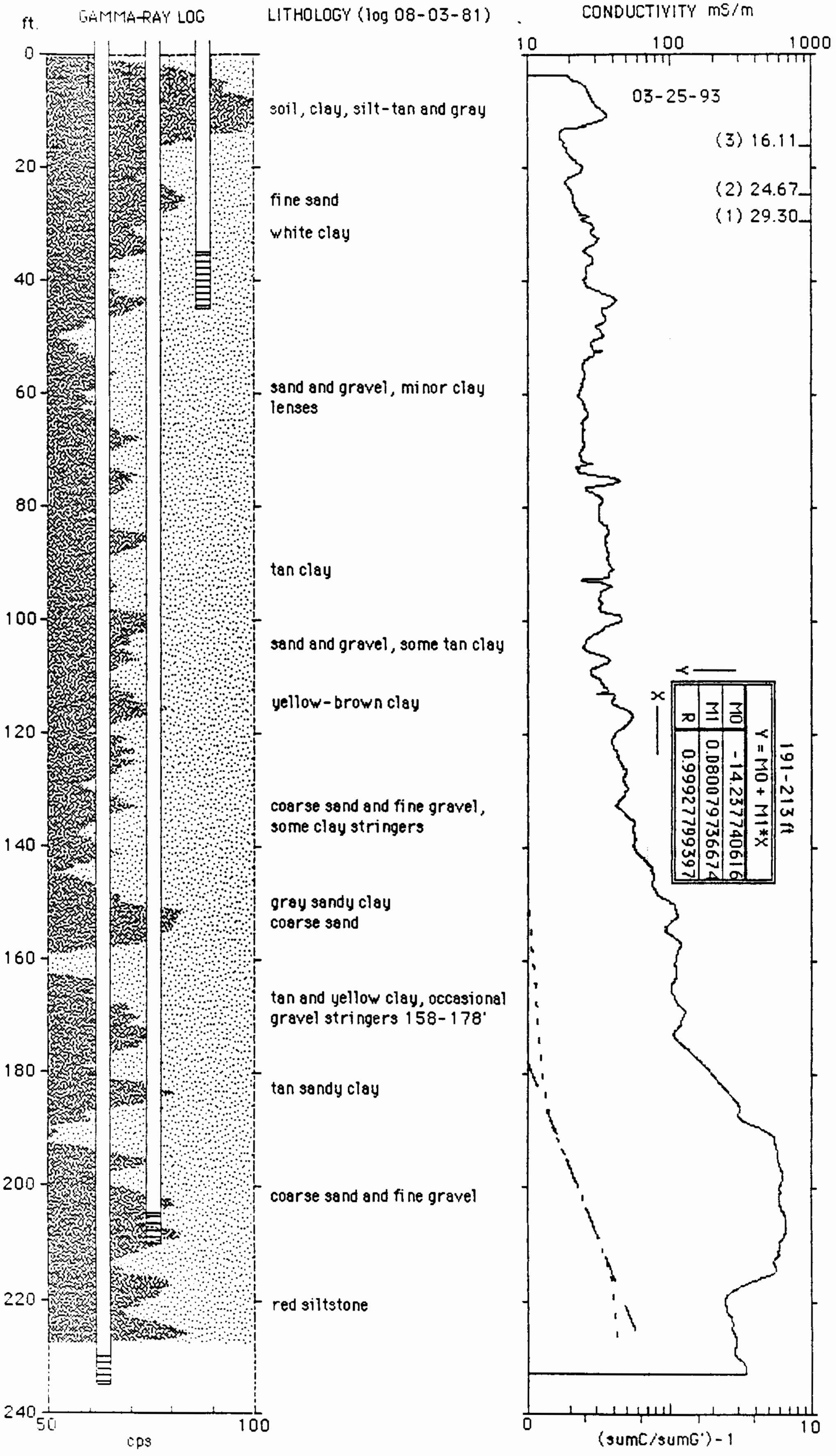
MONITORING SITE 20 25-13-31DDAA elev=1960 ft. N ⊙



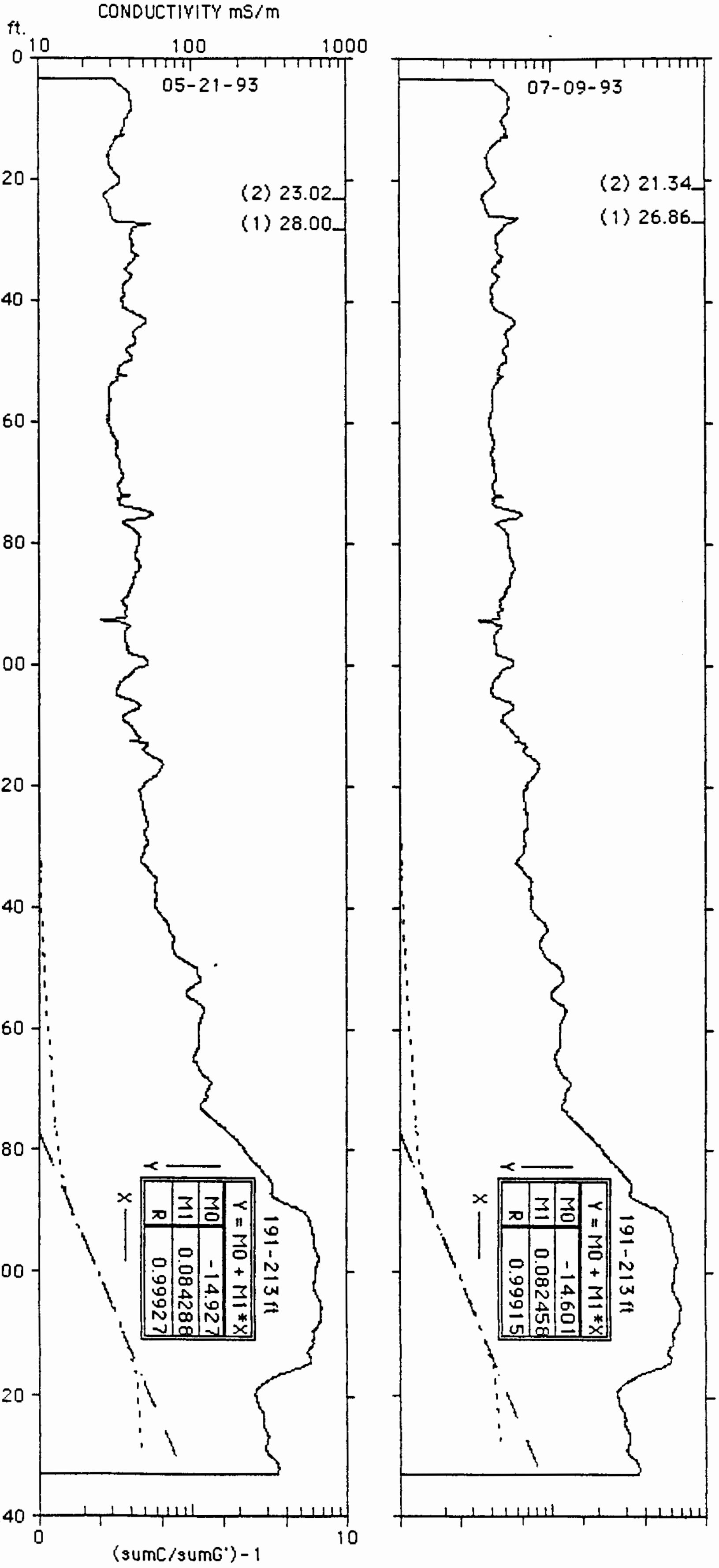
MONITORING SITE 21 26-11-01DDDA elev= 1801 ft. N



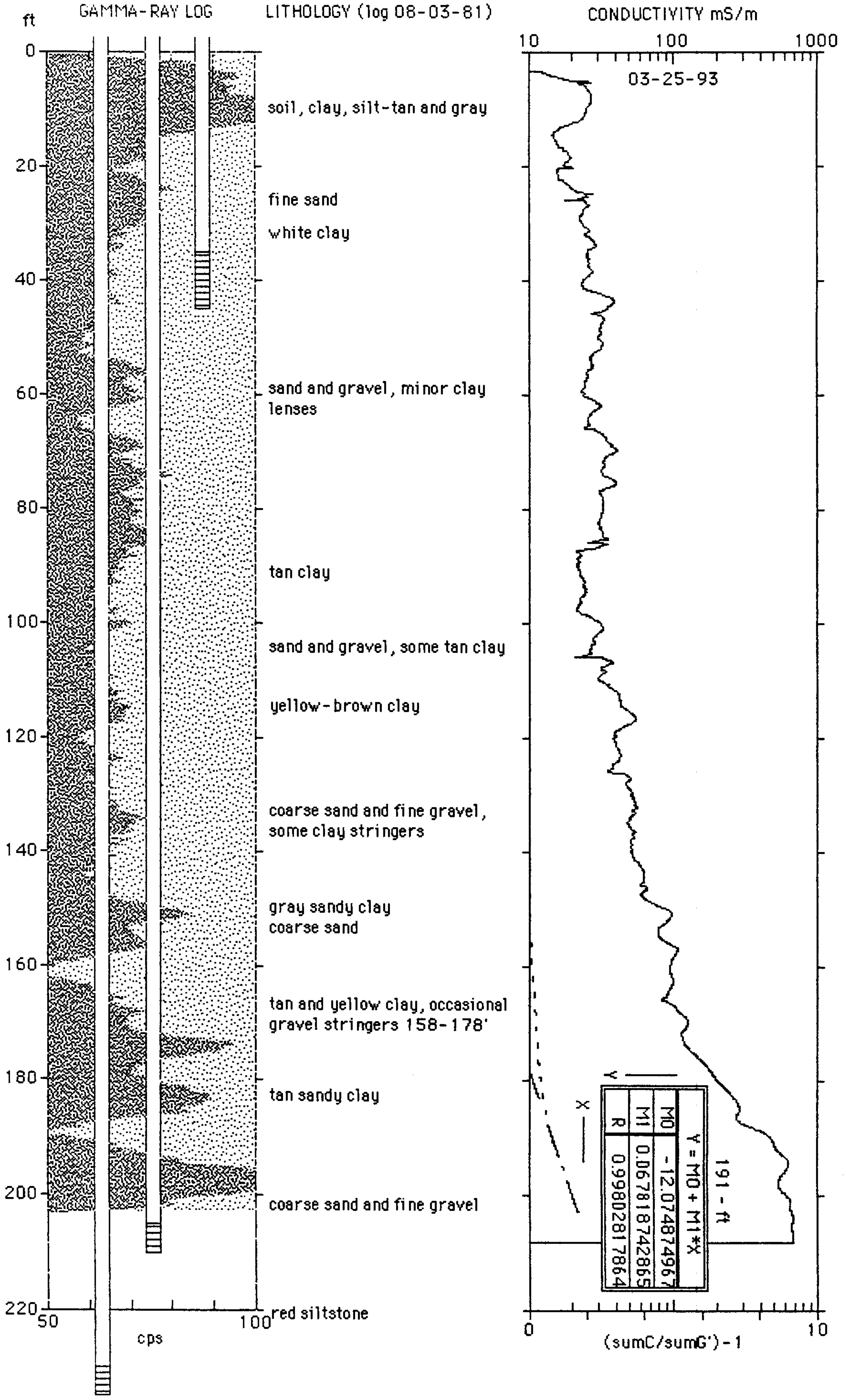
MONITORING SITE 22 21-12-06CCBC elev=1855 ft. N →



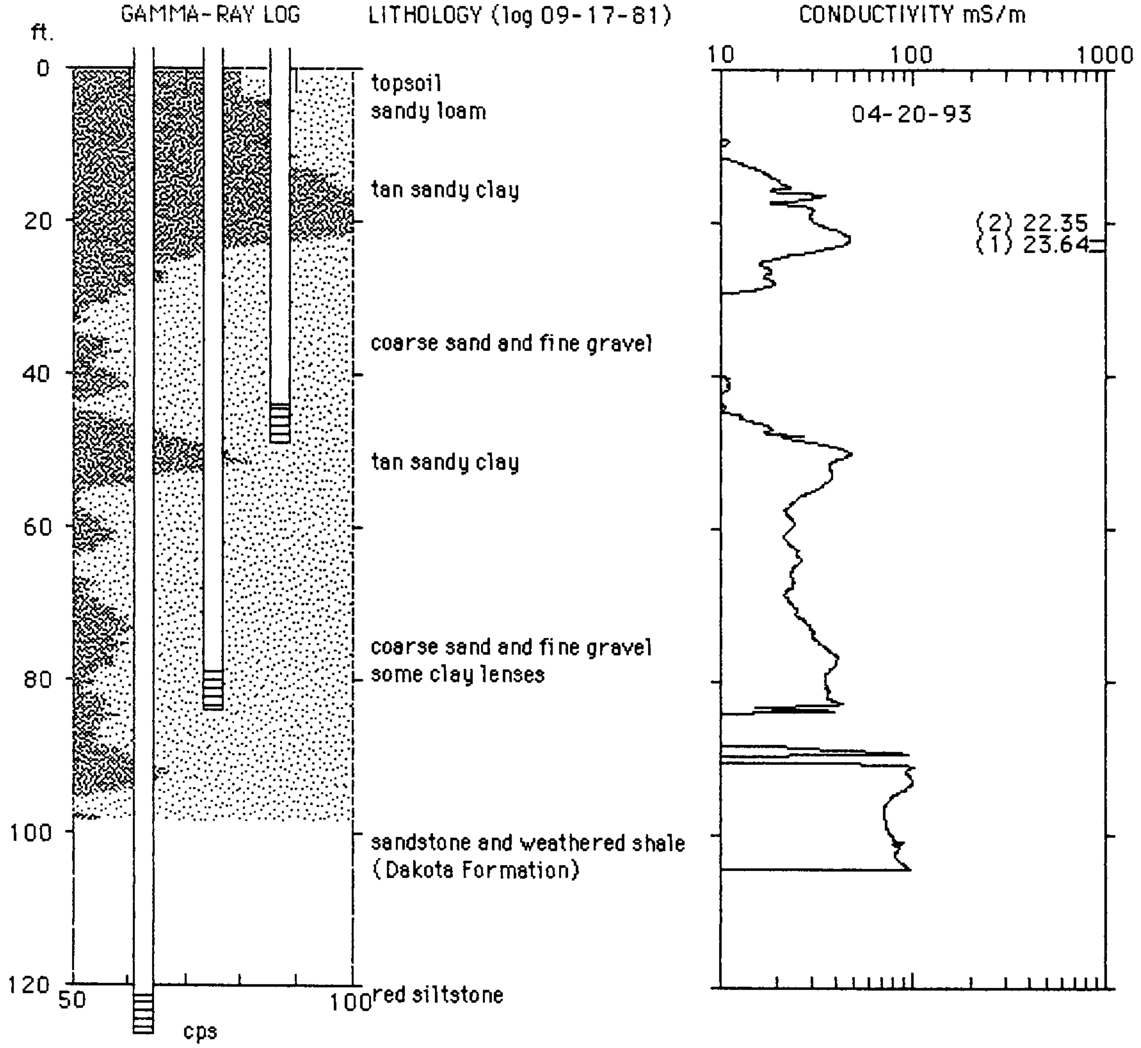
MONITORING SITE 22



MONITORING SITE 22 21-12-06CCBC elev=1855 ft. N →



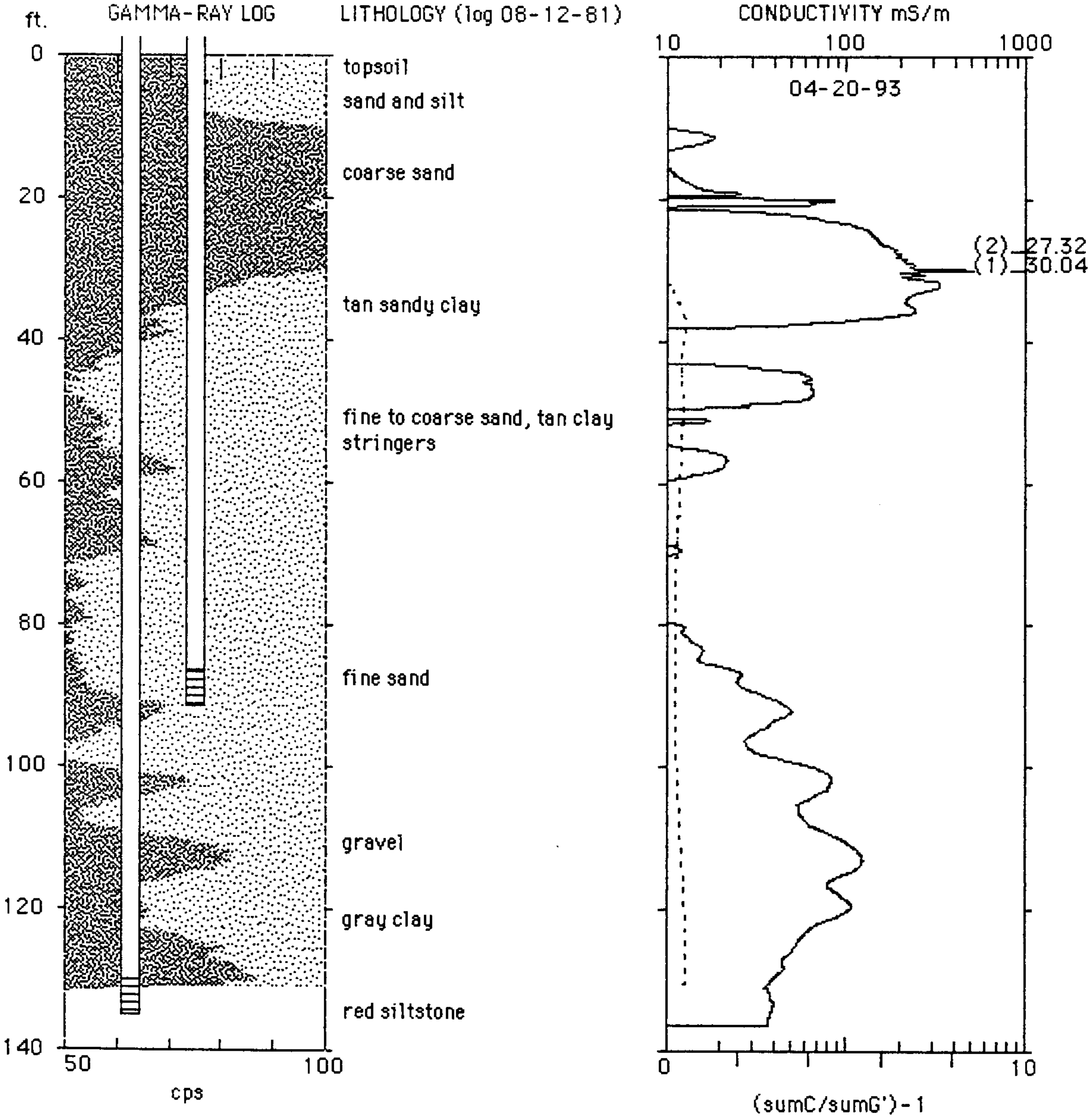
MONITORING SITE 23 21-10-06AADD elev= 1743ft. N ◄—



MONITORING SITE 24

22-10-01ADBC

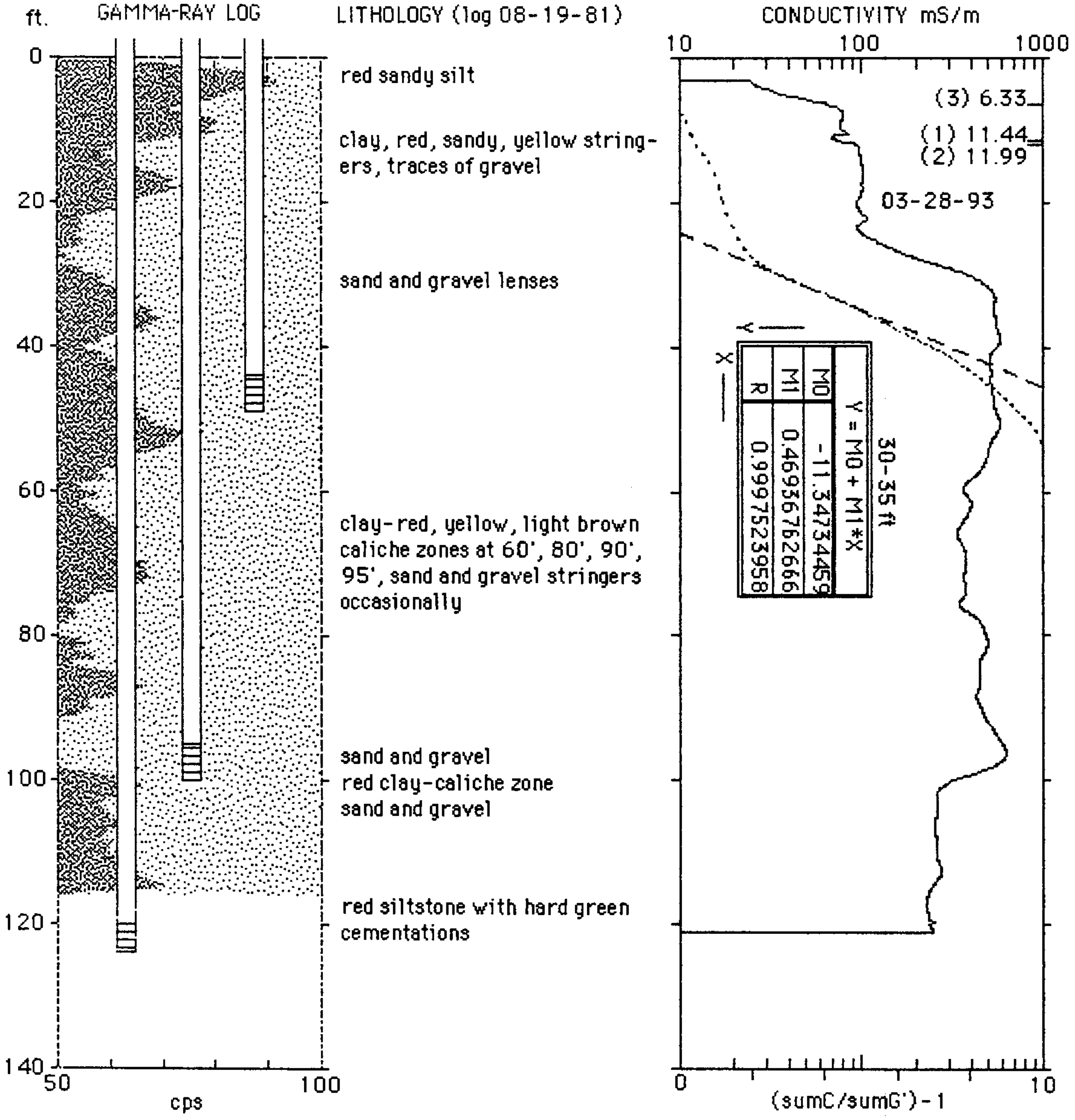
elev=1736 ft. N ◄—



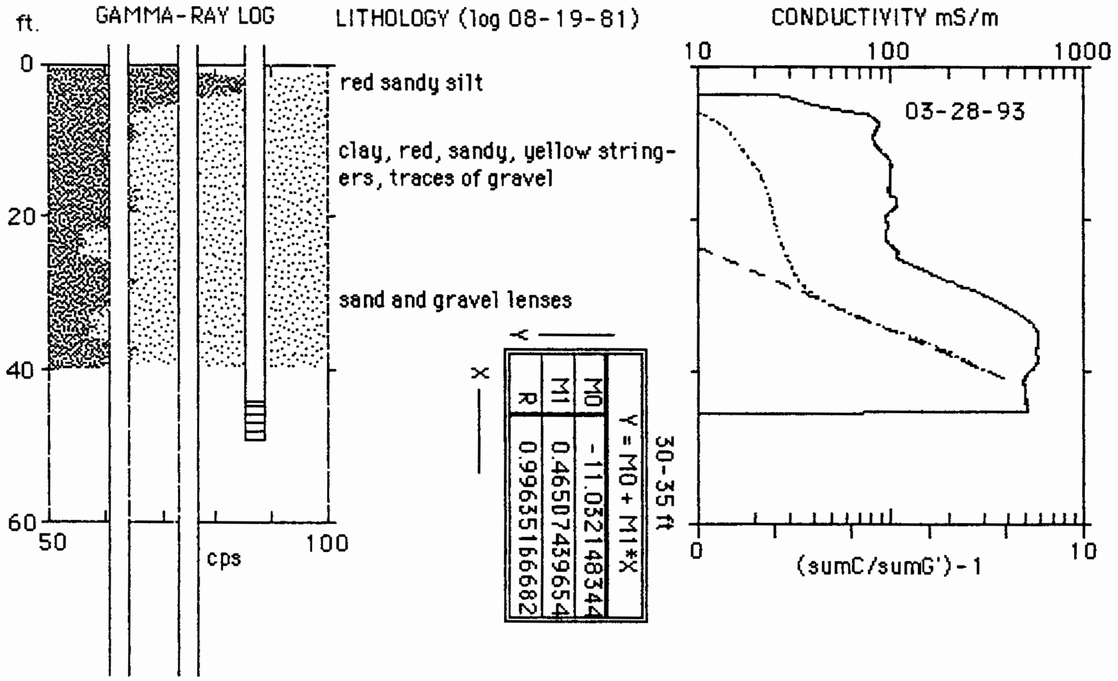
MONITORING SITE 25

23-10-06BBAB

elev= 1780ft. N ⊙



MONITORING SITE 25 23-10-06BBAB elev= 1780ft. N ⊙

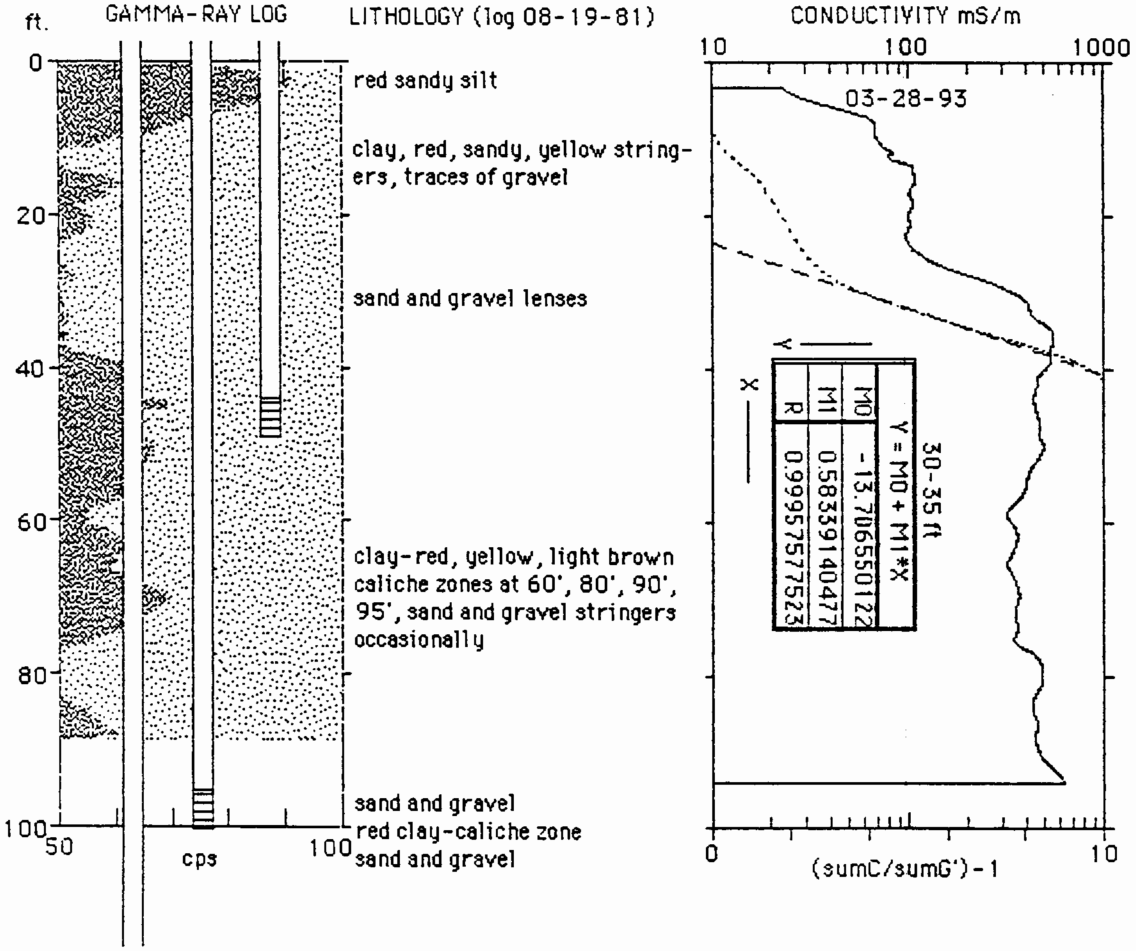


	Y = M0 + M1*X
M0	-11.032148344
M1	0.46507439654
R	0.99635166682

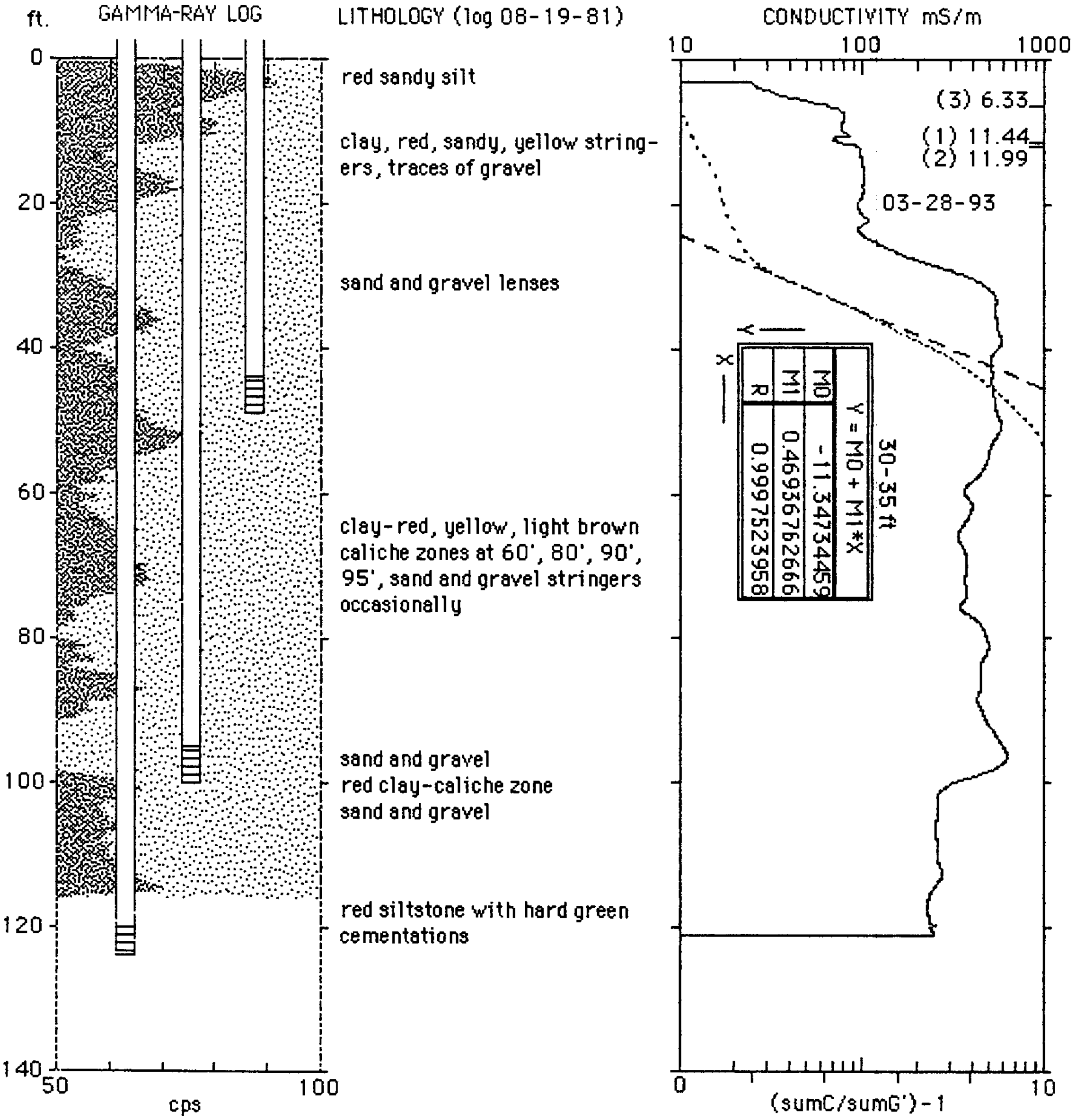
MONITORING SITE 25

23-10-06BBAB

elev= 1780ft. N ⊙



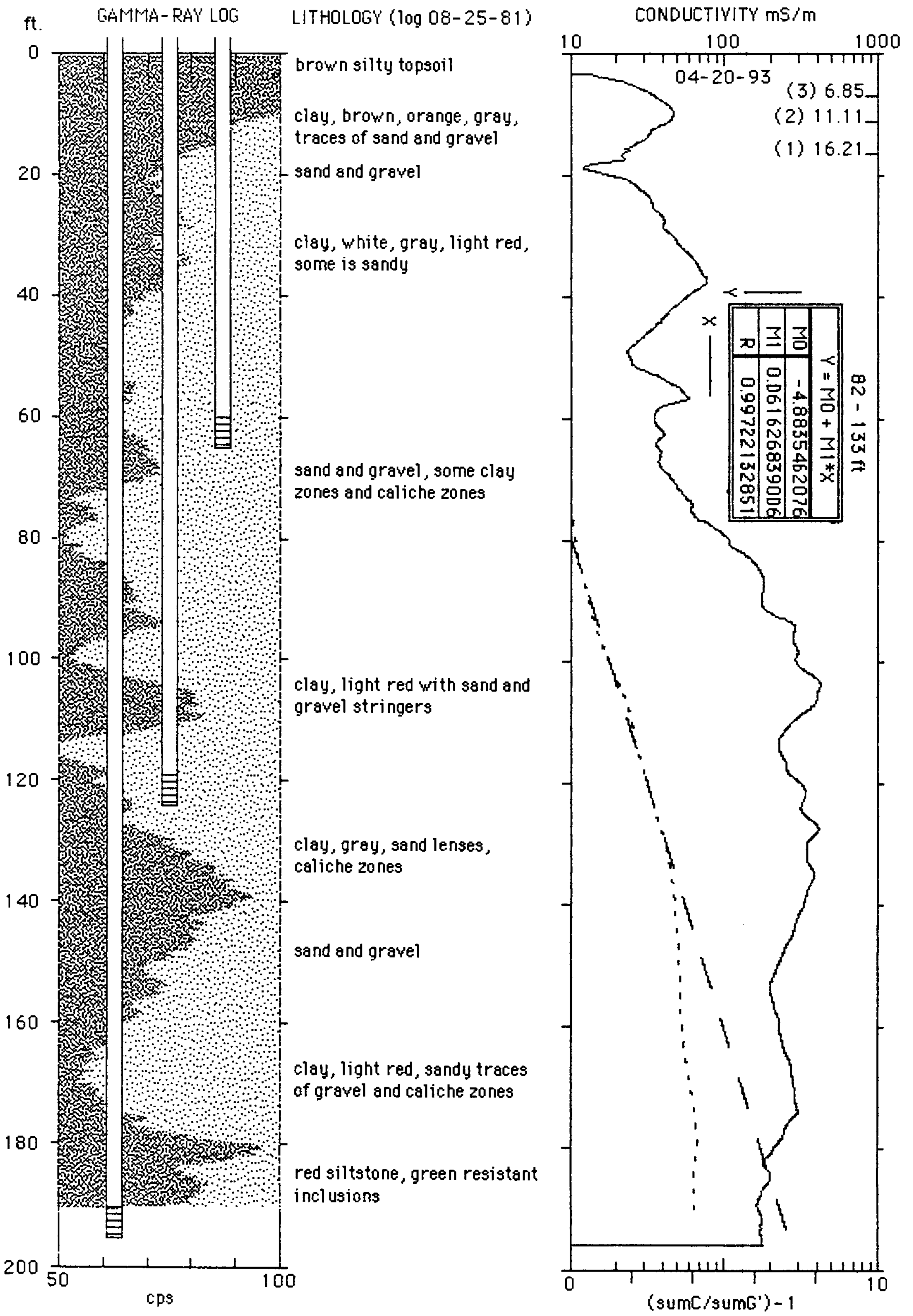
MONITORING SITE 25 23-10-06BBAB elev= 1780ft. N ⊙



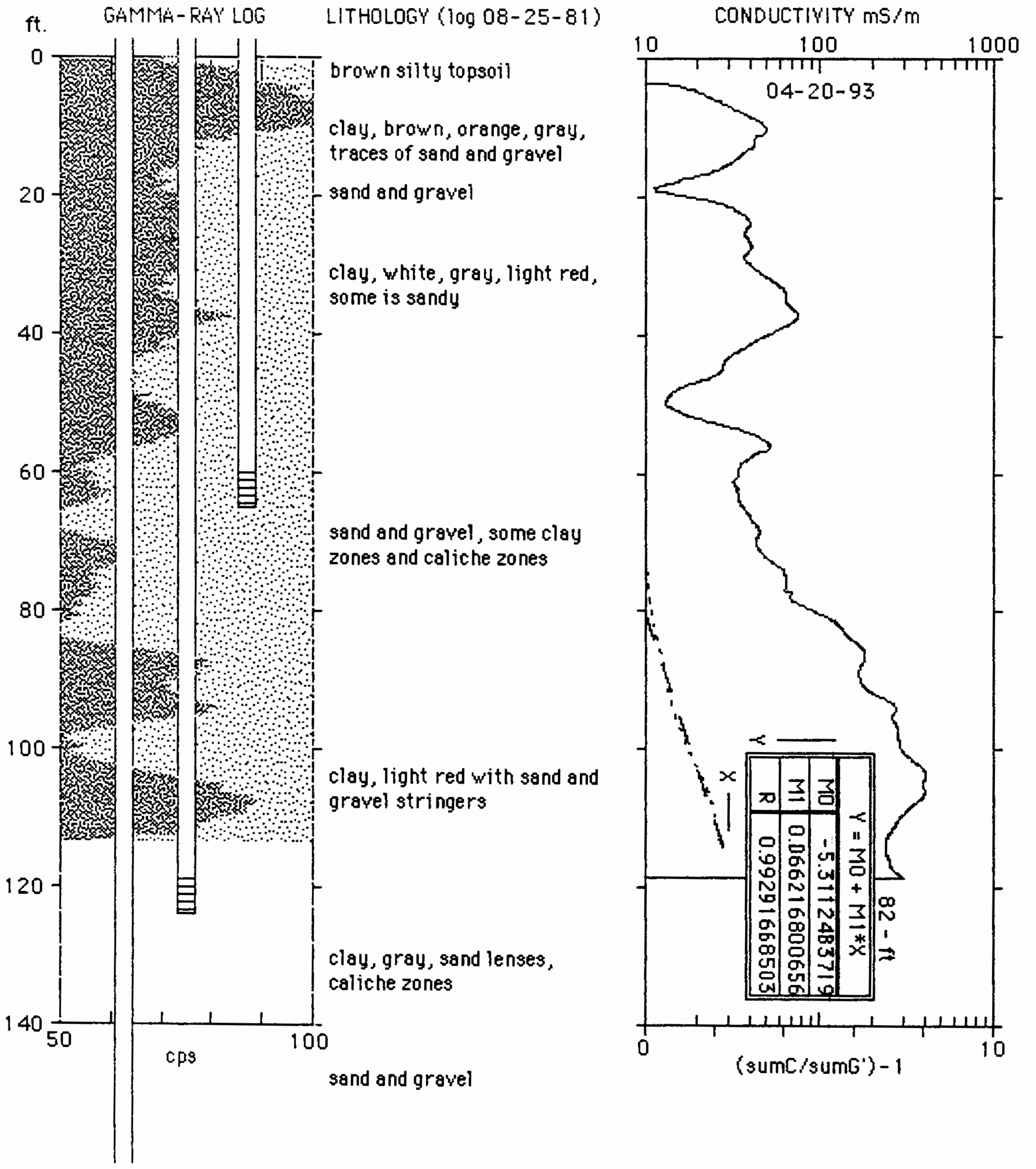
MONITORING SITE 26

23-10-01AAAA

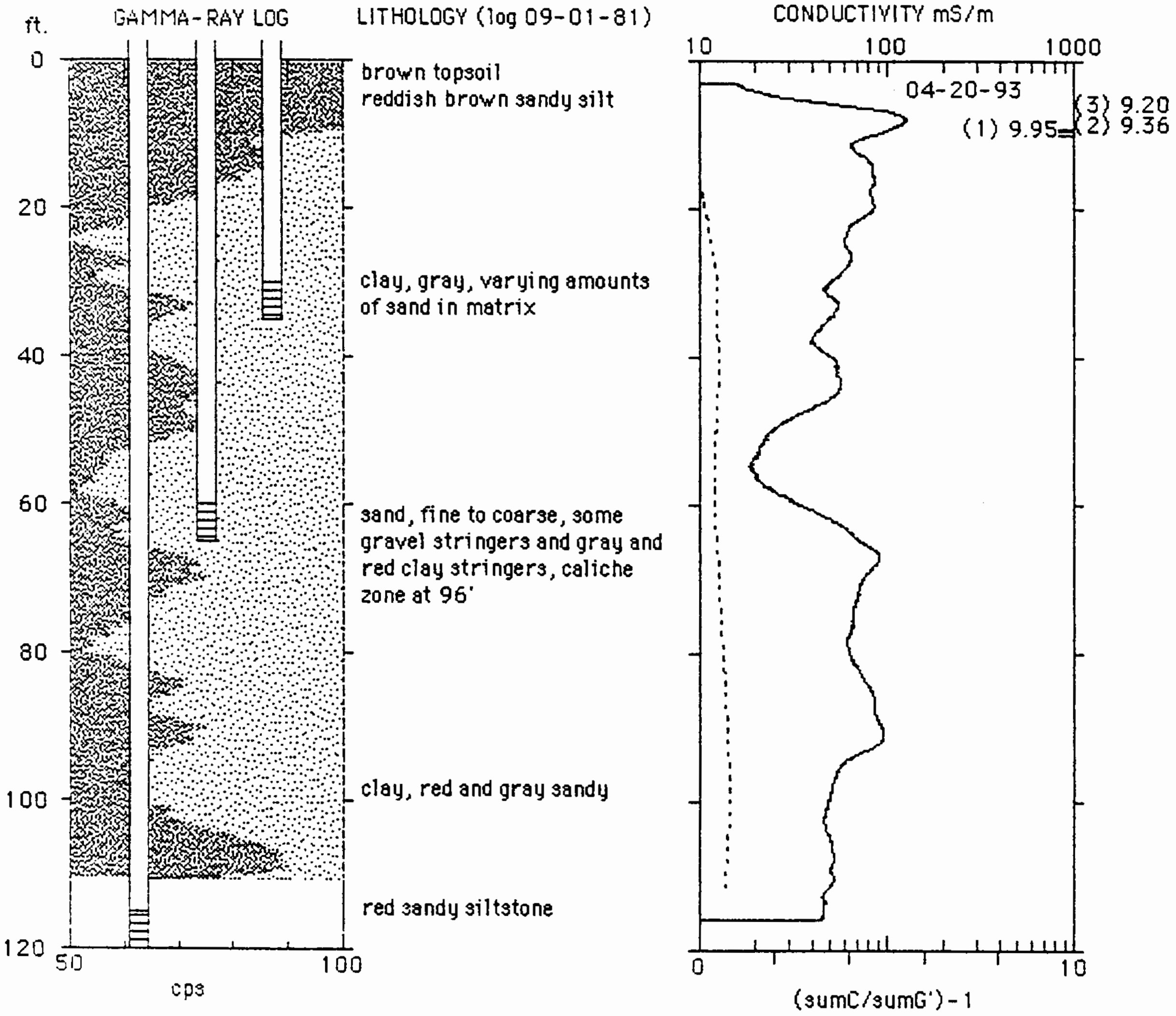
elev=1738 ft. N



MONITORING SITE 26 23-10-01AAAA elev=1738 ft. N



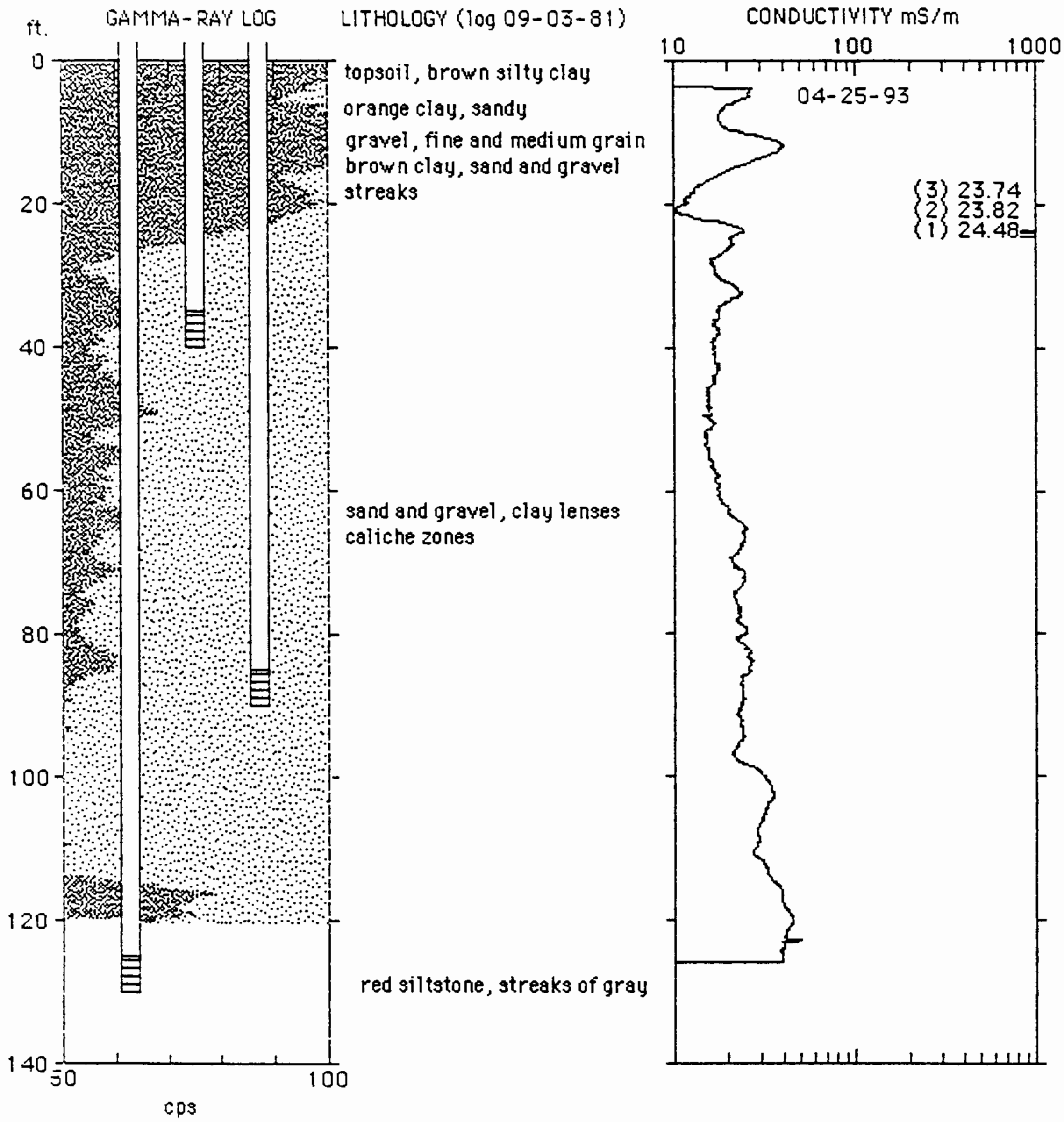
MONITORING SITE 27 23-09-01ADAA elev= 1685 ft. N ⊕



MONITORING SITE 28

25-09-01ADDA

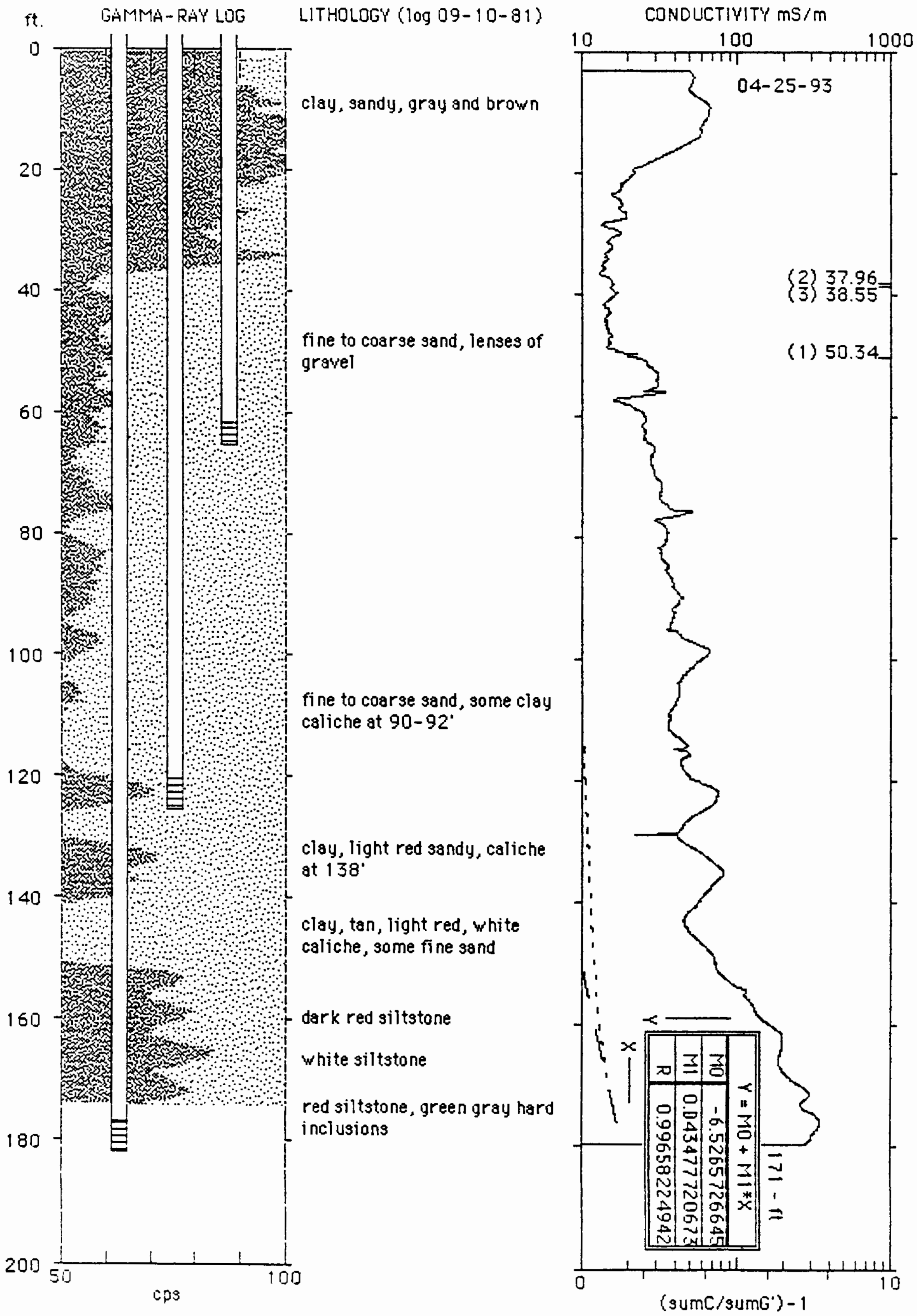
elev=1668 ft. N ⊙



MONITORING SITE 29

24-10-36AAAA

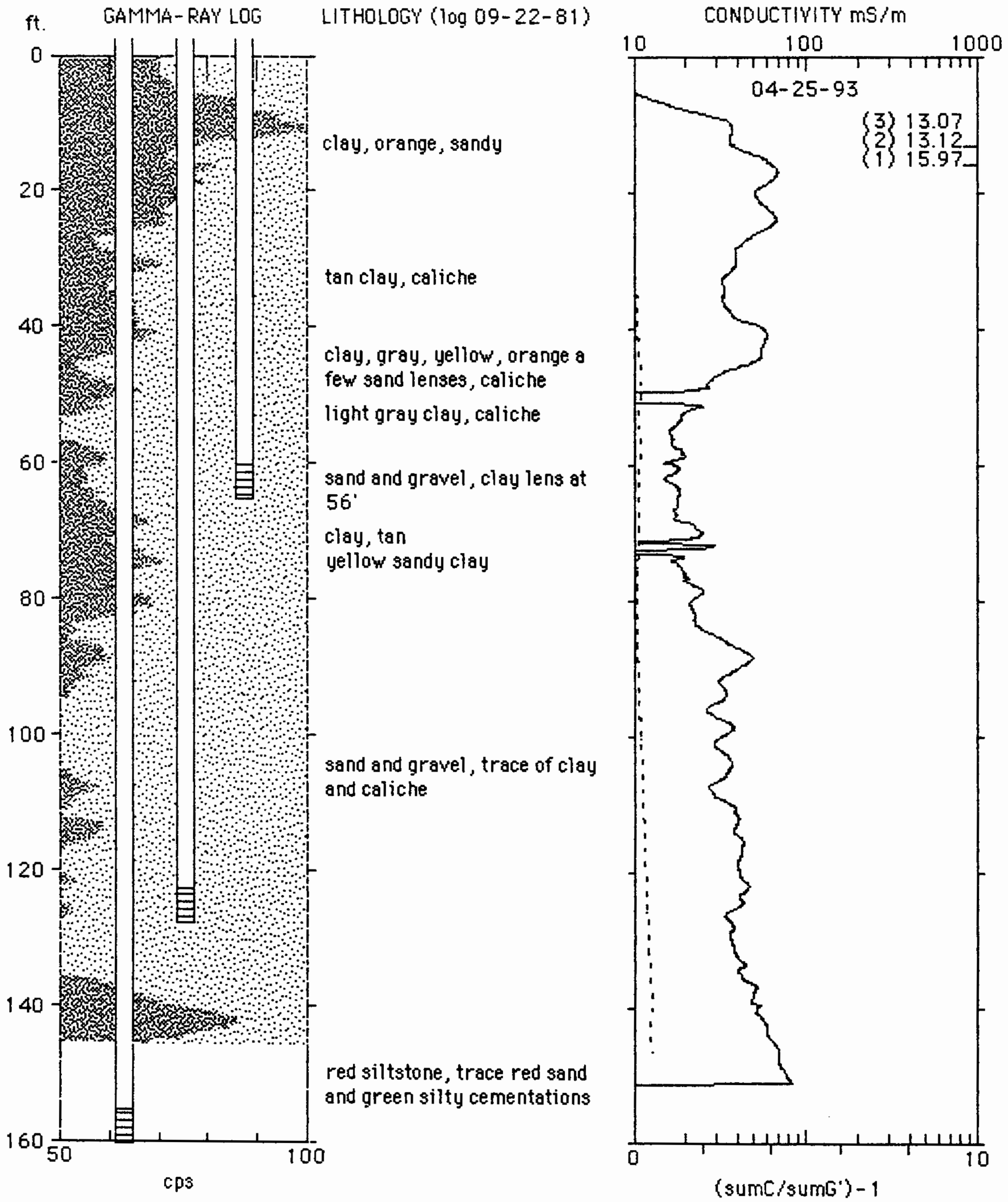
elev=1731 ft. N →



MONITORING SITE 30

23-10-36DAAA

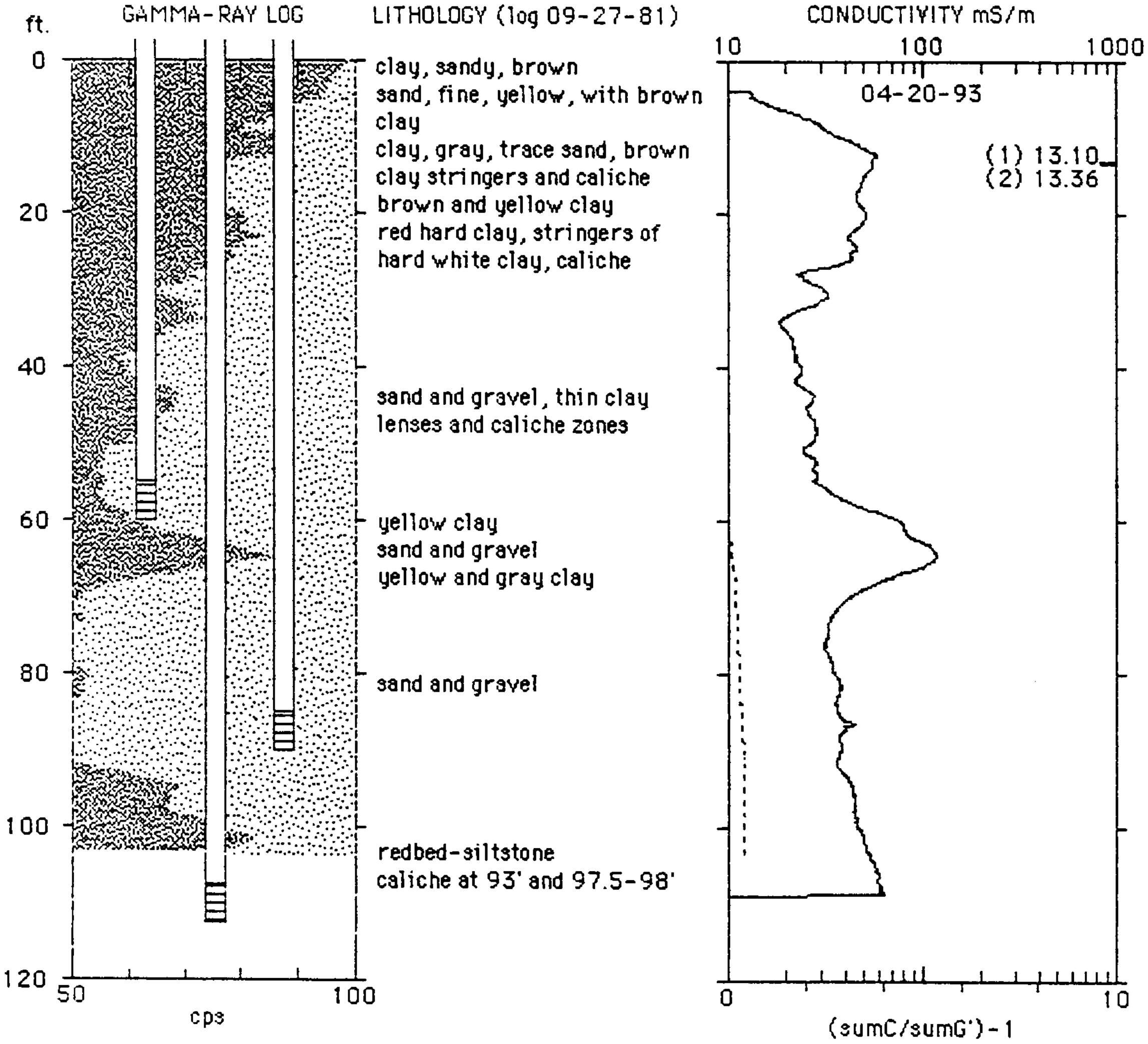
elev=1750 ft. N ⊕



MONITORING SITE 31

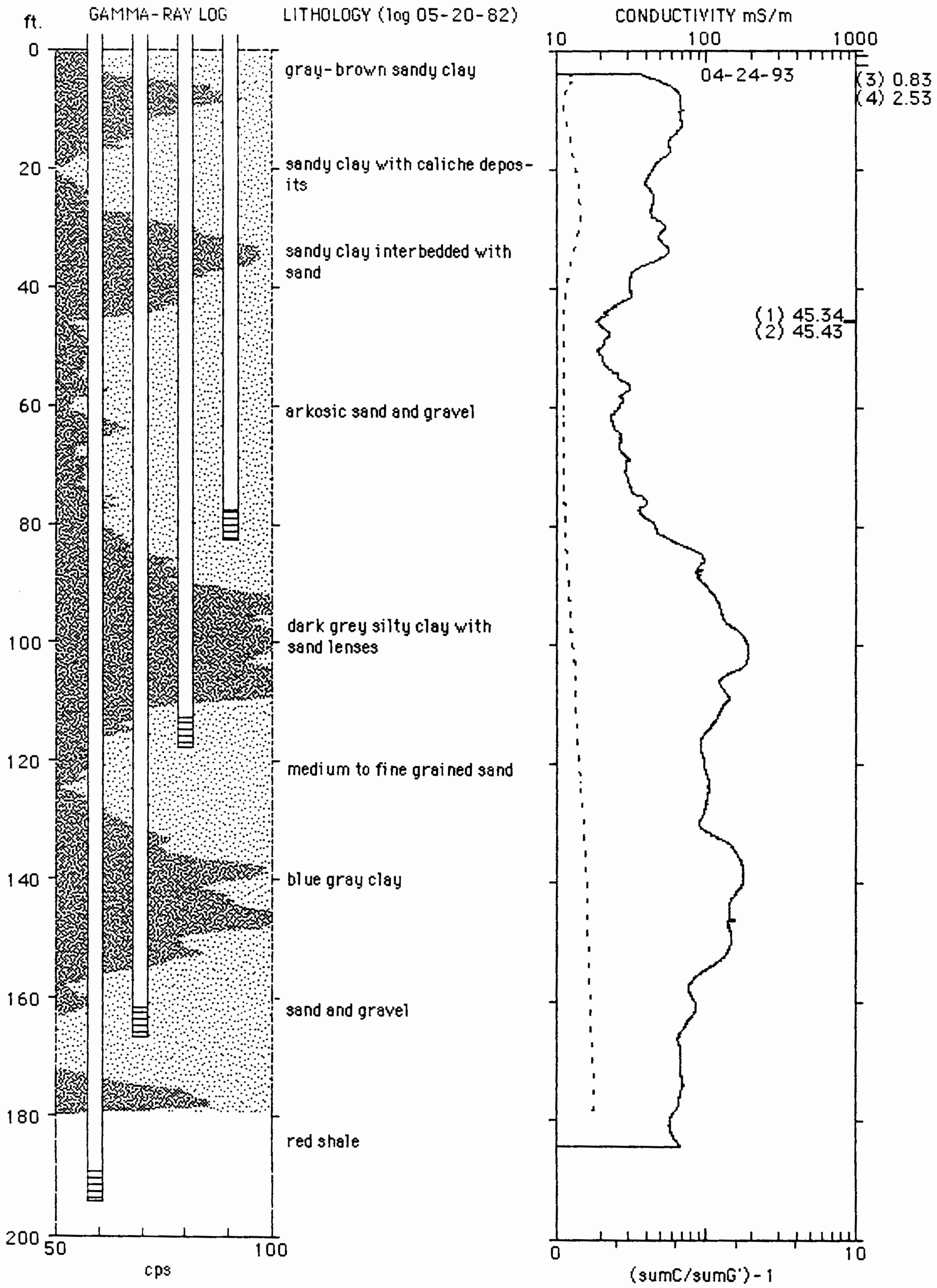
22-09-01ADAA

elev= 1665 ft. N ←



MONITORING SITE 32

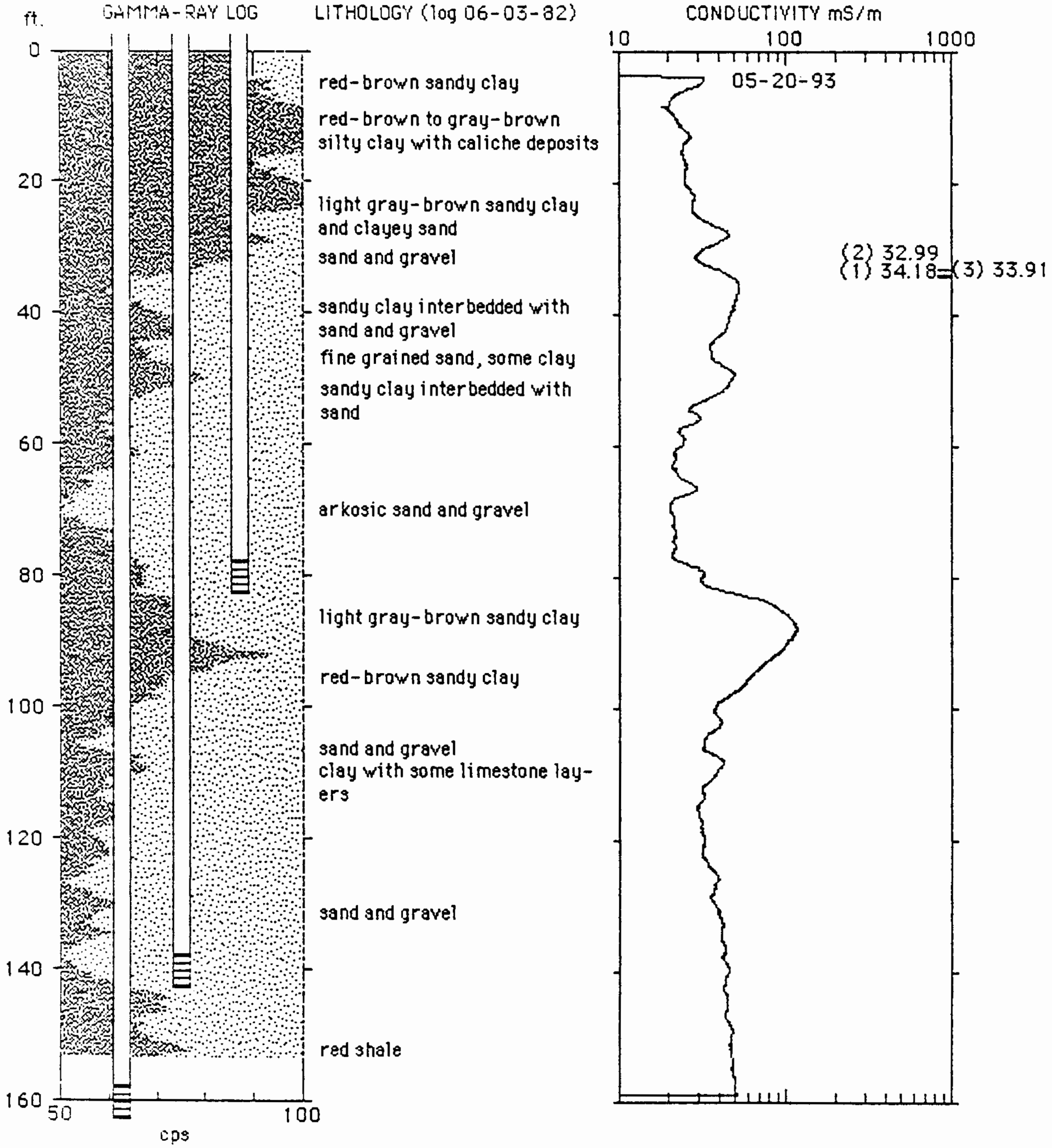
23-09-25DDDD elev=1689 ft. N ⊕



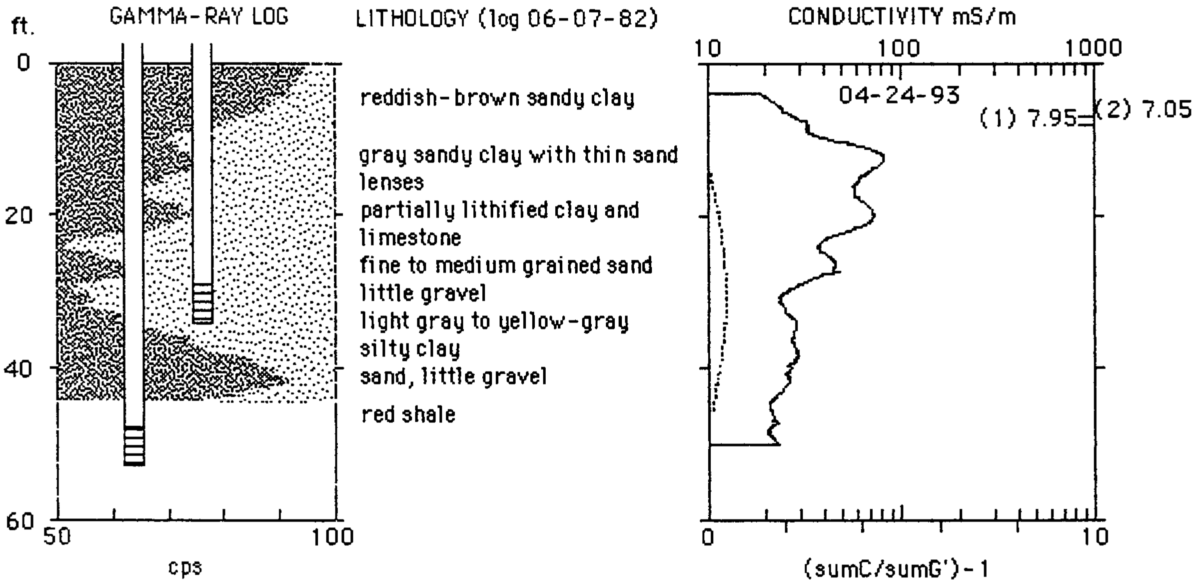
MONITORING SITE 33

25-12-36CBBA

elev= 1872 ft. N ⊕



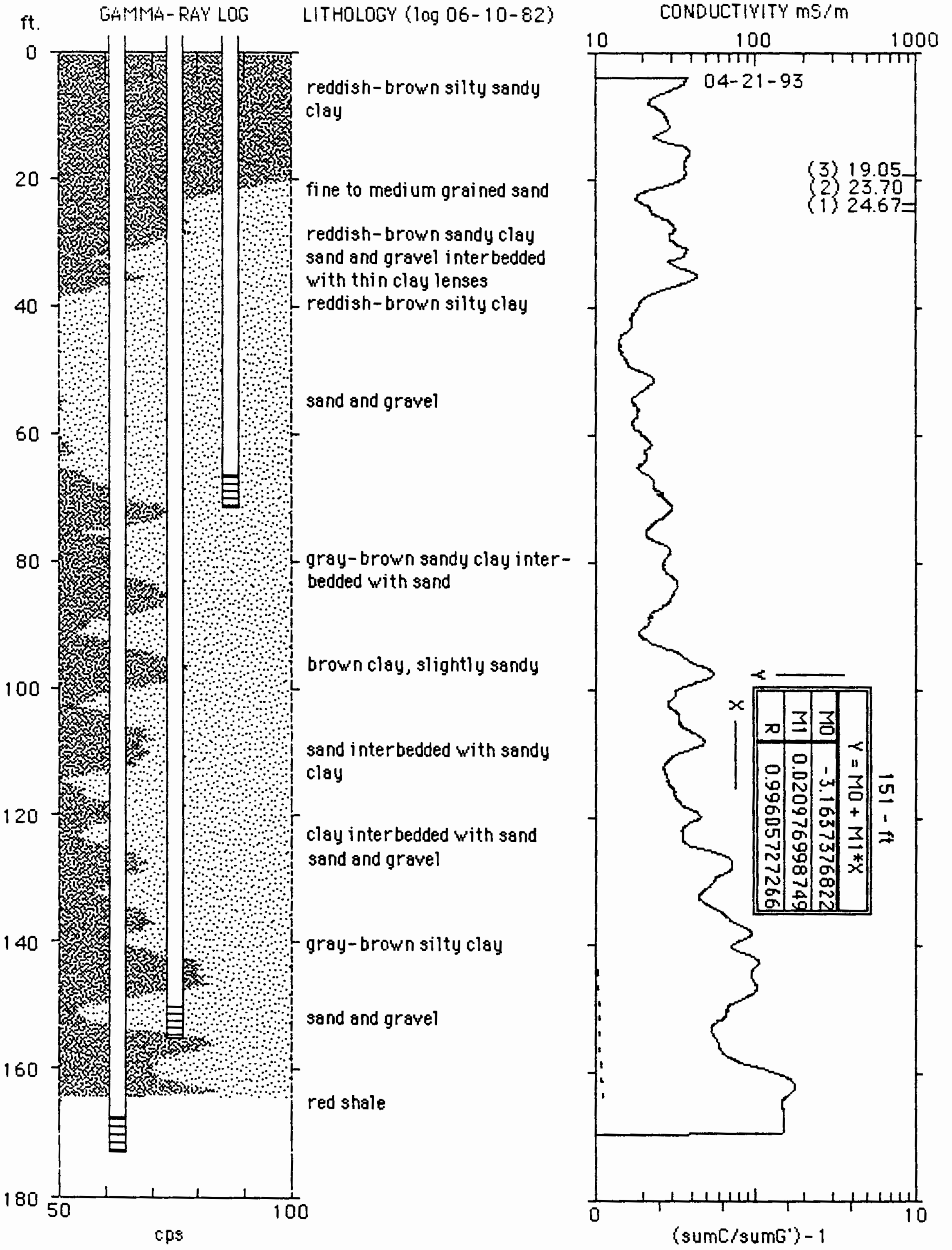
MONITORING SITE 34   25-09-36DDCC   elev=1653 ft. N⊕



MONITORING SITE 35

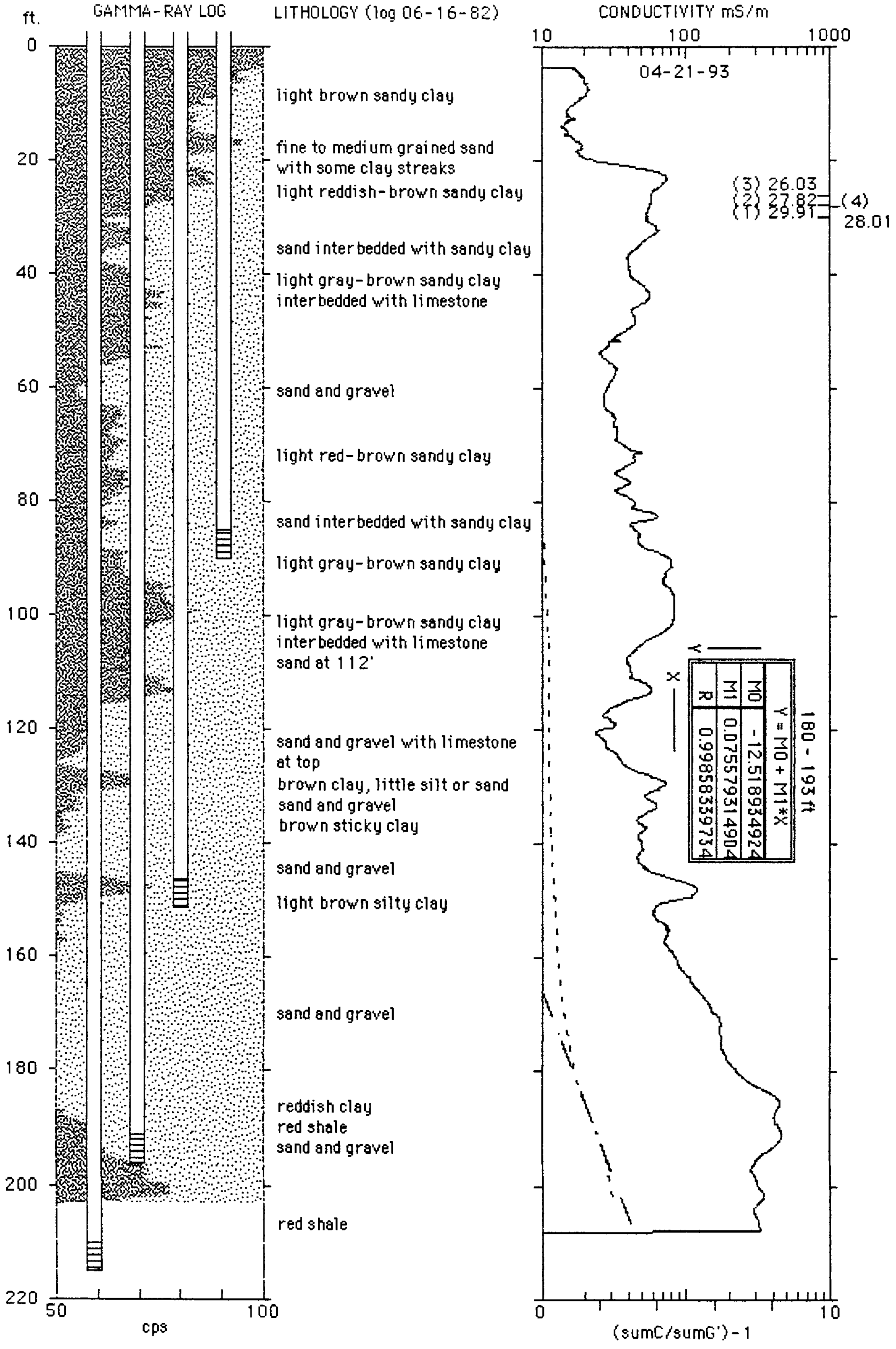
26-10-31CCCB

elev=1760 ft. N



MONITORING SITE 36

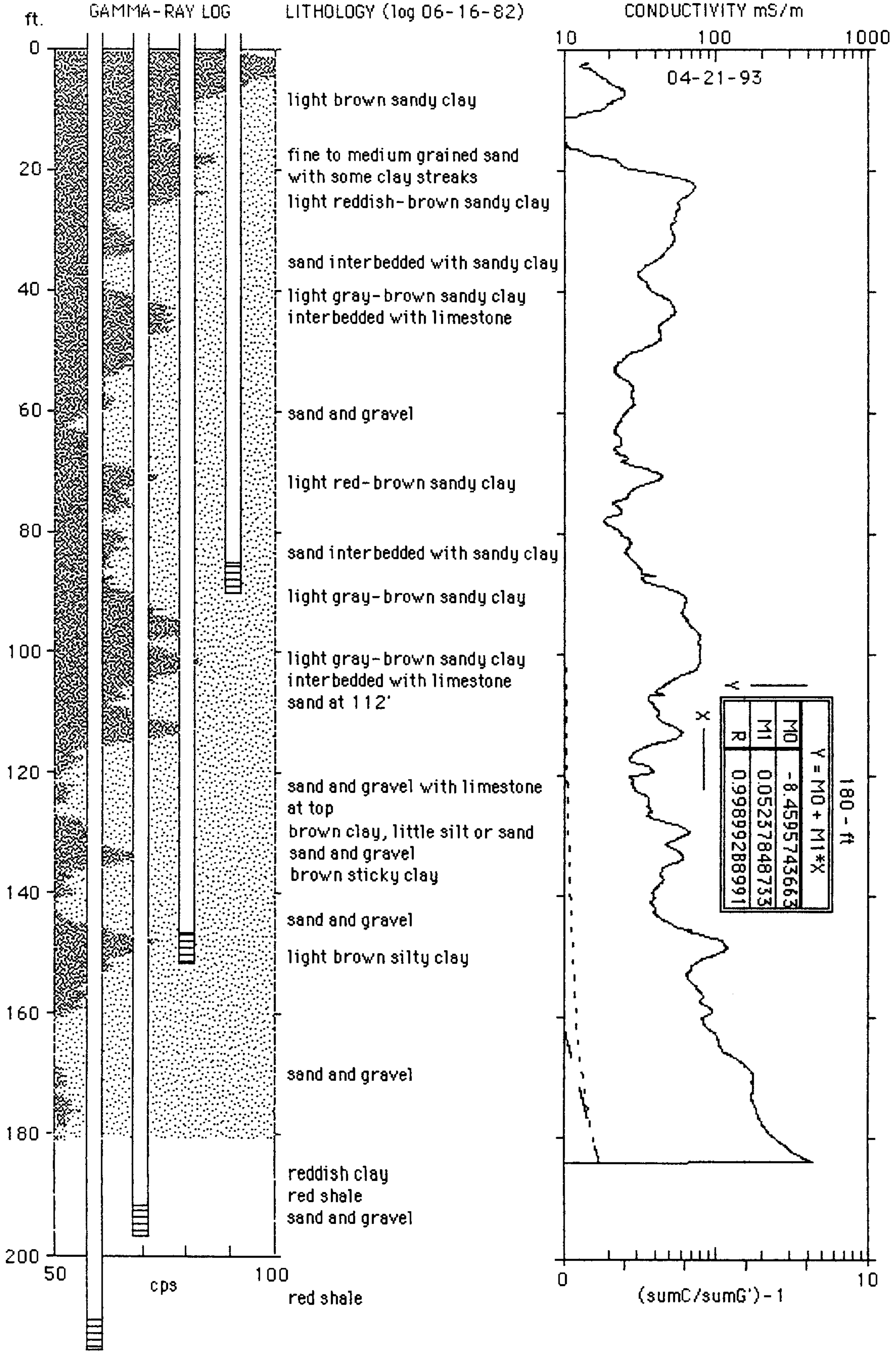
27-12-06BAAB elev=1892 ft. N ⊙



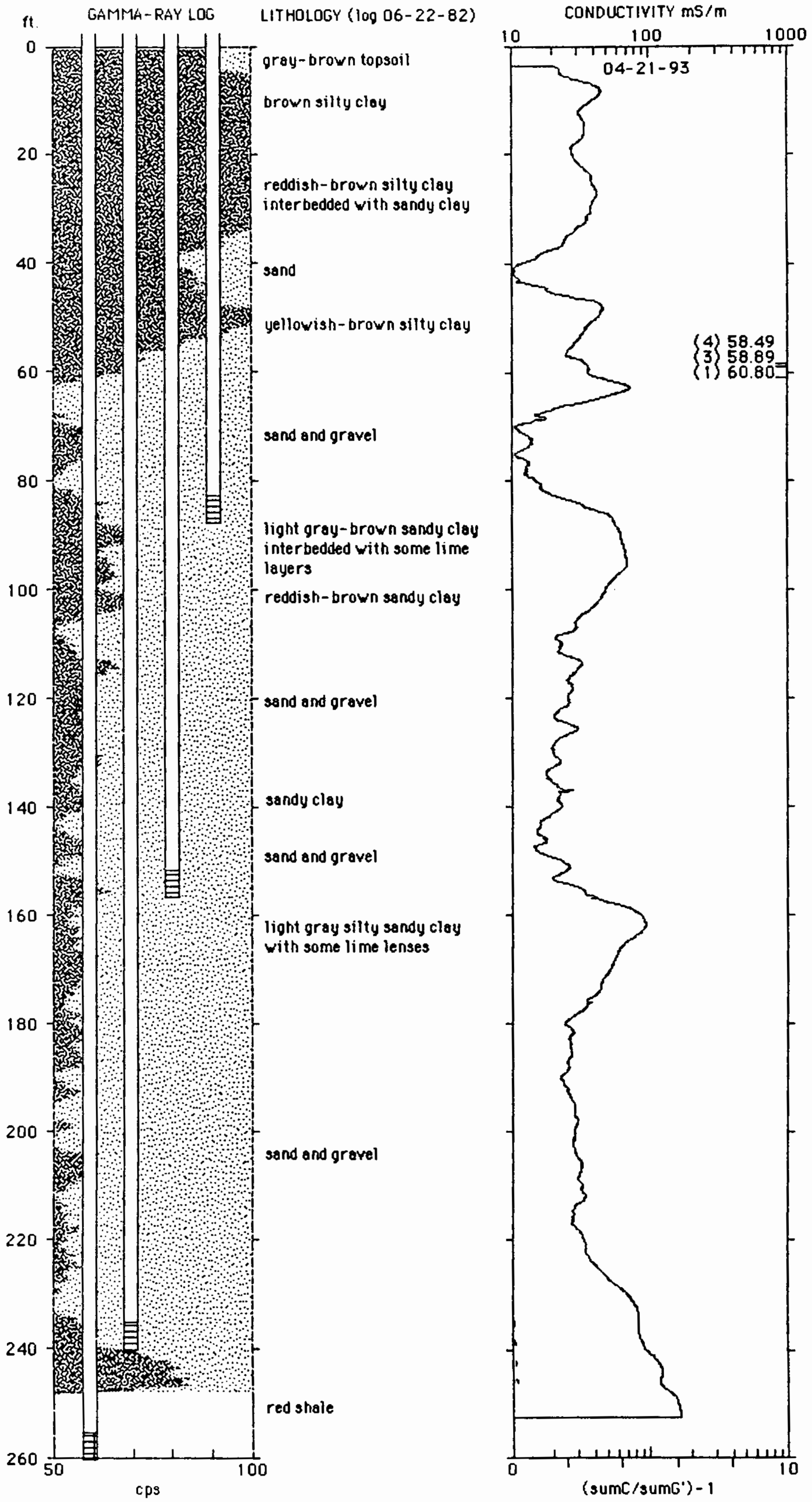
MONITORING SITE 36

27-12-06BAAB

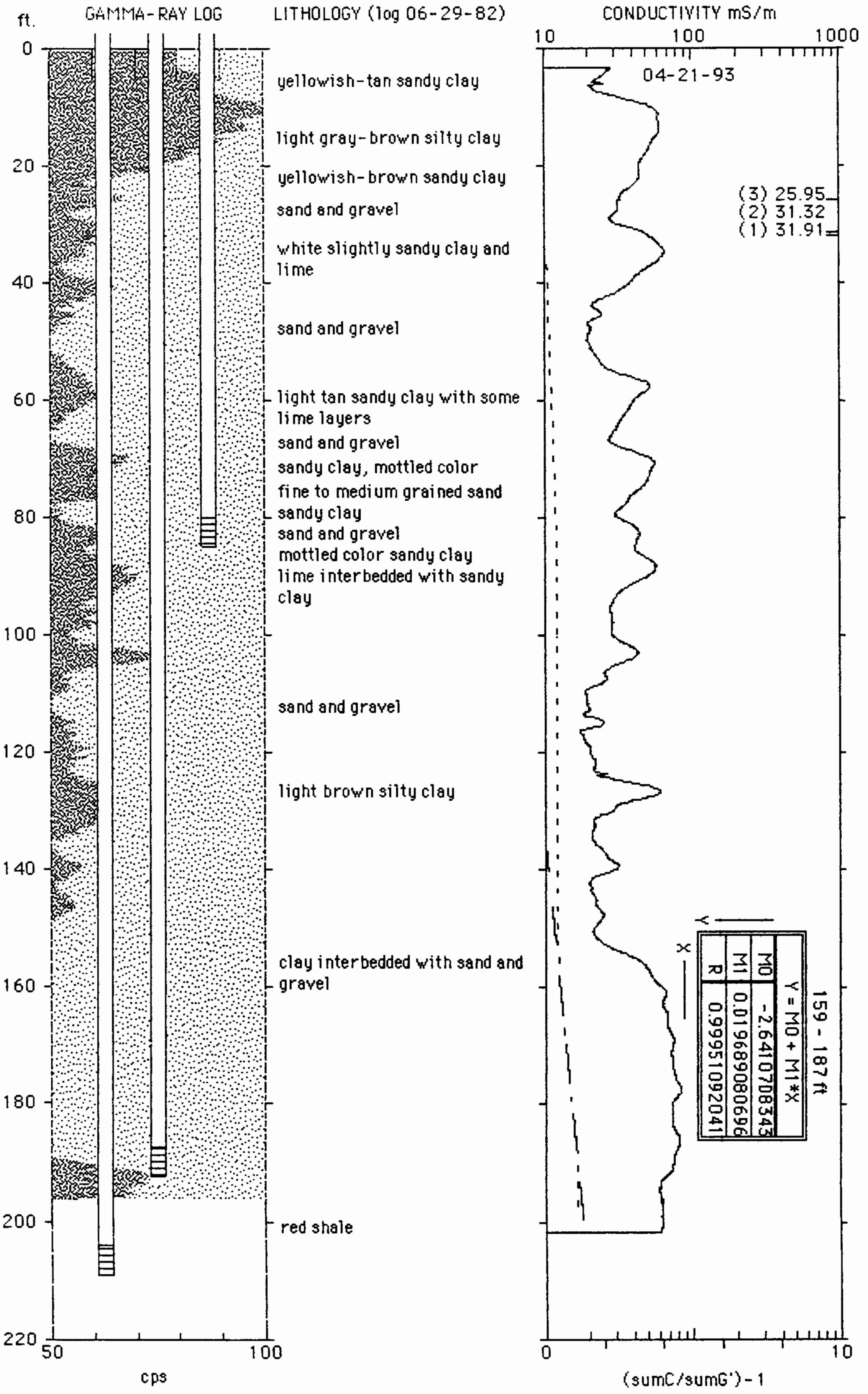
elev=1892 ft. N ⊙



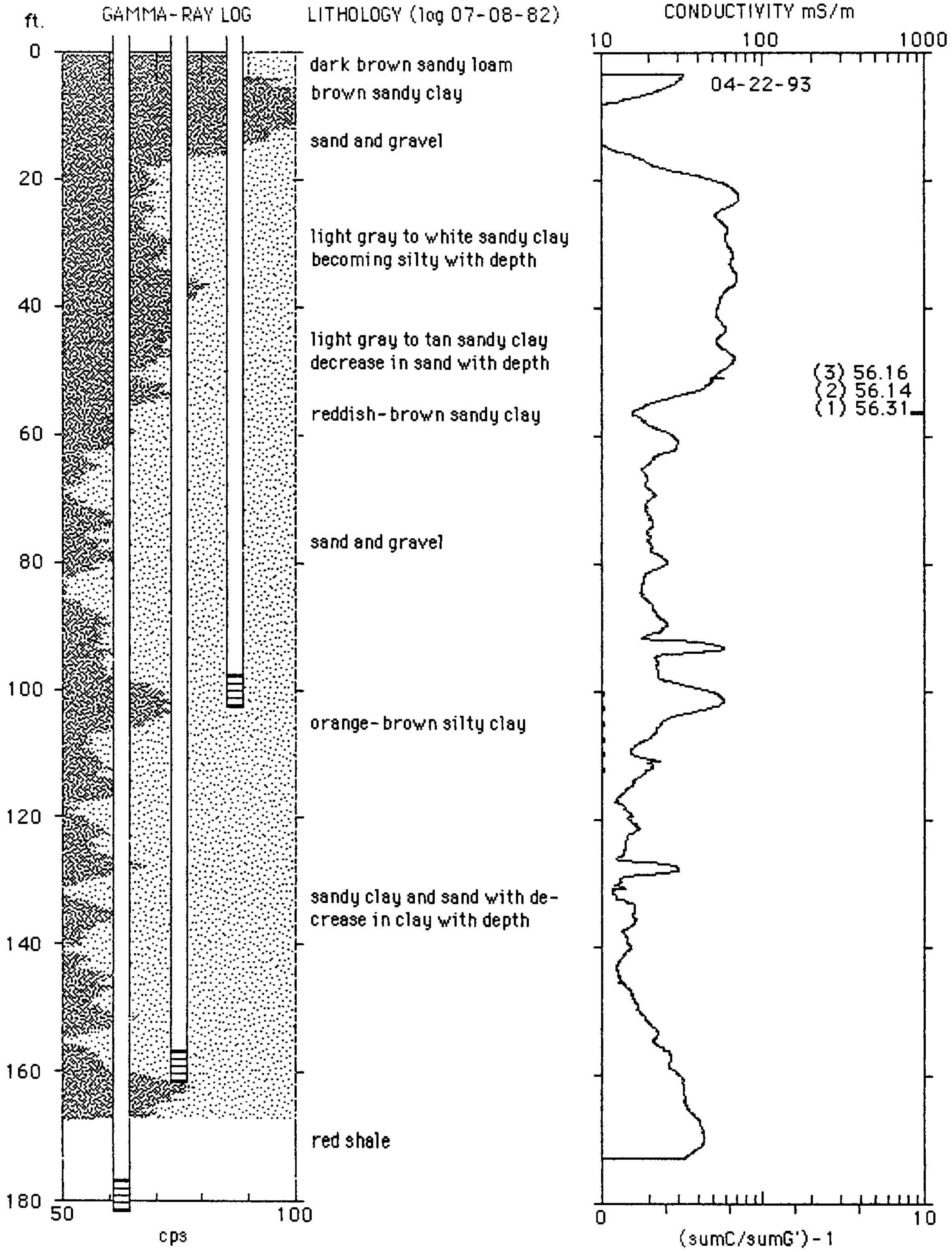
MONITORING SITE 37 27-13-05CABB elev=1971 ft. N ◄—



MONITORING SITE 38 26-12-36ADDA elev=1843.6 ft. N →



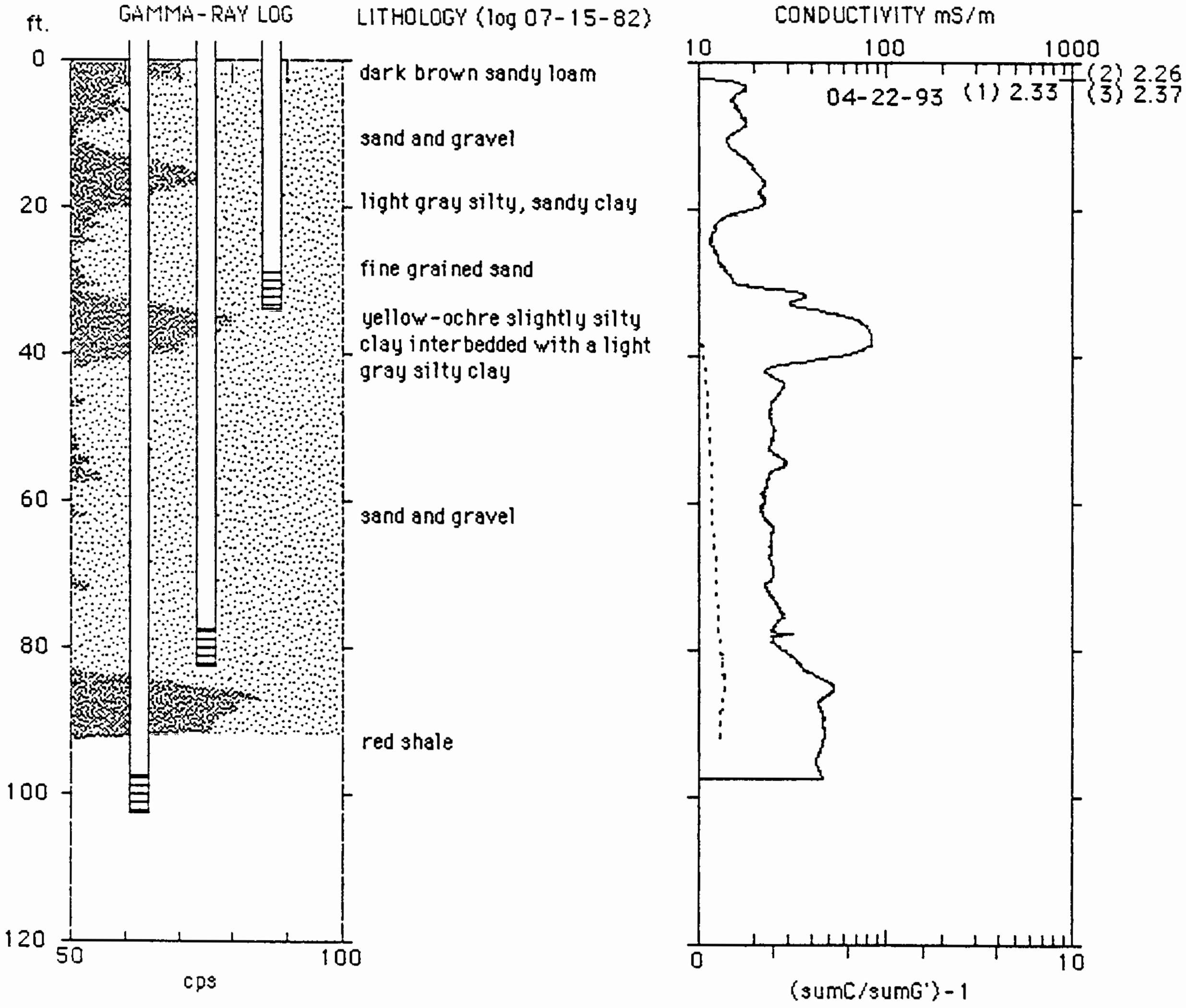
MONITORING SITE 40 26-09-31CDDD elev=1735 ft. N →



MONITORING SITE 41

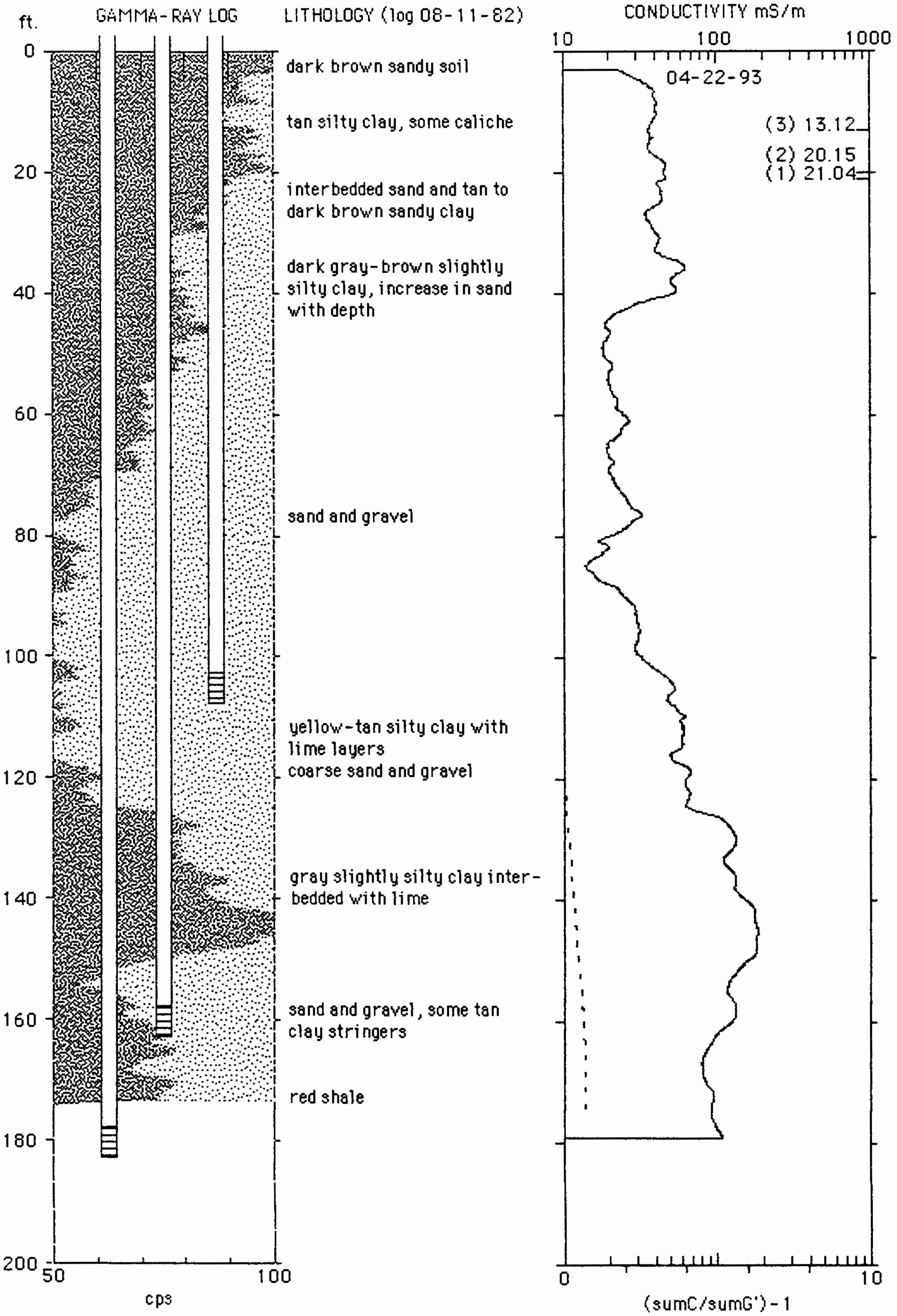
26-09-35ADAD

elev=1654ft. N ⊕

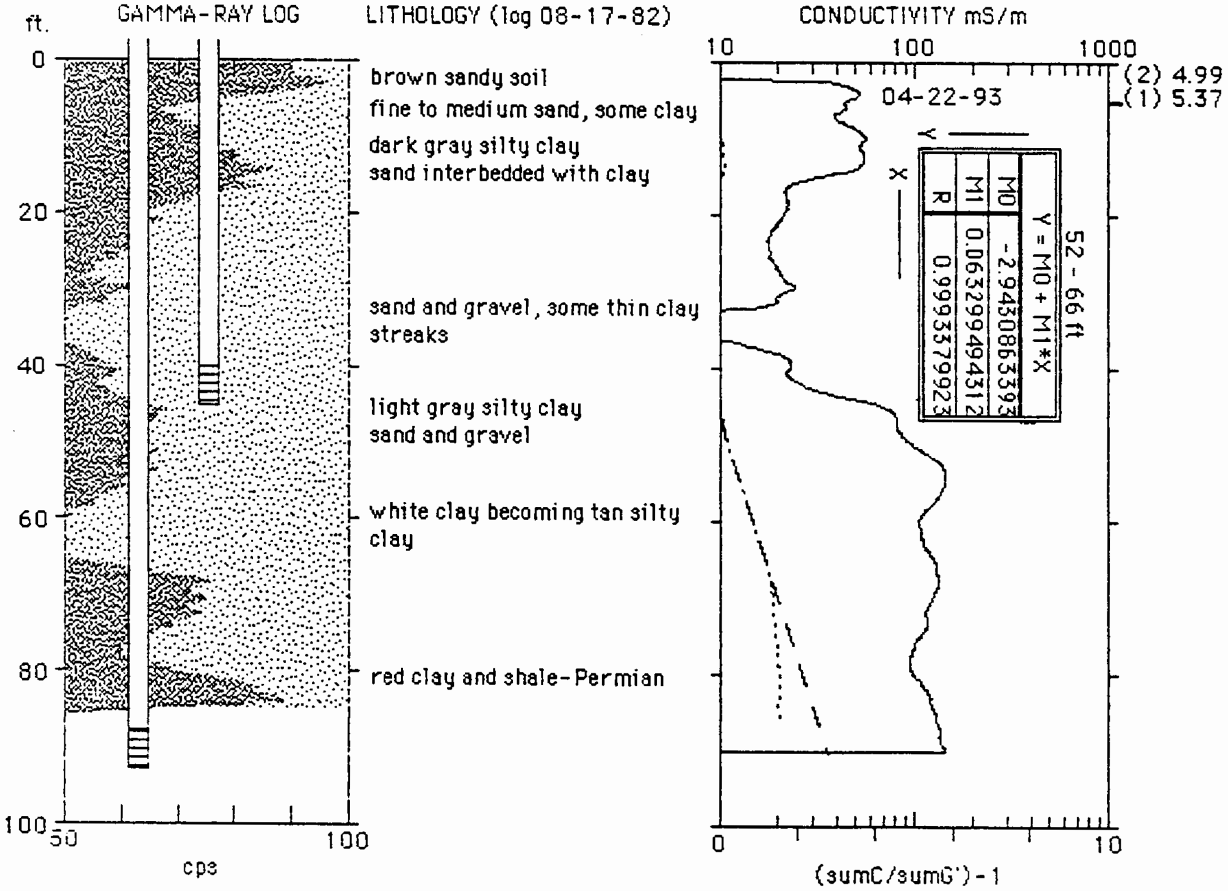


MONITORING SITE 42

28-13-01CBAA elev= 1829 ft. N



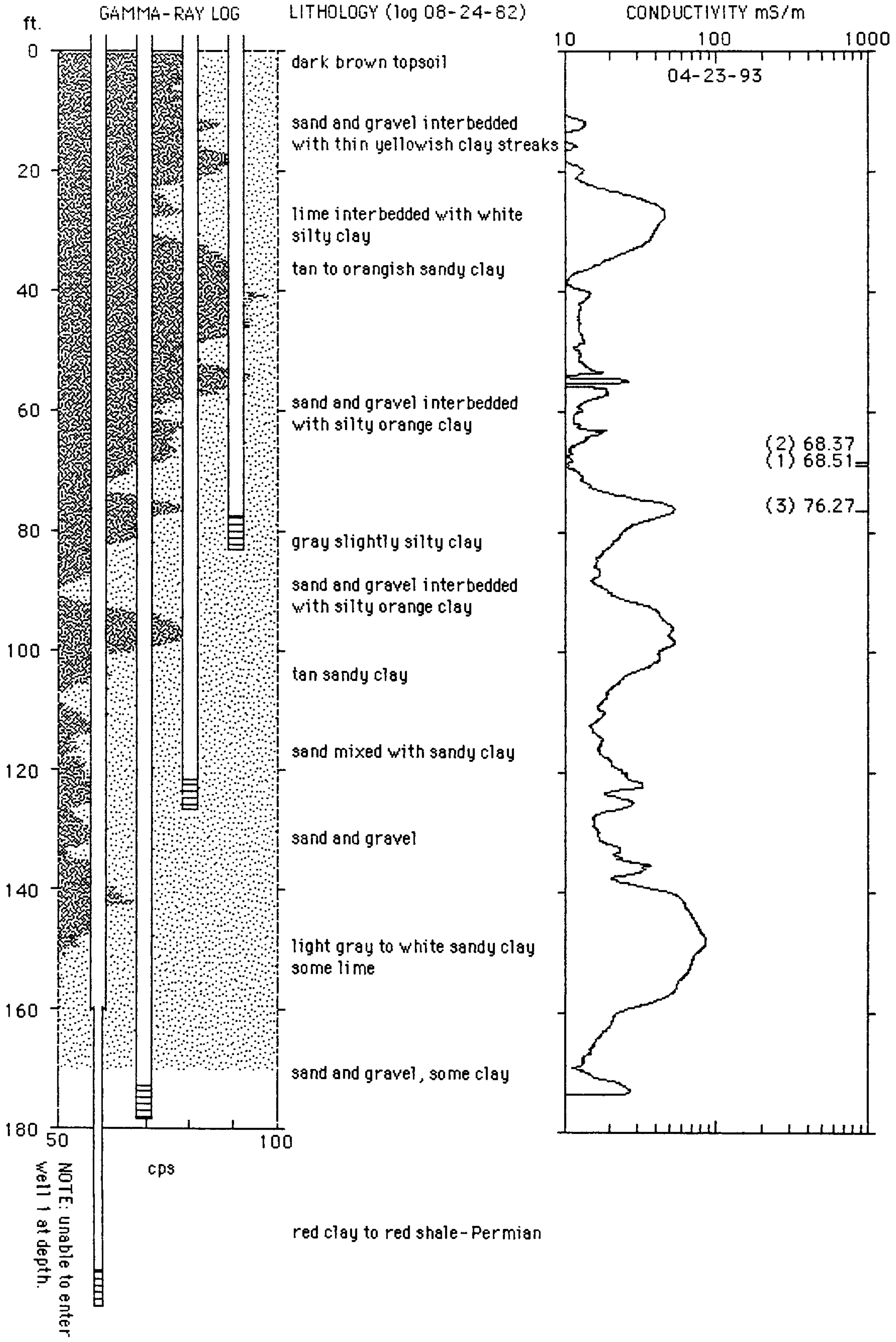
MONITORING SITE 43 27-13-31DDDD elev= 1872 ft N →



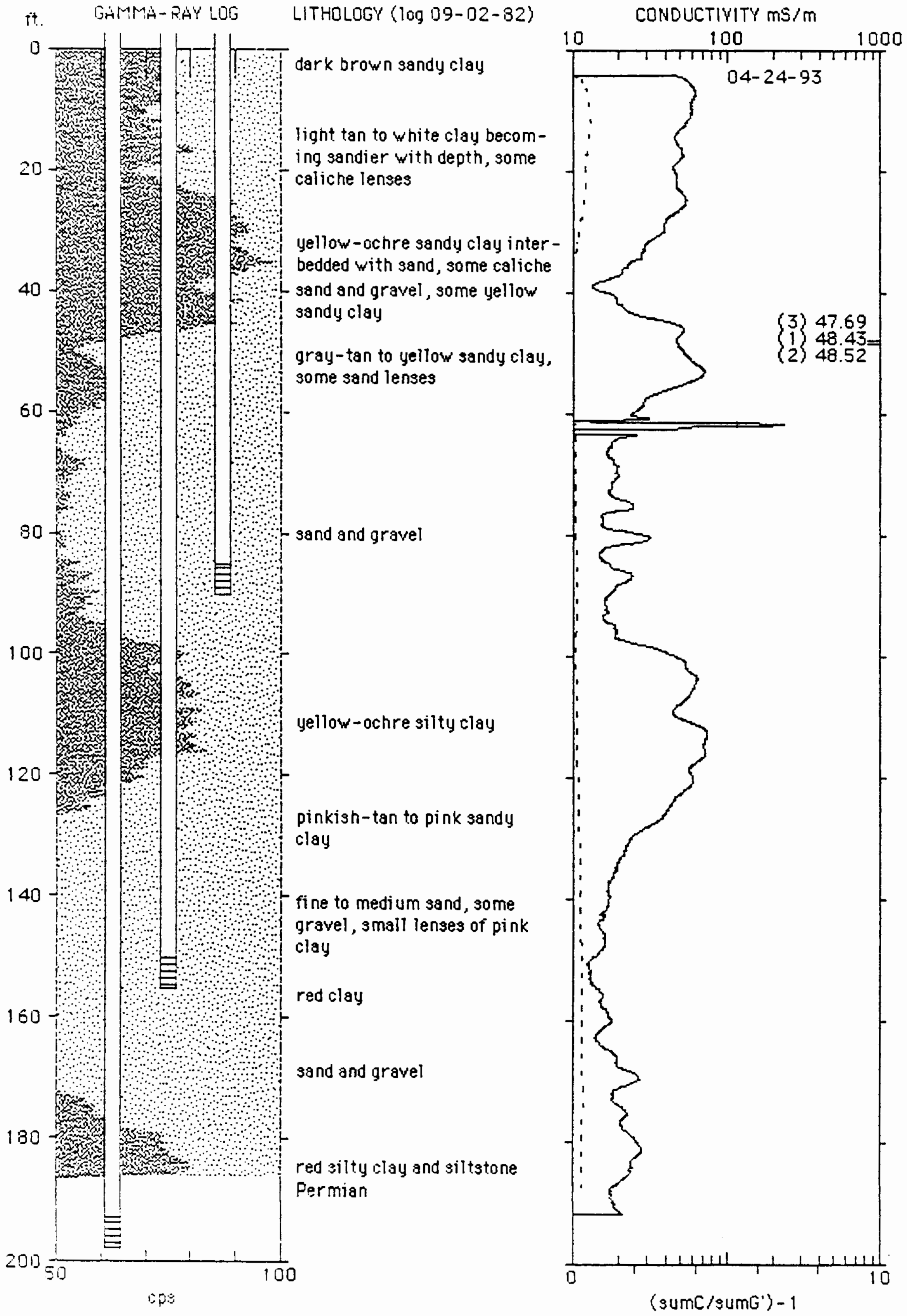
MONITORING SITE 44

29-13-35ABBA

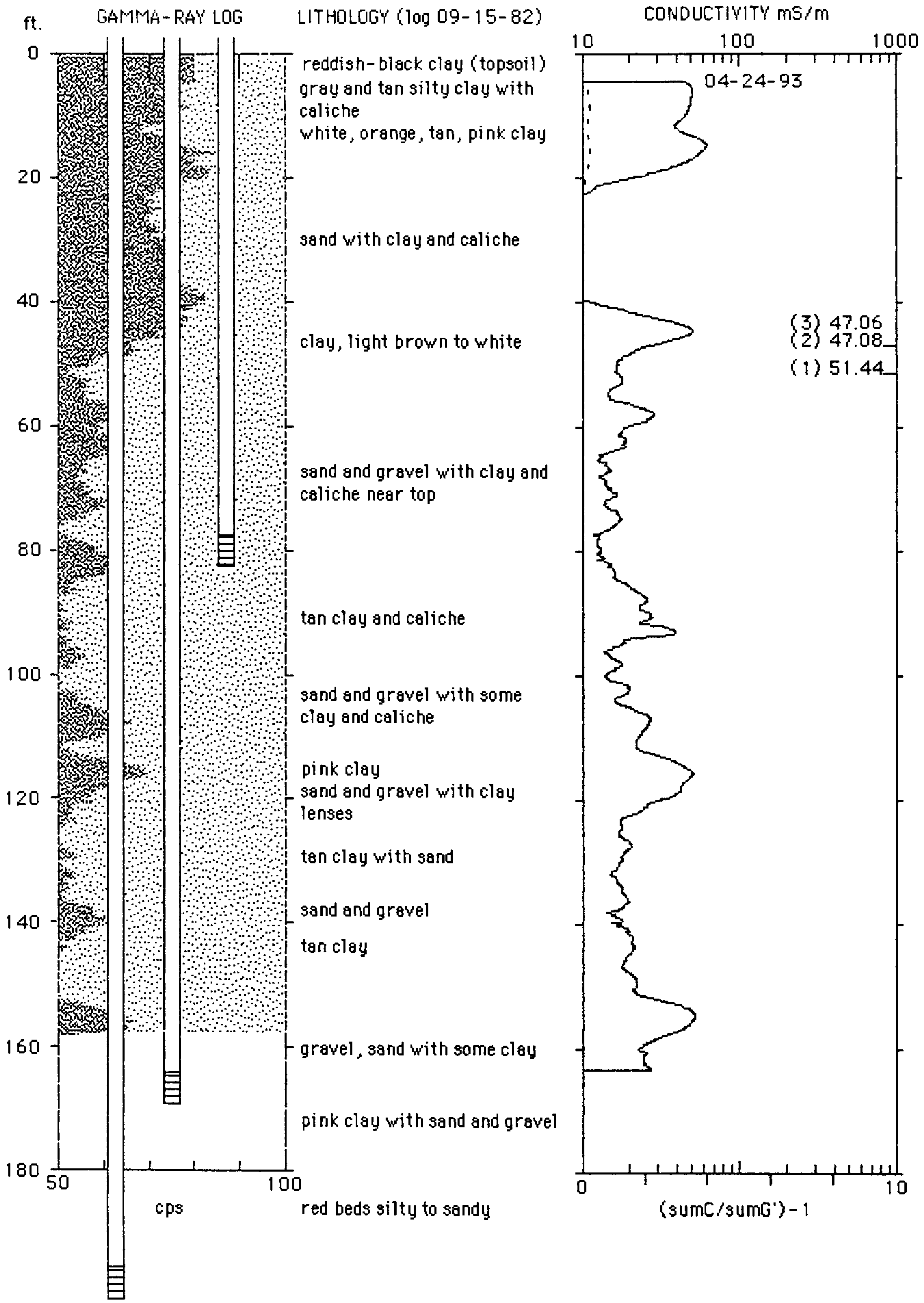
elev= 1891ft. N ⊙



MONITORING SITE 45 29-11-01DADA elev= 1795 ft. N ⊕



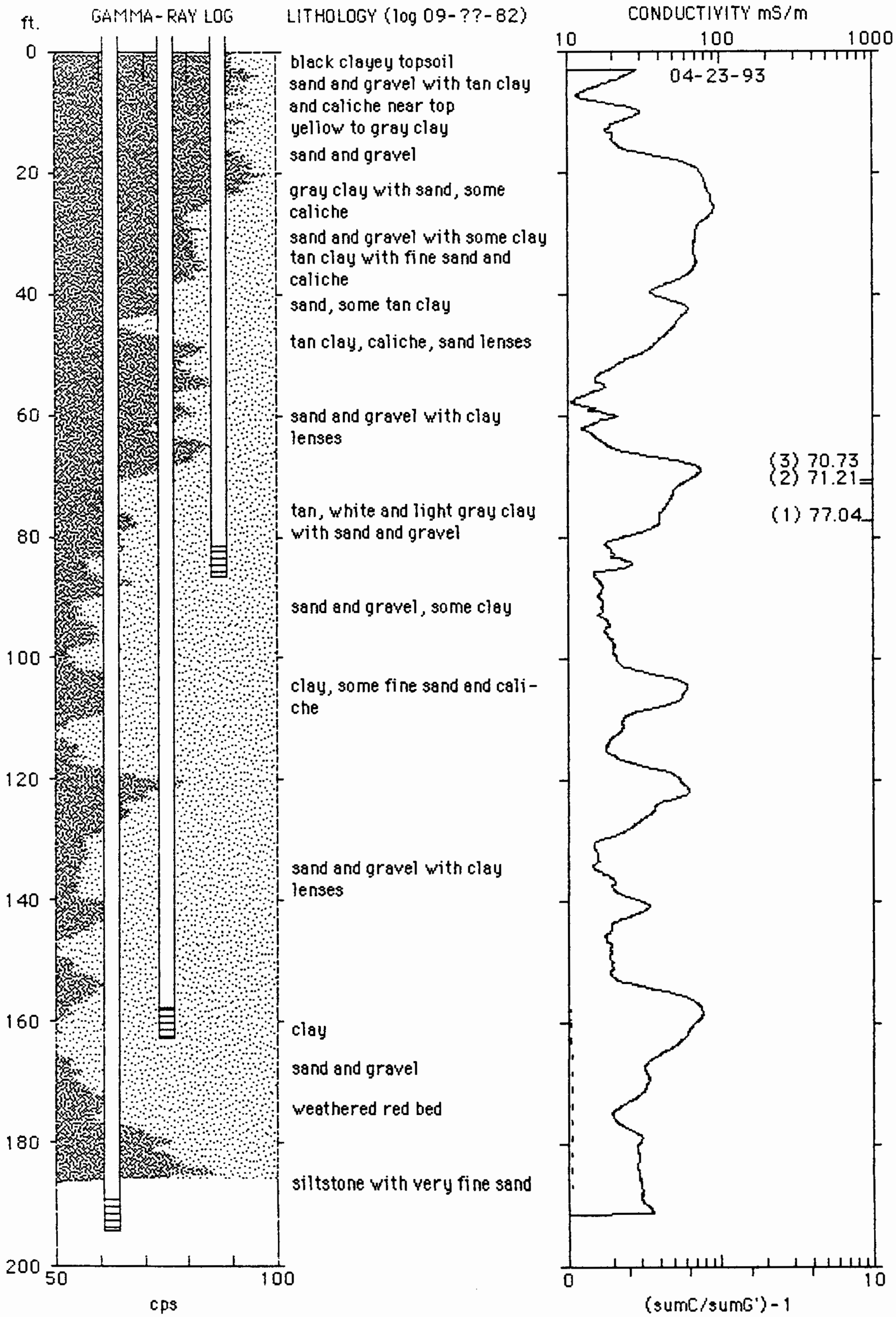
MONITORING SITE 46 29-11-06AAAB elev= 1830ft. N ⊕



MONITORING SITE 47

29-13-12ABBA

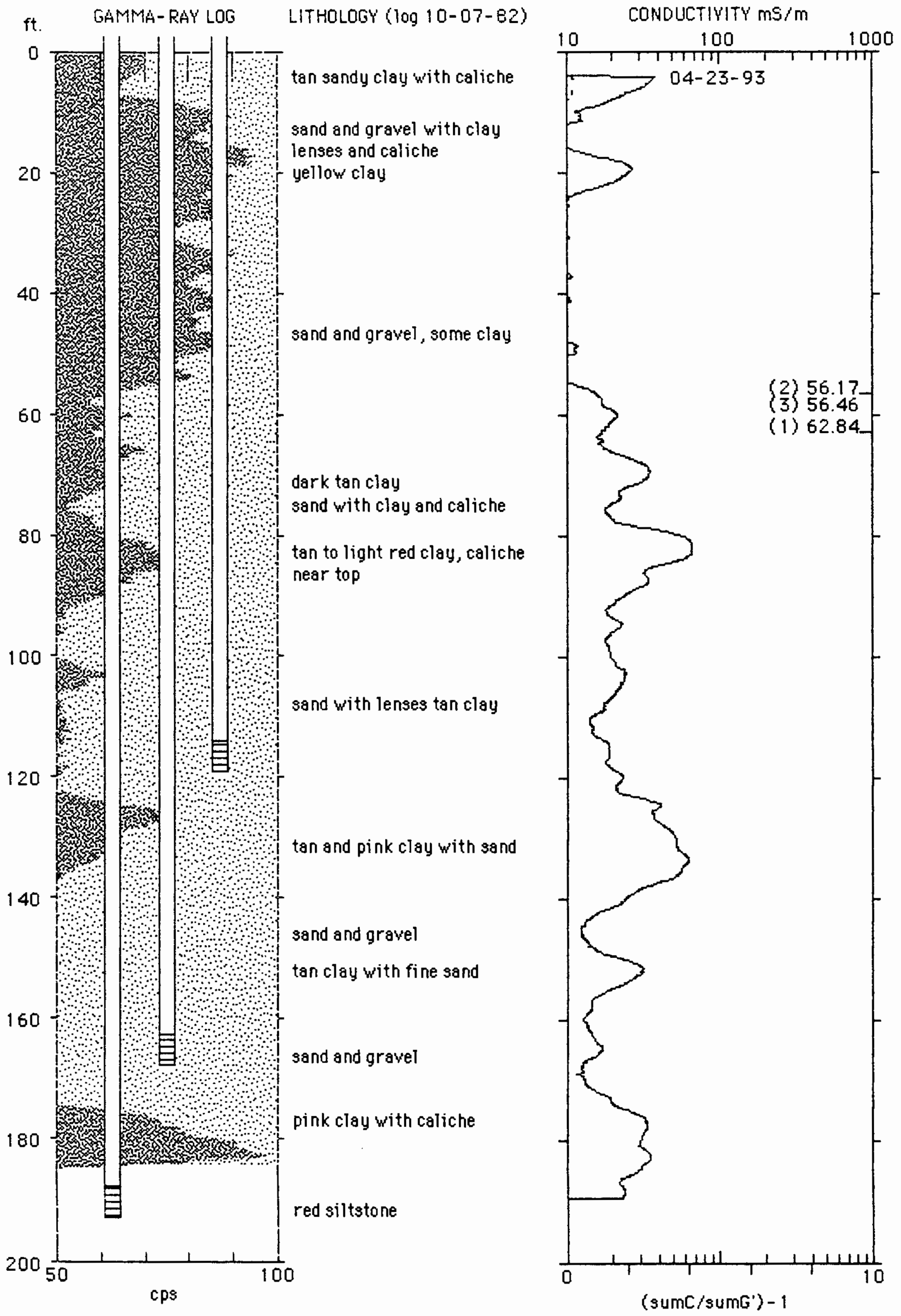
elev= 1900 ft. N ⊕



MONITORING SITE 48

29-12-36DCCD

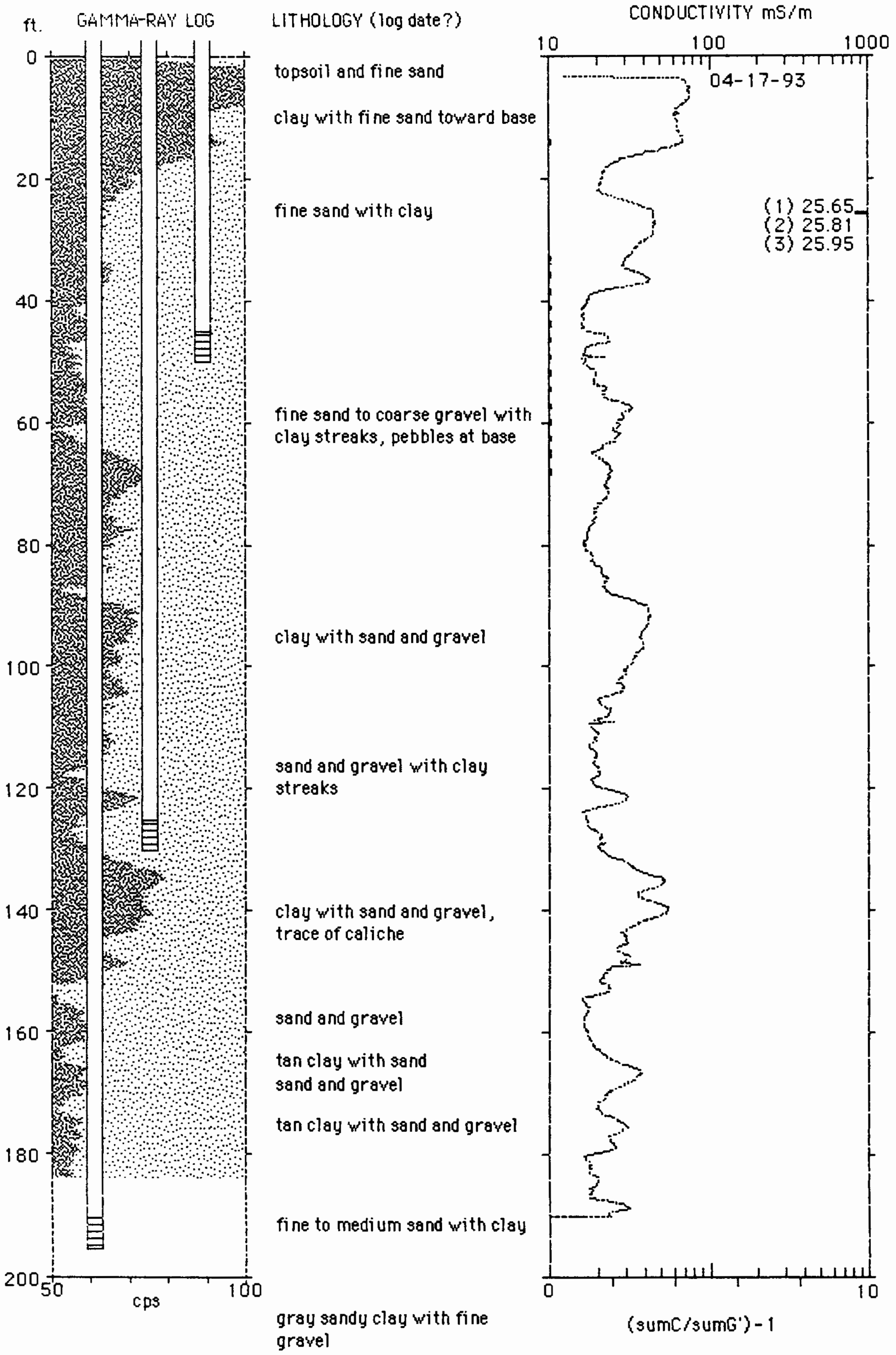
elev= 1842 ft. N



MONITORING SITE 50

21-13-06BCCC

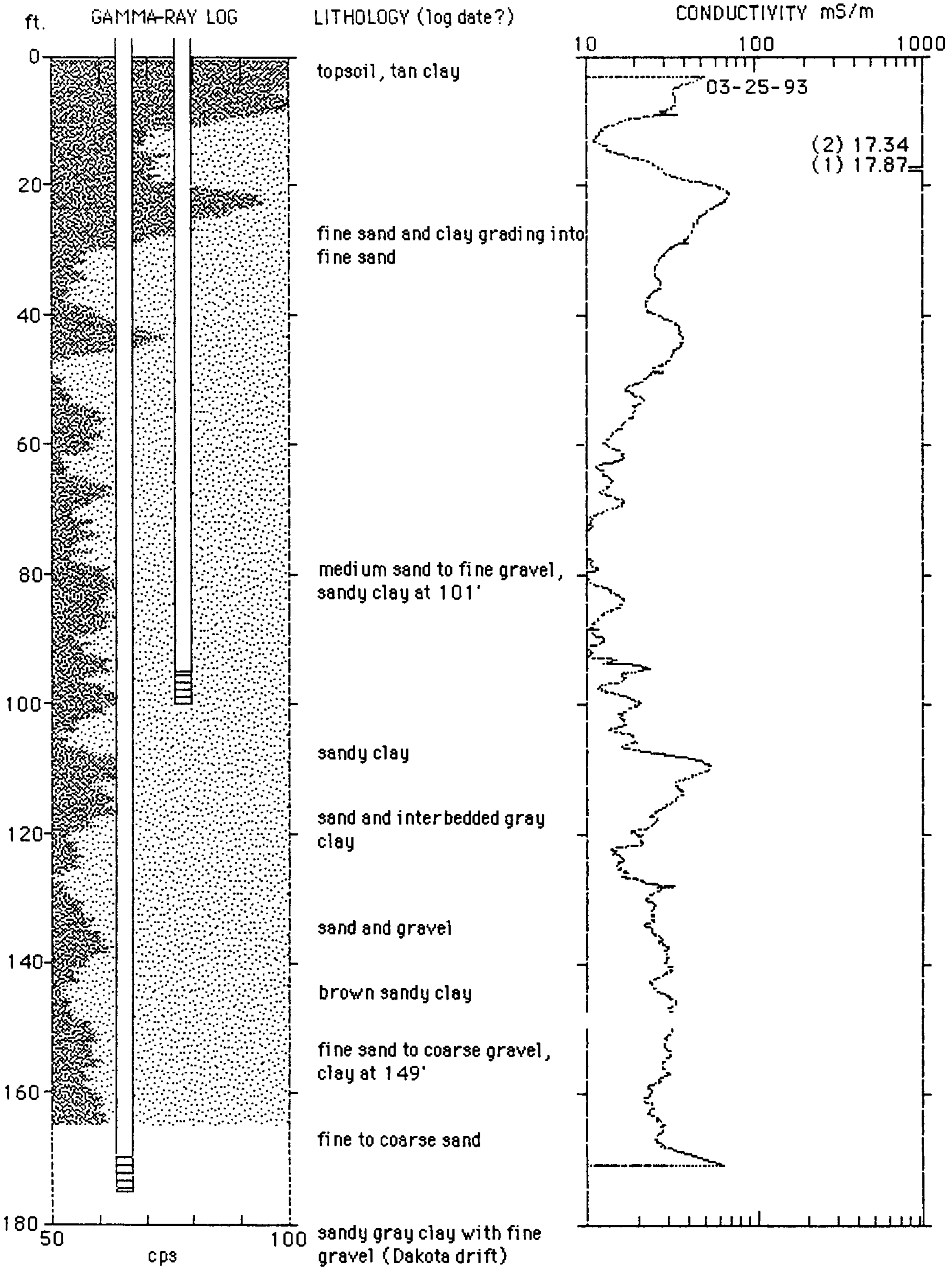
elev=1912 ft. N ⟶



MONITORING SITE 51

21-14-36DDDA

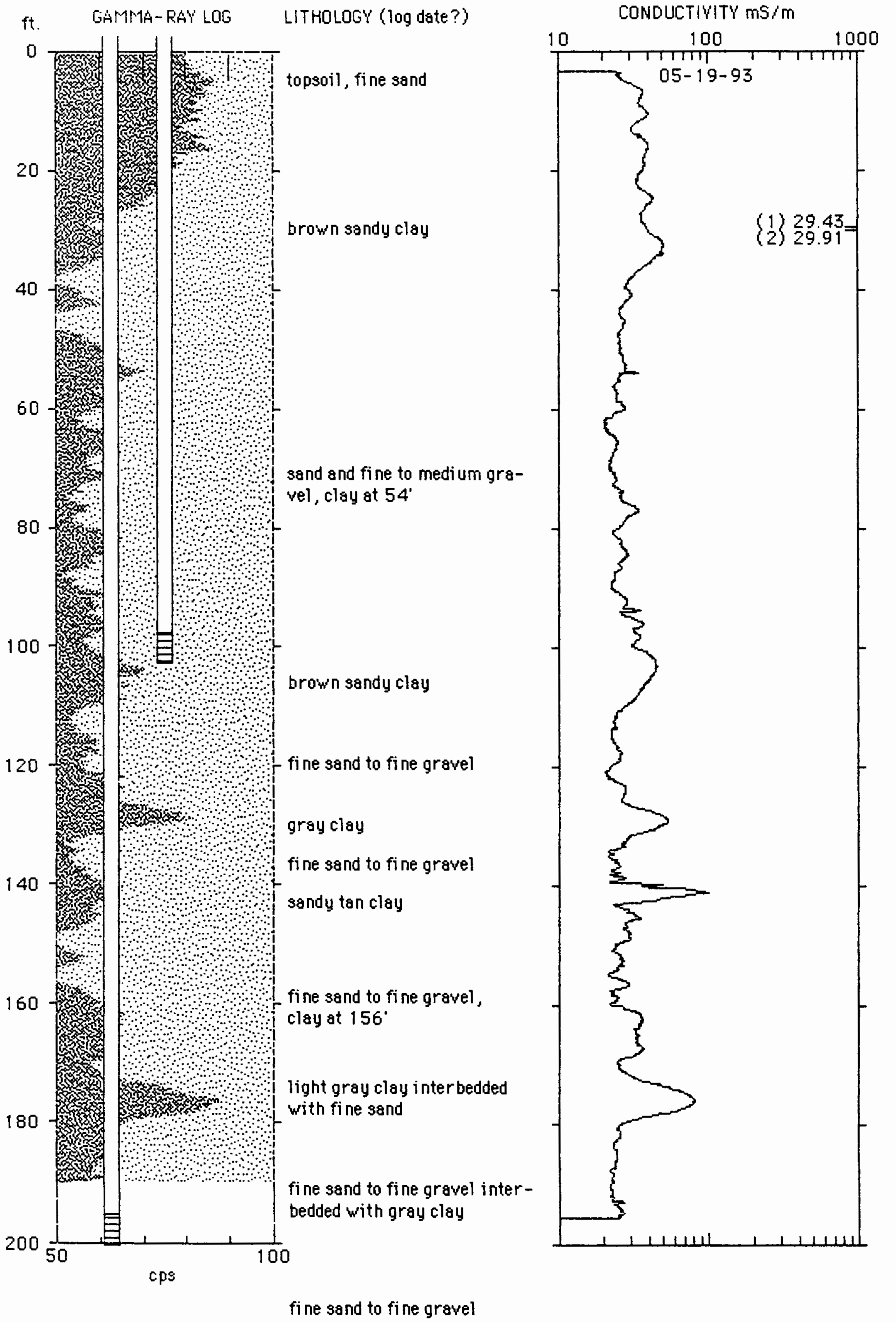
elev=1915 ft. N ←



MONITORING SITE 52

23-13-06BBBC

elev=1920 ft. N



Appendix B. Intensive Study Site Installations and Well Logs

Installation Procedures:

A description of the intensive study site, well characteristics, and the logs of the Permian monitoring well are included in Section II of the report. This appendix contains additional information on the installation, and the available log information for the other wells.

The following is a summary of the drilling and installation procedures used for the Permian monitoring well at the Siefkes site. Figure B-1 schematically illustrates the steps in the procedure, as follows:

B-1a -- site conditions prior to drilling, with stratigraphic units estimated from available well logs.

B-1b -- a 5.5"-dia. borehole was drilled (mud-rotary) 10' past the initial point of contact (186') with the Permian bedrock, to TD of 197'.

B-1c -- a 3" dia. schdule 40 PVC casing was installed, with a cement shoe (check valve assembly) on the bottom. A 1"-dia. tremie pipe with left-hand threads is attached to the cement shoe fitting inside the casing (see fig. B-2 for a schematic of the cement shoe design).

B-1d -- sufficient cement is pumped through the tremie and cement shoe to grout the borehole annulus to an elevation well above the saltwater interface. The tremie is then unscrewed and removed, the cement is held in place by the cement shoe check valve, and is allowed to set up.

B-1e -- after the cement is set up, the cement shoe and bottom plug are cored out and an additional 30' of the Permian formation is cored below the bottom of the original hole (197-227').

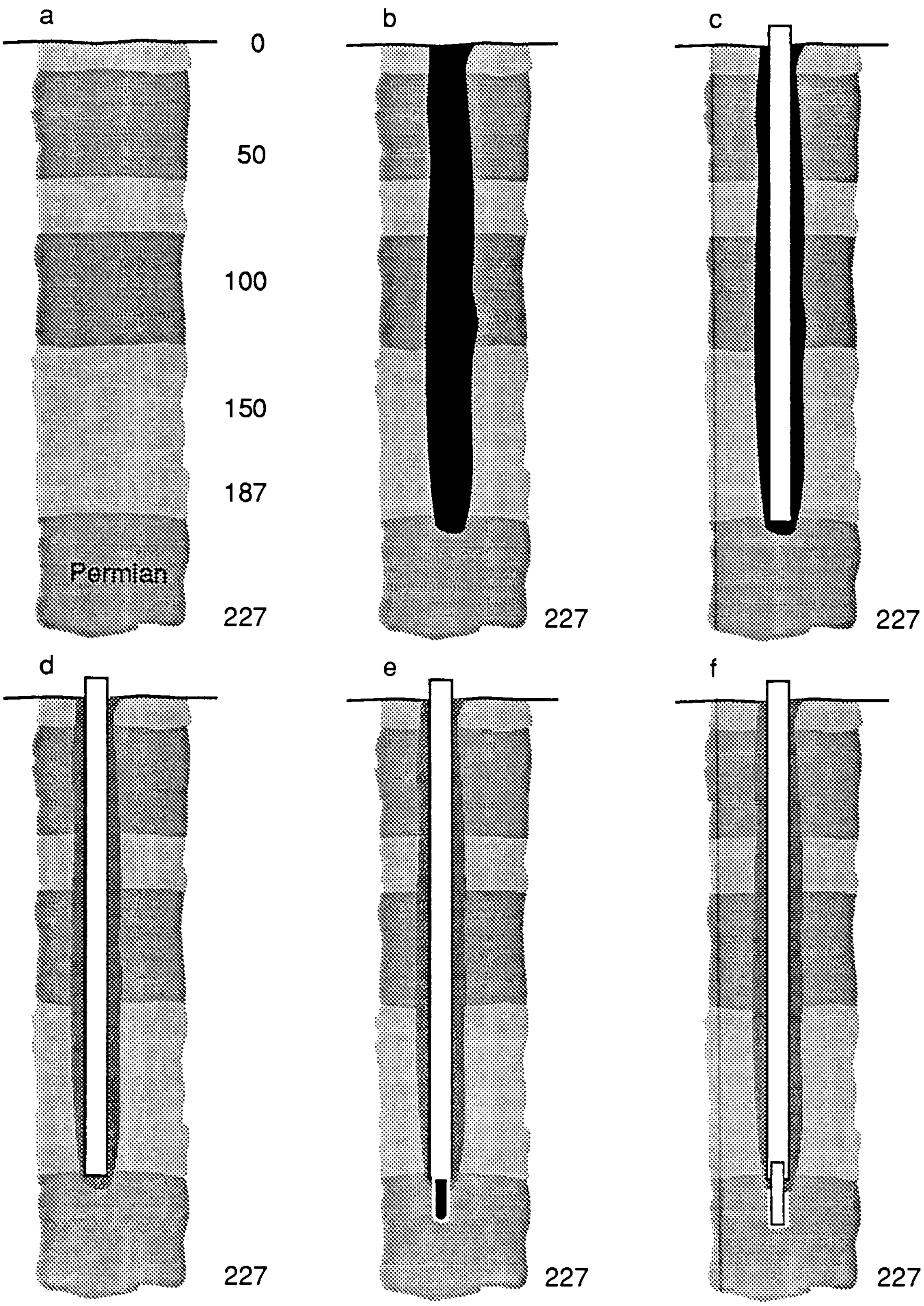


Figure B-1. Sequence of Permian monitoring-well installation operations

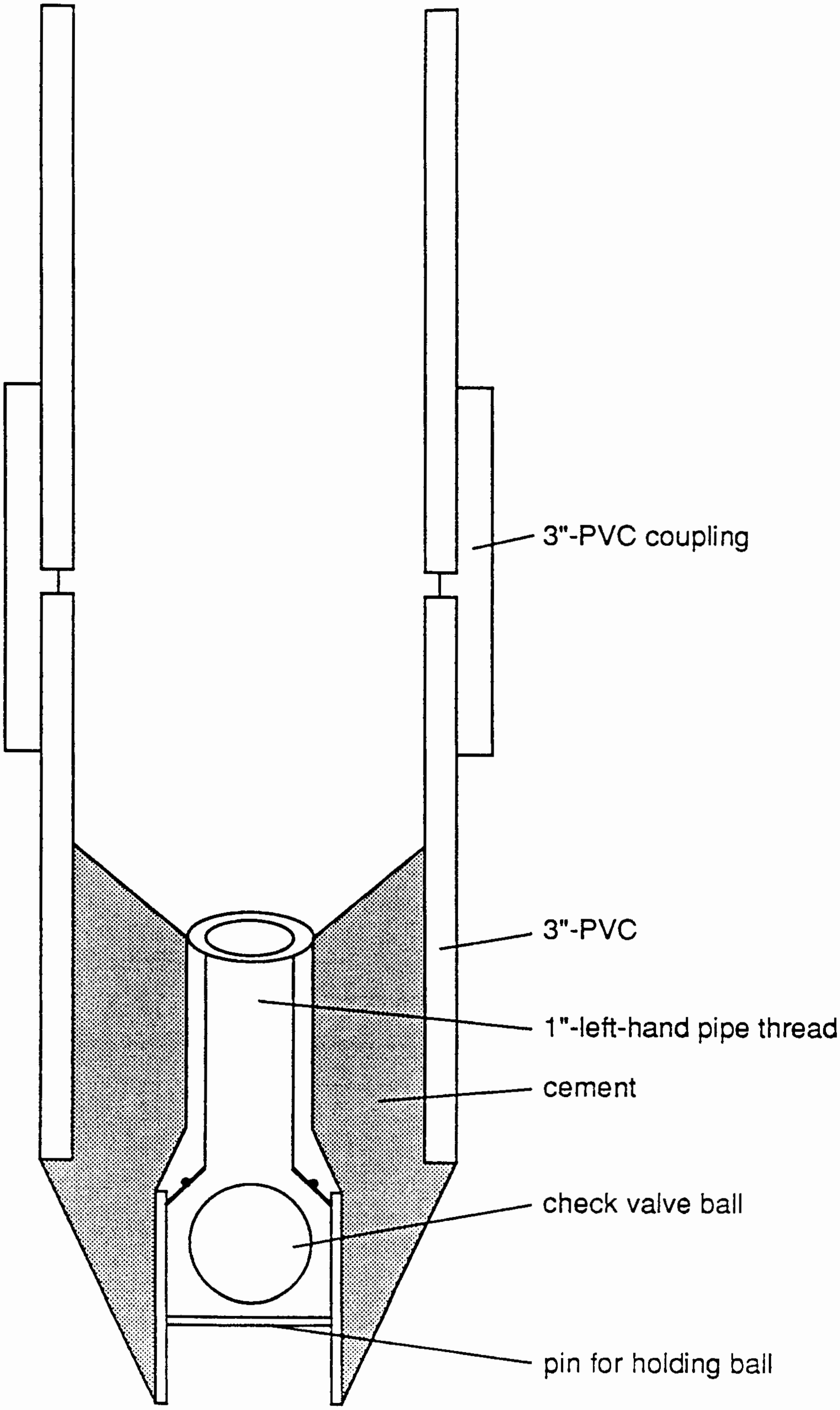


Figure B-2. Cement shoe design (see text for explanation of use).

B-1f -- 40' of 2"-dia. schedule 40 PVC screen slot 10 is to protect the open core hole section against collapse; the top of the screen is measured to ensure installation to the bottom of the hole.

Following installation the borehole grout was sounded at 20' and the upper part of the annular borehole was sealed with bentonite to ground level. The well was developed by airlifting and sampled for water quality.

A generally similar approach was used for installation of the deep aquifer well, but since coring was not required the cement shoe was not used. Drilling was stopped when fluid returns showed the first sign of the clay layer that had been observed directly above the bedrock at the Permian well (TD = 167'). Well was constructed with 10' of schedule-40 2"-dia. slot-20 screen at the bottom with 157 feet of 3"-dia. schedule-40 casing above that. Borehole annulus was filled using conventional tremie tube technique: gravel to 152', fine sand to 147', cement to 100', bentonite to ground surface. The well was airlifted to develop and sampled for water chemistry.

Chronology of Drilling

March 23, 1993: Initiated drilling at site 52' east and 5' south of irrigation well. Problems were experienced with the mud pump, fluid return was inadequate, and hole collapse prevented penetration below 132'. The hole was abandoned on March 24, grouted with cement from TD to 69.5 feet, then filled with bentonite topped with soil.

March 25, 1993: Moved 25' due east, drilled to 217', installed casing and cement shoe, and pumped grout to 34' below surface in annulus. March 26 -- cement shoe failed, grout flowed back into casing and cemented tremie pipe into casing. Attempts to overdrill were unsuccessful, and the hole was abandoned.

April 12, 1993: reoccupied site, commenced drilling 15' west of the second abandoned hole. Drilling proceeded normally according to plans summarized above, and installation was completed April 14. Drilling of the deep aquifer well was begun April 14 and completed April 15.

Intensive Study Site Well Logs

Logs of the Permian monitoring well are presented in section II this report. Available well logs (Form WWC-5) for other wells in the area of the intensive study site follow. See appendix A for the gamma and EM logs of all wells.

USE TYPEWRITER OR BALL POINT PEN–PRESS FIRMLY, PRINT CLEARLY.

MJ-SS-I

WATER WELL RECORD
KSA 82a-1201-1215

Kansas Department of Health and Environment–Division of Environment
(Water well Contractors)
Topeka, Kansas 66620

1. Location of well:	County	Fraction	Section number	Township number	Range number
	Stafford	1/4 1/4 CSE 1/4	27	T 21 S	R 12 E/W

2. Distance and direction from nearest town or city: 8 miles Northeast of Hudson, KS

Street address of well location if in city:

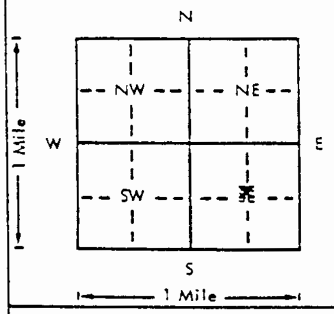
3. Owner of well: Dennis Siefkes

R.R. or street: Route 3

City, state, zip code: Hudson, KS 67545

4. Locate with "X" in section below:

Sketch map:



5. Type and color of material	From	To
top soil & sand	0	9
brown & gray clay	9	35
brown clay & sandstone streaks	35	57
sand & gravel	57	65
brown clay & limestone streaks	65	78
sand & gravel	78	80
brown clay	80	90
sand & gravel	90	120

IRRIGATION

I

(Use a second sheet if needed)

6. Bore hole dia. 24 in. Completion date 12-7-76

Well depth 120 ft.

7. __ Cable tool __ Rotary __ Driven __ Dug __ Hollow rod __ Jetted __ Bored X Reverse rotary

8. Use: __ Domestic __ Public supply __ Industry X Irrigation __ Air conditioning __ Stock __ Lawn __ Oil field water __ Other

9. Casing: Material steel

Threaded ____ Welded X

RMP ____ PVC ____

Dia. 16 in. to 60 ft. depth

Dia 16 in. to 90 ft. depth

Height: Above or below Surface 12 in.

Weight 30.3 lbs./ft.

Wall Thickness: inches or gage No. 7 ga.

10. Screen: Manufacturer's name Doerr

Type double-slot Dia. 16"

Slot/gauze 1/8" Length 50'

Set between 60 ft. and 80 ft.

90 ft. and 120 ft.

Gravel pack? yes Size range of material 3/8-200

11. Static water level: 14'6" ft. below land surface Date 10-1-76 mo./day/yr.

12. Pumping level below land surfaces: N/C

____ ft. after ____ hrs. pumping ____ g.p.m.

____ ft. after ____ hrs. pumping ____ g.p.m.

Estimated maximum yield ____ g.p.m.

13. Water sample submitted: __ Yes X No Date ____ mo./day/yr.

14. Well head completion: __ Pitless adapter 12 Inches above grade

15. Well grouted? yes

With: X Neat cement ____ Bentonite ____ Concrete

Depth: From 0 ft. to 10 ft.

16. Nearest source of possible contamination: NONE KNOWN

ft. ____ Direction ____ Type ____

Well disinfected upon completion? ____ Yes XX No

17. Pump: ____ Not installed

Manufacturer's name Peerless Pump

Model number 12MB-5 HP 60 Volts 460

Length of drop pipe 80 ft. capacity 900 g.p.m.

Type:

__ Submersible X Turbine

__ Jet __ Reciprocating

__ Centrifugal __ Other

18. Elevation:

Topography:

____ Hill

____ Slope

____ Upland

____ Valley

19. Remarks:

20. Water well contractor's certification:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Clarke Well & Equip., Inc. 135

Business name License No.

Address Great Bend, KS 67530

Signed ____ 12-8-76

Authorized representative Date

Forward the white, blue and pink copies to the Department of Health and Environment

Form WWC-5

WATER WELL RECORD Form WWC-5 KSA 82a-1212

MI-55-WDS

CATION OF WATER WELL:	Fraction	Section Number	Township Number	Range Number
Stafford	C ¼ SE ¼ ¼	27	T 21 S	R 12W E

e and direction from nearest town or city street address of well if located within city?
E, 6½ N of Hudson, Kansas

TER WELL OWNER: J. Shumway L. D. Drilling
St. Address, Box # : Hudson, Ks. Route 1
State, ZIP Code : 67545 Great Bend, Ks. 67530
Board of Agriculture, Division of Water Resc
Application Number: T82-511

CATE WELL'S LOCATION WITH
X" IN SECTION BOX:

	N	
W	NW NE	E
	SW SE(X)	
	S	

4 DEPTH OF COMPLETED WELL 85 ft. ELEVATION: Unknown
Depth(s) Groundwater Encountered 1. 25 ft. 2. ft. 3.
WELL'S STATIC WATER LEVEL 25 ft. below land surface measured on mo/day/yr 1/21/83
Pump test data: Well water was ft. after hours pumping gp
Est. Yield 60 gpm: Well water was ft. after hours pumping gp
Bore Hole Diameter 8 in. to 85 ft., and in. to
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot [✓ 6 Oil field water supply] 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Lawn and garden only 10 Observation well
Was a chemical/bacteriological sample submitted to Department? Yes No; If yes, mo/day/yr sample was
mitted Water Well Disinfected? Yes No

E OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile CASING JOINTS: [✓ Glued] Clamped
Steel 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded
[✓ 2 PVC] 4 ABS 7 Fiberglass Threaded
asing diameter 5 in. to 65 ft., Dia in. to ft., Dia in. to
height above land surface 12 in., weight 2.8 lbs./ft. Wall thickness or gauge No. Sch. 40
OF SCREEN OR PERFORATION MATERIAL: [✓ 7 PVC] 10 Asbestos-cement
Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify)
Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)
EN OR PERFORATION OPENINGS ARE: 5 Gauzed wrapped [✓ 8 Saw cut] 11 None (open hole)
1 Continuous slot 3 Mill slot 6 Wire wrapped 9 Drilled holes
Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify)
EN-PERFORATED INTERVALS: From 65 ft. to 85 ft., From ft. to
From ft. to ft., From ft. to
GRAVEL PACK INTERVALS: From 10 ft. to 85 ft., From ft. to
From ft. to ft., From ft. to
ROUT MATERIAL: [✓ 1 Neat cement] 2 Cement grout 3 Bentonite 4 Other
Intervals: From 0 ft. to 10 ft., From ft. to ft., From ft. to
s the nearest source of possible contamination: 10 Livestock pens 14 Abandoned water well
Septic tank 4 Lateral lines 7 Pit privy 11 Fuel storage [✓ 15 Oil well/Gas well]
2 Sewer lines 5 Cess pool 8 Sewage lagoon 12 Fertilizer storage 16 Other (specify below)
Watertight sewer lines 6 Seepage pit 9 Feedyard 13 Insecticide storage
on from well? East How many feet? 60

OM	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0	50	Sandy Clay (C4)			
50	85	Sand and Gravel (17)			WDS
					OIL + SUPPLY

NTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was [✓ (1) constructed], (2) reconstructed, or (3) plugged under my jurisdiction and
leted on (mo/day/year) 1/21/83 and this record is true to the best of my knowledge and belief. Kar
Well Contractor's License No. 186 This Water Well Record was completed on (mo/day/yr) 2/25/83
he business name of Kellys Water Well Service by (signature)
RUCTIONS. Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send
copies to Kansas Department of Health and Environment, Division of Environment, Environmental Geology Section, Topeka, KS 66620. Send one to WATER W

USE TYPEWRITER OR BALL POINT PEN—PRESS FIRMLY, PRINT CLEARLY.

MI-55-5

WATER WELL RECORD
KSA 82a-1201-1215

Kansas Department of Health and Environment—Division of Environment
(Water well Contractors)
Topeka, Kansas 66620

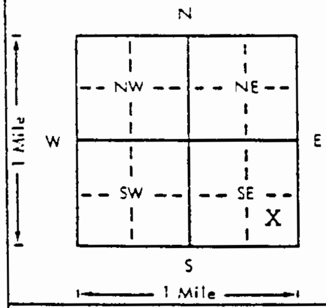
1. Location of well:	County	Fraction	Section number	Township number	Range number
	Stafford	1/4 SE 1/4 SE 1/4	27	T 21 S	R 12

2. Distance and direction from nearest town or city: 7½ miles Northeast of Hudson, KS
Street address of well location if in city:

3. Owner of well: Dennis Siefkes
R.R. or street: Route 3
City, state, zip code: Hudson, KS 67545

4. Locate with "X" in section below:

Sketch map:



5. Type and color of material

	From	To
Top soil	0	3
Brown & gray clay & limestone	3	56
Sand	56	62
Brown clay & limestone	62	72
Sand & gravel	72	76
Brown clay	76	81
Sand & gravel	81	90
STUCK		
5		

(Use a second sheet if needed)

6. Bore hole dia. 9 in. Completion date 11-16-78
Well depth 90 ft.

7. __ Cable tool X Rotary __ Driven __ Dug
__ Hollow rod __ Jetted __ Bored __ Reverse rotary

8. Use: __ Domestic __ Public supply __ Industry
__ Irrigation __ Air conditioning X Stock
__ Lawn __ Oil field water __ Other

9. Casing: Material Styrene
Height: [✓ Above] or below
Surface 12 in.
Threaded ____ Welded X
RMP ____ PVC ____
Weight 1.5 lbs./ft.
Dia. 5 in. to 80 ft. depth
Dia. __ in. to __ ft. depth
Wall Thickness: inches or gage No. .200

10. Screen: Manufacturer's name Jess & Lowell
Type Styrene 200 Dia. 5"
[✓ Slot] gauze 1/8" Length 10'
Set between 80 ft. and 90 ft.
____ ft. and ____ ft.
Gravel pack? Yes Size range of material 3/8-200

11. Static water level: 16'6" ft. below land surface Date mo./day/yr. 11-16-78

12. Pumping level below land surfaces: N/C
____ ft. after ____ hrs. pumping ____ g.p.m.
____ ft. after ____ hrs. pumping ____ g.p.m.
Estimated maximum yield ____ g.p.m.

13. Water sample submitted: __ Yes X No Date mo./day/yr. ____

14. Well head completion:
__ Pitless adapter 12 Inches above grade

15. Well grouted? Yes
With: X Neat cement __ Bentonite __ Concrete
Depth: From 0 ft. to 10 ft.

16. Nearest source of possible contamination: FIELD
ft. ____ Direction ____ Type ____
Well disinfected upon completion? X Yes __ No

17. Pump: X Not installed
Manufacturer's name ____
Model number ____ HP ____ Volts ____
Length of drop pipe ____ ft. capacity ____ g.p.m.
Type:
__ Submersible __ Turbine
__ Jet __ Reciprocating
__ Centrifugal __ Other

18. Elevation:

Topography:
__ Hill
__ Slope
__ Upland
__ Valley

19. Remarks:

20. Water well contractor's certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Clarke Well & Eq., Inc. 185
Business name License No.
Address Great Bend, KS 67530
Signed ____ Date 11-17-
Authorized representative

Forward the white, blue and pink copies to the Department of Health and Environment

Form WWC-5

#1

WATER WELL RECORD Form WWC-5 KSA 82a-1212

ER WELL.	Fraction	Section Number	Township Number	Range Number
ed	SE ¼ SW ¼ NE ¼	27	T 21 S	R 12 E

n from nearest town or city street address of well if located within city?
3 EAST 7 NORTH 1 WEST 1/4 SOUTH

NER: L. D. Drilling Co. **MI-SS-NDS** W. SIEFKES, STAFFORD, KS
ox # : Rt. 1 Box 183-8
e : Great Bend, Ks. 67530
Board of Agriculture, Division of Water Resou
Application Number: T85-517

LOCATION WITH
N BOX:
N
NE
SE
S
E

4 DEPTH OF COMPLETED WELL........ 120 ft. ELEVATION: ....
Depth(s) Groundwater Encountered 1.......... 95 ...ft. 2.................... ft. 3.............
WELL'S STATIC WATER LEVEL ..... 23 ft. below land surface measured on mo/day/yr 5/7/85
Pump test data: Well water was .... ft. after .... hours pumping .... gpm
Est. Yield .... gpm: Well water was .... ft. after .... hours pumping .... gpm
Bore Hole Diameter.... 7 7/8 .in. to ..... 120 ......ft., and.....................in. to ....

WELL WATER TO BE USED AS:
1 Domestic
2 Irrigation
3 Feedlot
4 Industrial
5 Public water supply
[✓ 6 Oil field water supply]
7 Lawn and garden only
8 Air conditioning
9 Dewatering
10 Observation well
11 Injection well
12 Other (Specify below) ....

Was a chemical/bacteriological sample submitted to Department? Yes..........No..........; If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes No

NK CASING USED:
3 RMP (SR)
4 ABS
5 Wrought iron
6 Asbestos-Cement
7 Fiberglass
8 Concrete tile
9 Other (specify below)
....

CASING JOINTS: Glued . XX Clamped .....
Welded ....
Threaded.................

neter .... 5 ..in. to .... 100 ... ft., Dia ....in. to ....ft., Dia .... in. to ....
bove land surface........... 12 ..in., weight .... 2.65 .... lbs./ft. Wall thickness or gauge No. .... .214 .....

EN OR PERFORATION MATERIAL:
3 Stainless steel
4 Galvanized steel
5 Fiberglass
6 Concrete tile
[✓ 7 PVC]
8 RMP (SR)
9 ABS
10 Asbestos-cement
11 Other (specify) ....
12 None used (open hole)

PERFORATION OPENINGS ARE:
ous slot
ed shutter
3 Mill slot
4 Key punched
5 Gauzed wrapped
6 Wire wrapped
7 Torch cut
[✓ 8 Saw cut]
9 Drilled holes
10 Other (specify) ....
11 None (open hole)

RFORATED INTERVALS: From.......... 100 ... ft. to .... 120 ...ft., From .... ft. to ....
From.................. ft. to ....ft., From .... ft. to ....
VEL PACK INTERVALS: From.......... 90 ... ft. to .... 120 ...ft., From .... ft. to ....
From ft. to ft., From ft. to

ATERIAL: 1 Neat cement 2 Cement grout [✓ 3 Bentonite] 4 Other ....
s: From........ 0 ..ft. to ...... 10 ... ft., From .... ft. to............. ft., From .... ft. to ....

nearest source of possible contamination: NONE
tic tank
r lines
ertight sewer lines
4 Lateral lines
5 Cess pool
6 Seepage pit
7 Pit privy
8 Sewage lagoon
9 Feedyard
10 Livestock pens
11 Fuel storage
12 Fertilizer storage
13 Insecticide storage
14 Abandoned water well
15 Oil well/Gas well
16 Other (specify below)
....

om well?
How many feet?

TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
4	Sandy Top Soil			
10	Sandy clay			
70	clay			NORTH OIL-SUPPLY
80	SANDY clay			
90	clay			
95	SANDY clay			NDS
120	GRAVEL			

ACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and
on (mo/day/year) .. 5/7/85 .... and this record is true to the best of my knowledge and belief. Kan
Contractor's License No. .... 387 .... This Water Well Record was completed on (mo/day/yr) 5/9/85
business name of Reiser Water Well Service, Co by (signature) Rudolph J Reiser

IONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send
Environment, Division of Environment, Environmental Geology Section, Topeka, KS 66620. Send one to WATER WE

WATER WELL RECORD Form WWC-5 KSA 82a-1212

CATION OF WATER WELL Fraction C ½ ¼ S ½ ¼ NE ¼ | Section Number 34 | Township Number T 21 S | Range Number R 12 E

Stafford

ce and direction from nearest town or city? 1½ East - ¼ South of Seward, Ks | Street address of well if located within city?

ATER WELL OWNER: Hawkins Drilling

St. Address, Box # : Box 1131

tate, ZIP Code : Great Bend, Ks. 67530

MJ-55-SDS

Board of Agriculture, Division of Water Reso

Application Number: T79-302

EPTH OF COMPLETED WELL ... 100 ... ft. Bore Hole Diameter ... 12 ¼ ... in. to ... 100 ... ft., and .... in. to ....

ater to be used as: 5 Public water supply 8 Air conditioning 11 Injection well

omestic 3 Feedlot [✓ 6 Oil field water supply] 9 Dewatering 12 Other (Specify below)

Irrigation 4 Industrial 7 Lawn and garden only 10 Observation well

static water level ..... 21 ..... ft. below land surface measured on .... 1 ....month .... 12 ...... day 80

Test Data NA : Well water was............. ft. after .... hours pumping.

ield gpm: Well water was ft. after hours pumping

YPE OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile Casing Joints: Glued ✓ Clamped ...

Steel 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded ....

[✓ 2 PVC] 4 ABS 7 Fiberglass .... Threaded..............

casing dia ... 5½ .... in. to ..... 80 ..... ft., Dia .... in. to .... ft., Dia .... in. to

height above land surface .... 12 .... in., weight .... lbs./ft. Wall thickness or gauge No ... .258

OF SCREEN OR PERFORATION MATERIAL: [✓ 7 PVC] 10 Asbestos-cement

1 Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify) ....

2 Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)

or Perforation Openings Are: 5 Gauzed wrapped [✓ 8 Saw cut] 11 None (open hole

Continuous slot 3 Mill slot 6 Wire wrapped 9 Drilled holes

2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify) ....

-Perforation Dia ... 5½ ... in. to ..... 100 ..... ft., Dia .... in. to .... ft., Dia .... in to

-Perforated Intervals: From......... 80 ...... ft. to .... 100 .... ft., From .... ft. to ....

From.............................. ft. to .... ft., From .... ft. to ....

Pack Intervals: From......... 10 ...... ft. to .... 100 .... ft., From .... ft. to ....

From ft. to ft., From ft. to

GROUT MATERIAL: [✓ 1 Neat cement] 2 Cement grout 3 Bentonite 4 Other ....

ted Intervals: From...... 0 ..... ft. to ..... 10 ..... ft., From .... ft. to .... ft., From .... ft. to ....

is the nearest source of possible contamination: 10 Fuel storage 14 Abandoned water well

1 Septic tank 4 Cess pool 7 Sewage lagoon 11 Fertilizer storage [✓ 15 Oil well/Gas well]

2 Sewer lines 5 Seepage pit 8 Feed yard 12 Insecticide storage 16 Other (specify below)

3 Lateral lines 6 Pit privy 9 Livestock pens 13 Watertight sewer lines

on from well ...... North ...... How many feet .... 65 ....? Water Well Disinfected? Yes ... HTH ... No

a chemical/bacteriological sample submitted to Department? Yes .... No ✓ ....: If yes, date sa

ubmitted .... month .... day .... year: Pump Installed? Yes .... No ✓

Pump Manufacturer's name .... Model No. .... HP .... Volts ....

h of Pump Intake .... ft. Pumps Capacity rated at .... ga

of pump: 1 Submersible 2 Turbine 3 Jet 4 Centrifugal 5 Reciprocating 6 Other

NTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was [✓ (1) constructed], (2) reconstructed, or (3) plugged under my jurisdiction and

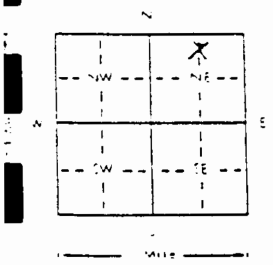
pleted on .... 1 .... month .... 12 .... day 80

this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 134

Water Well Record was completed on .... 2 .... month ...... 4 ...... day ...... 80 ...... year under the bus

of Wassmer-Dantz - Bemis by (signature) Frederic Dunham

LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:



FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0	3	Sandy Top Soil			
3	11	Brown Clay			
11	58	light gray Clay			
58	68	Brown Clay			South
68	79	Clay w/ Sand			of oil well
79	100	Sand & gravel			?
					SDS

ATION:

(s) Groundwater Encountered 1. 21 ft. 2 .... ft. 3 .... ft. 4 .... ft. (Use a second sheet if needed)

RUCTIONS. Use typewriter or ball point pen, *please press firmly* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top
ies to Kansas Department of Health and Environment, Division of Environment, Water Well Contractors, Topeka, KS 66620. Send one to WATER WELL OWNER

WATER WELL RECORD Form WWC-5 KSA 82a-1212

ATION OF WATER WELL:	Fraction	Section Number	Township Number	Range Number
y: Stafford	SW ¼ SE ¼ SW ¼	26	T 21 S	R 12W

e and direction from nearest town or city street address of well if located within city?

E, 5 N of Hudson, Kansas

MI-SS-EDS

ATER WELL OWNER: D. Siefkes Revelon Drilling
t. Address, Box # : Route 3 Box 88
ate, ZIP Code : Hudson, Kansas 67545 Russell, Kansas 67665

Board of Agriculture, Division of Water Resou
Application Number: Unknown

ATE WELL'S LOCATION WITH "X" IN SECTION BOX:

N

NW	NE
SW X	SE

E

S

DEPTH OF COMPLETED WELL 100 ft. ELEVATION: Unknown

Depth(s) Groundwater Encountered 1. 28 ft. 2. ft. 3.

WELL'S STATIC WATER LEVEL 28 ft. below land surface measured on mo/day/yr 3/13/82

Pump test data: Well water was ft. after hours pumping

Est. Yield 60 gpm: Well water was ft. after hours pumping

Bore Hole Diameter 8 in. to 100 ft., and in. to

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot [✓ 6 Oil field water supply] 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Lawn and garden only 10 Observation well

Was a chemical/bacteriological sample submitted to Department? Yes No; If yes, mo/day/yr sample was mitted

Water Well Disinfected? Yes No

E OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile CASING JOINTS: [✓ Glued] Clamped
Steel 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded
[✓ PVC] 4 ABS 7 Fiberglass Threaded

casing diameter 5 in. to 80 ft., Dia in. to ft., Dia in. to

height above land surface 12 in., weight 2.8 lbs./ft. Wall thickness or gauge No. Sch. 40

F SCREEN OR PERFORATION MATERIAL: [✓ 7 PVC] 10 Asbestos-cement
1 Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify)
Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)

N OR PERFORATION OPENINGS ARE: 5 Gauzed wrapped [✓ 8 Saw cut] 11 None (open hole)
1 Continuous slot 3 Mill slot 6 Wire wrapped 9 Drilled holes
2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify)

N-PERFORATED INTERVALS: From 80 ft. to 100 ft., From ft. to
From ft. to ft., From ft. to

GRAVEL PACK INTERVALS: From 10 ft. to 100 ft., From ft. to
From ft. to ft., From ft. to

UT MATERIAL: [✓ 1 Neat cement] 2 Cement grout 3 Bentonite 4 Other

Intervals: From 0 ft. to 10 ft., From ft. to ft., From ft. to

the nearest source of possible contamination: 10 Livestock pens 14 Abandoned water well
Septic tank 4 Lateral lines 7 Pit privy 11 Fuel storage [✓ 15 Oil well/Gas well]
2 Sewer lines 5 Cess pool 8 Sewage lagoon 12 Fertilizer storage 16 Other (specify below)
3 Watertight sewer lines 6 Seepage pit 9 Feedyard 13 Insecticide storage

n from well? South How many feet? 60

M	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0	75	Sandy Clay			
75	100	Sand and Gravel			

EAST OIL SUPPLY

EDS

NTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was [✓ (1) constructed], (2) reconstructed, or (3) plugged under my jurisdiction and leted on (mo/day/year) 3/13/82 and this record is true to the best of my knowledge and belief. Ka Well Contractor's License No. 186 This Water Well Record was completed on (mo/day/yr) 4/29/82
he business name of Kellys Water Well Service by (signature)

UCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send copies to Kansas Department of Health and Environment, Division of Environment, Environmental Geology Section, Topeka, KS 66620. Send one to WATER NER and retain one for your records.

WATER WELL RECORD Form WWC-5 KSA 82a-1212

ATION OF WATER WELL:	Fraction	Section Number	Township Number	Range Number
y: STAFFORD	NW ¼ SE ¼ NW ¼	25	T 21 S	R 12 E W

ce and direction from nearest town or city street address of well if located within city?

[illegible]-N 1-E OF HUDSON, KS.

ATER WELL OWNER: PHILLIPS PETROLEUM CO.

St. Address, Box # : RR3 BOX 20-A

ate, ZIP Code : GREAT BEND, KS, 67530

MI-SS-NED

Board of Agriculture, Division of Water Resou

Application Number: 92-0358

ATE WELL'S LOCATION WITH "X" IN SECTION BOX:

	N	
NW X		NE
		E
SW		SE
	S	

4 DEPTH OF COMPLETED WELL. . . . . . 110 . . . . ft. ELEVATION: . . . .

Depth(s) Groundwater Encountered 1. . . . . ft. 2. . . . . ft. 3. . . . .

WELL'S STATIC WATER LEVEL . . . 33 . . . . . ft. below land surface measured on mo/day/yr . . . .

Pump test data: Well water was . . . . ft. after . . . . hours pumping . . . . gp

Est. Yield . . . . gpm: Well water was . . . . ft. after . . . . hours pumping . . . . gp

Bore Hole Diameter . . 9 . . . . . . in. to . . . . ft., and . . . . in. to . . . .

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well

1 Domestic 3 Feedlot XX Oil field water supply 9 Dewatering 12 Other (Specify below)

2 Irrigation 4 Industrial 7 Lawn and garden only 10 Monitoring well . . . .

Was a chemical/bacteriological sample submitted to Department? Yes. . . . . No. XX . . . . ; If yes, mo/day/yr sample was s mitted

Water Well Disinfected? Yes X No

PE OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile CASING JOINTS: Glued . . X . . . Clamped . . . . .

Steel 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded . . . .

PVC 4 ABS 7 Fiberglass . . . . Threaded. . . . .

casing diameter . . . 5 . . . . in. to . . . . 90 . . . . . . ft., Dia . . . . in. to . . . . ft., Dia . . . . in. to . . . .

height above land surface. . . . . . 24 . . . . in., weight . . . . lbs./ft. Wall thickness or gauge No. . . . .

OF SCREEN OR PERFORATION MATERIAL: XX PVC 10 Asbestos-cement

1 Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify) . . . .

2 Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)

EN OR PERFORATION OPENINGS ARE: 5 Gauzed wrapped 8 Saw cut 11 None (open hole)

Continuous slot XX Mill slot 6 Wire wrapped 9 Drilled holes

2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify) . . . .

EN-PERFORATED INTERVALS: From. . . . . 90 . . . . ft. to . . . . 110 . . . . . . ft., From . . . . ft. to . . . .

From. . . . . ft. to . . . . ft., From . . . . ft. to . . . .

GRAVEL PACK INTERVALS: From. . . . . . . 20 . . . . ft. to . . . . . . 110 . . . . ft., From . . . . ft. to . . . .

From ft. to ft., From ft. to

OUT MATERIAL: 1 Neat cement 2 Cement grout XX Bentonite 4 Other . . . .

Intervals: From. . 0 . . . . ft. to . . . . 20 . . . . . ft., From . . . . ft. to. . . . . ft., From . . . . ft. to . . . .

is the nearest source of possible contamination: 10 Livestock pens 14 Abandoned water well

Septic tank 4 Lateral lines 7 Pit privy 11 Fuel storage 15 Oil well/Gas well

Sewer lines 5 Cess pool 8 Sewage lagoon 12 Fertilizer storage 16 Other (specify below)

3 Watertight sewer lines 6 Seepage pit 9 Feedyard 13 Insecticide storage . . NONE . . . .

on from well? How many feet?

M	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	3	TOP SOIL			
3	10	SAND			
10	89	CLAY			
9	110	GRAVEL			

NE

OIL-SUPPLY

NED

NTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was XX) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and

eted on (mo/day/year) . . . . 10-24-92 . . . . and this record is true to the best of my knowledge and belief. Ka

r Well Contractor's License No. . . . . . 462-8 . . . . This Water Well Record was completed on (mo/day/yr) . . . . . . 12-5-92 . . . . . .

the business name of SAM'S WATER WEBL SERVICE by (signature)

CTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Departmen of Health and Environment, Bureau of Water, Topeka, Kansas 66620-0001. Telephone 913-296-5545. Send one to WATER WELL OWNER and retain one for your records.

WATER WELL RECORD Form WWC-5 KSA 82a-1212

:CATION OF WATER WELL | Fraction SE ¼ SW ¼ SW ¼ | Section Number 26 | Township Number T 21 S | Range Number R 12 E

nty: Stafford

ce and direction from nearest town or city? 5 miles North nd 2½ miles east of Hudson

Street address of well if located within city?

VATER WELL OWNER: Dennis Siefkes

St. Address, Box # : Route 3 - Box 68

State, ZIP Code : Hudson, KS 67545

MI-SS-DE

Board of Agriculture, Division of Water Res:

Application Number: Not Required

DEPTH OF COMPLETED WELL. . . 96. . . . . . ft. Bore Hole Diameter. . . . 9. . . . . . in. to . . . 96. . . . . . . ft., and . . . . in. to . . . .

Water to be used as: 5 Public water supply 8 Air conditioning 11 Injection well

[✓ Domestic] 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)

2 Irrigation 4 Industrial 7 Lawn and garden only 10 Observation well

's static water level . . . . 23 . . . ft. below land surface measured on . . . . 1 . . . . month . . . . . 14 . . . . day . . . . 1981 . . .

Test Data : Well water was. . . . . ft. after . . . . hours pumping. . . . .

ield not ck'd gpm: Well water was ft. after hours pumping

TYPE OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile Casing Joints: [✓ Glued] . XX . Clamped . . .

1 Steel [✓ 3 RMP (SR)] 6 Asbestos-Cement 9 Other (specify below) Welded. . . . .

2 PVC 4 ABS 7 Fiberglass . . . . Threaded. . . . .

nk casing dia . . . . . . 5. . . . . . . in. to . . . . . 79 . . . . ft., Dia in. to ft., Dia . . . . in. to . . . .

g height above land surface. . . . . 12 . . . . in., weight . . . . . 1.5 . . . . lbs./ft. Wall thickness or gauge No . . .200

OF SCREEN OR PERFORATION MATERIAL: 7 PVC 10 Asbestos-cement

1 Steel 3 Stainless steel 5 Fiberglass [✓ 8 RMP (SR)] 11 Other (specify) . . . .

2 Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)

n or Perforation Openings Are: 5 Gauzed wrapped 8 Saw cut 11 None (open hole

1 Continuous slot [✓ 3 Mill slot] 6 Wire wrapped 9 Drilled holes

2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify) . . . .

n-Perforation Dia . . . . . 5 . . . . . . in. to . . . . 96 . . . . ft., Dia in. to ft., Dia . . . . in to . . . .

n-Perforated Intervals: From. . . . . 79 . . . . ft. to . . . . 96 . . . . ft., From . . . . ft. to. . . . .

From. . . . . ft. to . . . . ft., From . . . . ft. to. . . . .

l Pack Intervals: From. . . . . 60 . . . . ft. to . . . . 96 . . . . ft., From . . . . ft. to . . . .

nnular fill From 10 ft. to 56 ft., From ft. to

GROUT MATERIAL: [✓ 1 Neat cement] 2 Cement grout 3 Bentonite 4 Other . . . .

uted Intervals: From. . 0 . . . . ft. to . . . . 10 . . . . ft., From . . . . 56 . . . . ft. to . . 60 . . . . ft., From . . . . ft. to . . . .

is the nearest source of possible contamination: 10 Fuel storage 14 Abandoned water well

1 Septic tank 4 Cess pool 7 Sewage lagoon 11 Fertilizer storage 15 Oil well/Gas well

2 Sewer lines 5 Seepage pit 8 Feed yard 12 Insecticide storage 16 Other (specify below)

3 Lateral lines 6 Pit privy [✓ 9 Livestock pens] -pigs 13 Watertight sewer lines . . . .

tion from well. . . . . north. . . . . How many feet . . . . 200 . . . . ? Water Well Disinfected? Yes . . XX . . . . . No . . . .

s a chemical/bacteriological sample submitted to Department? Yes . . . . No . . . . . XX . . . . ; If yes, date sa

submitted . . . . month . . . . day . . . . year: Pump Installed? Yes. . . . . No XX. . . . .

: Pump Manufacturer's name. . . . . Model No. . . . . HP . . . . Volts . . . .

th of Pump Intake . . . . ft. Pumps Capacity rated at . . . . ga

e of pump: 1 Submersible 2 Turbine 3 Jet 4 Centrifugal 5 Reciprocating 6 Other

ONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) [✓ constructed], (2) reconstructed, or (3) plugged under my jurisdiction an

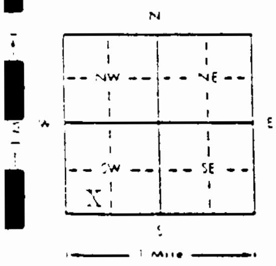
pleted on . . . . 1 . . . . month . . . . . . 14 . . . . day 1981

this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 185

Water Well Record was completed on. . . . . 4 . . . . month. . . . . . 20 . . . . day . . . . 1981 . . . . . . year under the bu

of Clarke Well & Eq., Inc. by (signature)

LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:



FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0	12	Fine sand			
12	74	Sandy brown clay			
74	76	Sand & gravel			
76	81	Brown & green clay			
81	96	Sand & gravel			

EAST DOMESTIC

DE

EVATION: unknown

h(s) Groundwater Encountered 1. . . 23. . . . . ft. 2. . . . . ft. 3. . . . . ft. 4. . . . . ft. (Use a second sheet if needed)

TRUCTIONS: Use typewriter or ball point pen, *please press firmly* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top pies to Kansas Department of Health and Environment, Division of Environment, Water Well Contractors, Topeka, KS 66620. Send one to WATER WELL OWNE ain one for your records.

MI-SS-DW

USE TYPEWRITER OR BALL
POINT PEN-PRESS FIRMLY,
PRINT CLEARLY.

T	R	EW	sec	1/4	1/4	1/4	No.

WATER WELL RECORD
KSA 82a-1201-1215

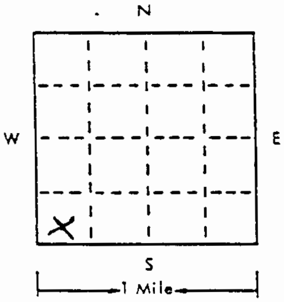
Kansas State Dept. Of Health
(Water Well Contractors)
Forbes-Bldg. 740
Topeka, Kansas 66620

1 Location of well:	County	Township name	Fraction	Section number	Town number	Range number
	Stafford	Byron	SW¼ of SW¼	XX 26	T21S	R12W

Distance and direction from nearest town or city: 6½ mi. North of Hudson, KS
Street address of well location if in city:

3 Owner of well: Dennis Siefkes
Address: Hudson, Kansas

Locate with "X" in section below: Sketch map:



4 Well depth: 90 ft. Date of completion 4-11-7
Well diameter 9 in.

5 ☐ Cable tool ☒ Rotary ☐ Driven ☐ Dug
☐ Hollow rod ☐ Jetted ☐ Bored ☐ Reverse rotary

6 Use: ☒ Domestic ☐ Public supply ☐ Industry
☐ Irrigation ☐ Air conditioning ☐ Commercial
☐ Test well ☐ ______

7 Casing: Material Styrene Height: [✓ above] below
Threaded ☐ Welded ☒ Surface 24 in.
Diam. Weight 1 5 lbs./ft. ____
5 in. to 80 ft. depth Drive shoe? ☐ Yes ☒ No
____ in. to ____ ft. depth

8 Screen:
Manufacturer Jess & Lowell
Type Styrene 200 Dia. 5"
[✓ Slot] gauze 1/8 Length 10'
Set between 80 ft. and 90 ft. ____
Fittings:
Gravel pack ☒ Yes ☐ No Size range of material 3/8-2

9 Static water level:
22 ft. below land surface Date 4-11-75

10 Pumping level below land surfaces: N/C
____ ft. after ____ hrs. pumping ____ g.p.m.
____ ft. after ____ hrs. pumping ____ g.p.m.
Estimated maximum yield ____ g.p.m.

11 Water sample submitted:
☐ Yes ☒ No Date ____

12 Well head completion: 24"
☐ Pitless adapter ~~XXX~~ inches above grade

13 Well grouted? ☒ Yes ☐ No
☒ Neat cement ☐ Bentonite ☐ ______
Depth: From 0 ft. to 10 ft.

14 Nearest source of possible contamination: NONE KNOWN
ft. ____ Direction ____ Type ____
Well disinfected upon completion? ☒ Yes ☐ No

15 Pump: ☒ Not installed
Manufacturer's name ____
Model number ____ HP ____ Volts ____
Length of drop pipe ____ ft. capacity ____ g.p.m.
Type:
☐ Submersible ☐ Turbine
☐ Jet ☐ Reciprocating
☐ Centrifugal ☐ Other

2 Type and color of material	From	To
Sandy Top soil	0	4
Sandy ~~xxx~~ clay	4	38
Fine sand	38	46
Gray clay & limestone	46	80'
Sand & gravel	80	90

(use a second sheet if needed)

WEST DOMESTIC

DW

16 Remarks: elevation

Topography:
☐ Hill
☐ Slope
☐ Upland
☐ Valley

17 Water well contractor's certification:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Clarke Well & Eq., Inc. 135
Business name License No.
Address Great Bend, KS
Signed ______ Date 4-11-
Authorized representative

Forward the white, blue and pink copies to the Kansas State Dept. Of Health.

Form WWC-3

APPENDIX C
SELECTED WATER QUALITY DATA
BIG BEND GROUNDWATER MANAGEMENT DISTRICT #5
STAFFORD, KANSAS

The following is a summary of selected water quality (chloride) data available from various studies Big Bend Groundwater Management District #5 has/ or is, undertaking. This information pertains to data collected from selected wells in northeastern Stafford County, and data collected from the lower reaches of Rattlesnake Creek.

In order for Big Bend Groundwater Management District #5 to formulate groundwater management policy, it requires the collection and analysis of an adequate base of data. This is especially true in the eastern portion of the District where natural mineral intrusion occurs as a result of subcropping Permian formations (Figure 1). This area has long raised serious concern not only for many local water users, but many scientific investigators as well: Latta 1950, Stramel 1967, Layton & Berry 1973, Stullken & Fader 1976, Hathaway 1978, Fader & Stullken 1978, Hargadine 1979, Cobb 1980, MacFarlane 1983, Whittemore 1989, Sophocleous & McAllister 1990b, Gillespie 1991, Sophocleous & Perkins 1992, Young 1992, and Whittemore 1993 (in press). In 1978, the realization of the potiential problems that might arise from this condition prompted the combined efforts of GMD #5 and Kansas Geological Survey in the installation of a network of observation wells (Figure 2).

The object of this report is not to elaborate on the existing published data at this time (or the findings and conclusions), but to provide other agencies with some data that has been collected by, and is on file with, the District.

As mentioned, the presence of saltwater has been historically known to exist in the freshwater aquifer, especially in northeastern Stafford County, where saline waters eventually reach the surface (in Rattlesnake Creek and the salt marshes of Quivira National Wildlife Refuge). It is known that under certain hydrogeologic conditions, the pumping and drawdown from large capacity wells on the aquifer, allows an upconing of the saltwater "interface". Because of this potiential upconing (and degredation to the fresh water), the District decided to see, if in fact, this might be occurring in that area.

In the Spring of 1990, the District began conducting preliminary investigations into irrigation water quality changes from the operation of large capacity wells in north-central Stafford County. The area of study is covered approximately by the Hudson NW Quadrangle (USGS 7.5' topographic sheet). See Figure 3. Samples of water were collected from selected wells throughout the growing (pumping) season. Intervals for collecting samples were dictated primarily by when the systems were operating.

Table 1 lists locations, dates of samples, and chloride concentrations (measured in milligrams/liter), from this investigation, along with any other miscellaneous chloride data that existed, or was taken, in this same general area (most of which is from domestic wells). Sampling continued until the early part of 1992, when the area began receiving more normal amounts of precipitation and pumping was reduced considerably. This preliminary sampling indicates that chloride levels within the water pumped from some wells continued to increase the longer the wells were in operation. Samples collected from a number of wells increased to total concentration levels of over 300 mg/l

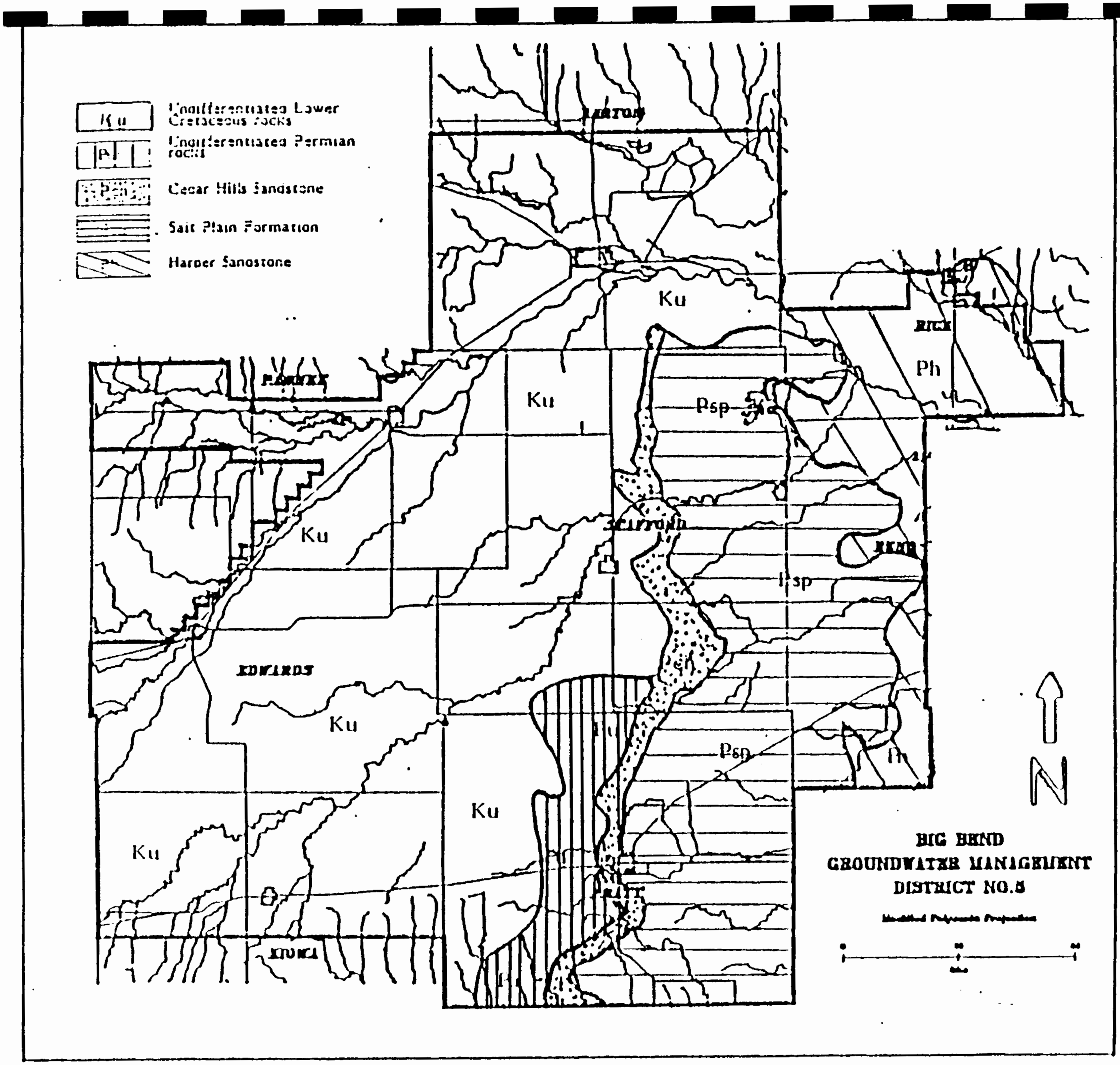


Figure 1 : Buried (subcrop) bedrock formations in Groundwater Management District #5.

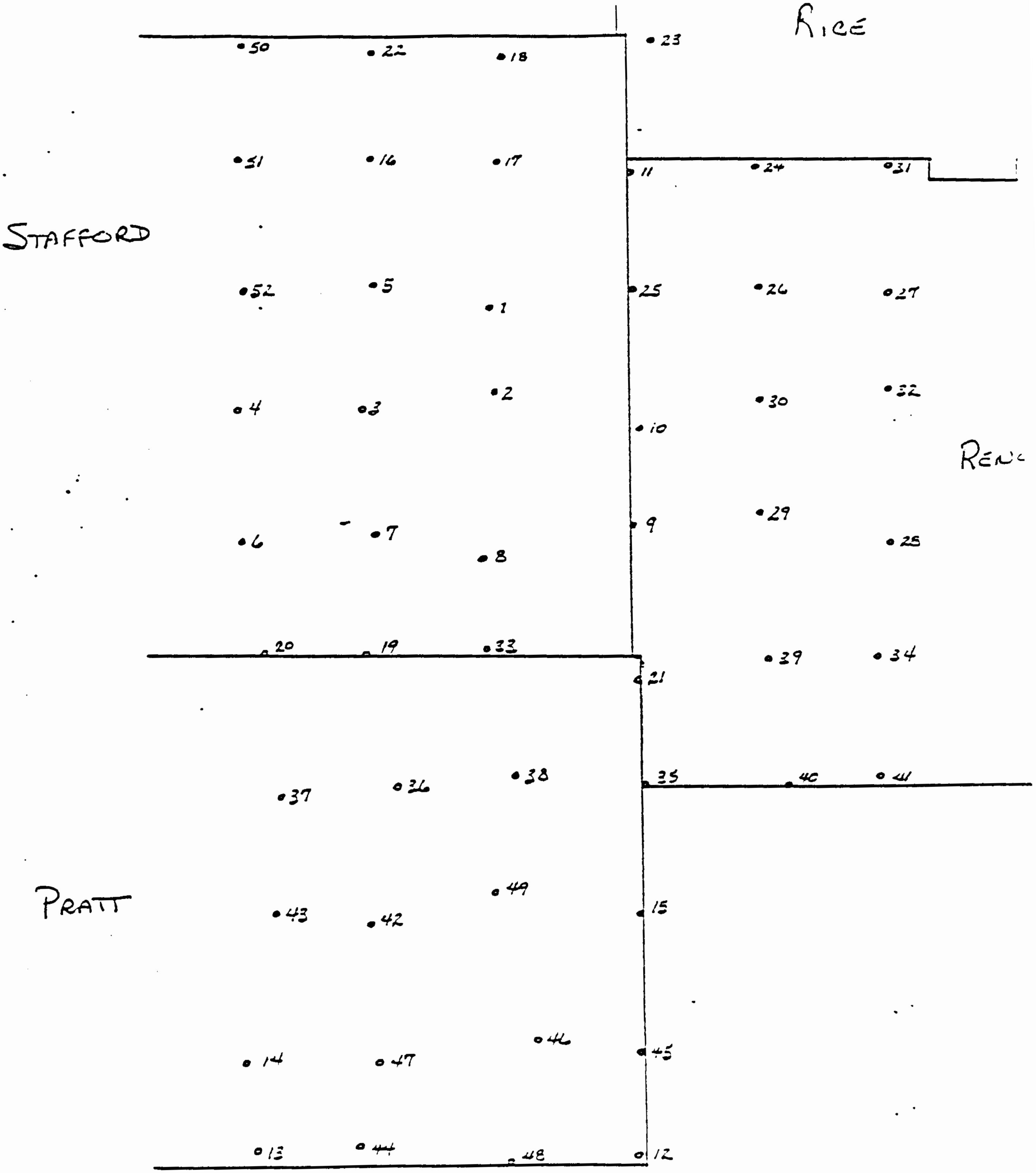


Figure 2. Location of Groundwater Management District #5 - Kansas Geological Survey water quality observation well network sites.

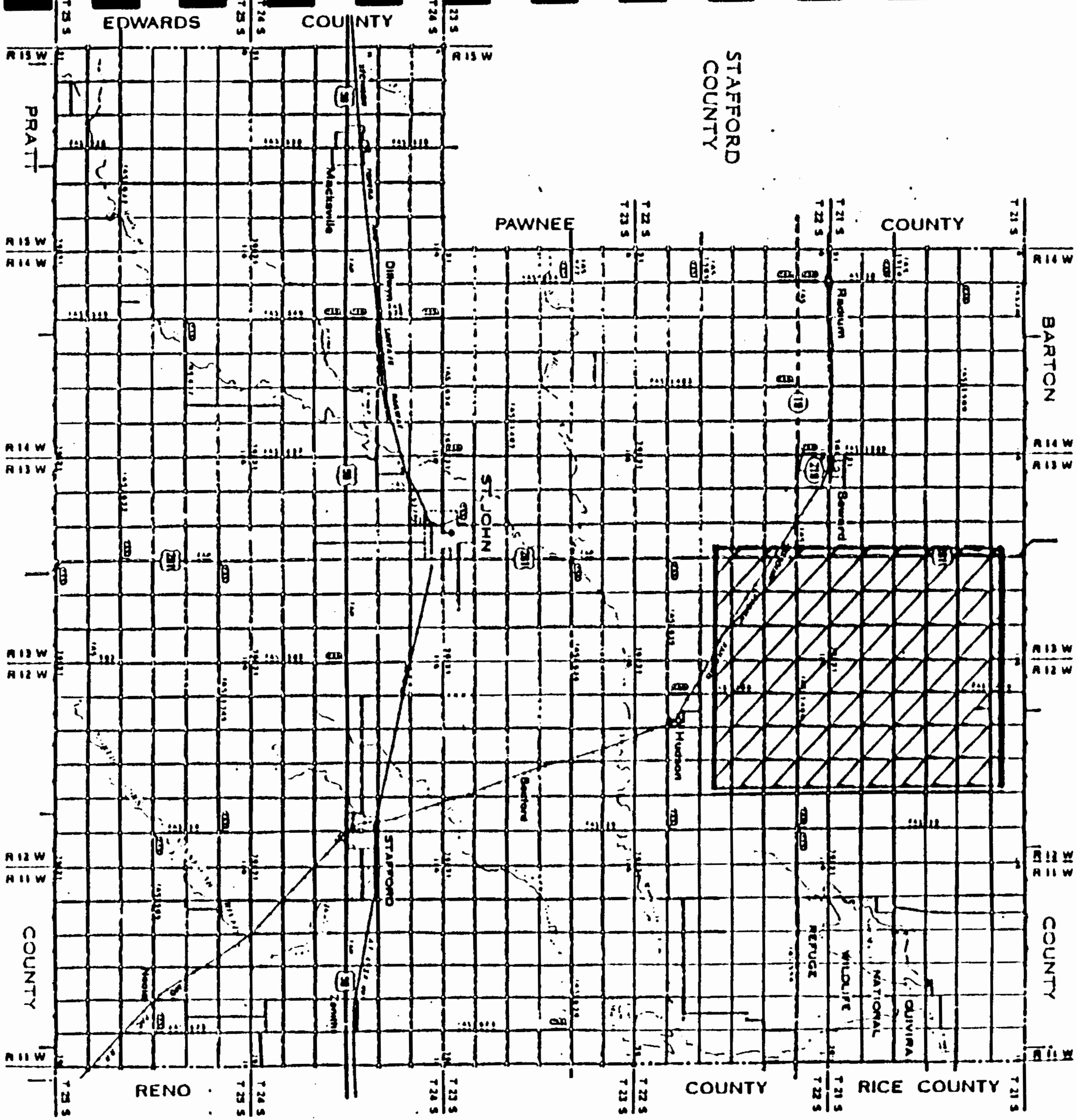


Figure 3. Groundwater Management District #5 study area for sampling irrigation water to monitor chloride concentrations.

chloride, and some even increased to over 500 mg/l chloride. However, once these wells were shut down for an extended period of time, the chloride levels would be decreased when the wells subsequently went back into operation. Of the 23 wells in which multiple samples were taken during a growing season, the following increases in chloride concentrations (total for the season) were observed: increases of 0-20 mg/l = 6 wells; 20-100 mg/l = 8 wells; 100-200 mg/l = 6 wells; and increases of more than 200 mg/l = 3 wells. This preliminary sampling data seems to indicate that in this area, the pumping (and subsequent drawdowns) from large capacity wells, does have some effect on the movement of saline water in the aquifer. But to what extent the total change (degradation to the aquifer) that is occurring under various pumping conditions has yet to be determined.

From the GMD #5-KGS observation well network, it was learned that a "head" (pressure) differential exists among the Permian, the basal freshwater aquifer, and the upper watertable in most areas. These "heads" (measured as waterlevels) also vary from region to region. However, when the Permian, or the basal aquifer (which is usually saltwater) possesses the highest head, there could be a natural tendency for upward migration of the saltwater. Therefore, in considering the total problem of water quality, the District also wanted to examine the interaction of the aquifer with surface flows. Since in fact, some of these surface flows are derived from the underlying aquifer, and are thus a drain (?pressure release) on the system. Especially, as was stated earlier, since natural saline waters from the deeper portion of the aquifer do eventially reach the surface (this occurs primarily in the flows of the lower reaches of Rattlesnake Creek, and in the artesian seepage around the salt marshes of Quivira).

Several times during past investigations, limited water quality sampling along Rattlesnake Creek has given evidence of a notable change in surface water chloride concentrations (Latta, Stramel, and Bidleman). This change (ie. increased concentrations) occurs in the lower reach of the stream, in the area where the stream passes over the Permian subcrop.

The summer of 1991 was dry, with the area receiving below normal precipitation. The District conducted a preliminary water sample survey on October 18, 1991 (Figure 4). At that time, only minimal flow conditions existed (estimate at less than 1 cfs) in the west half of township T23S-R12W, and in the east half of township T23S-R13W. These samples also indicated increases in chloride concentrations along this stretch of the stream (Table 2). From this first preliminary information, the District decided to expand its water sampling, and to begin gaging stream discharge flows at some of the sample locations. Stream gaging was considered necessary as the only USGS gage stations were either many miles upstream (Macksville station) or many miles downstream (Zenith station). It was also decided to collect data on a quarterly basis, to coincide with the waterlevel measure-

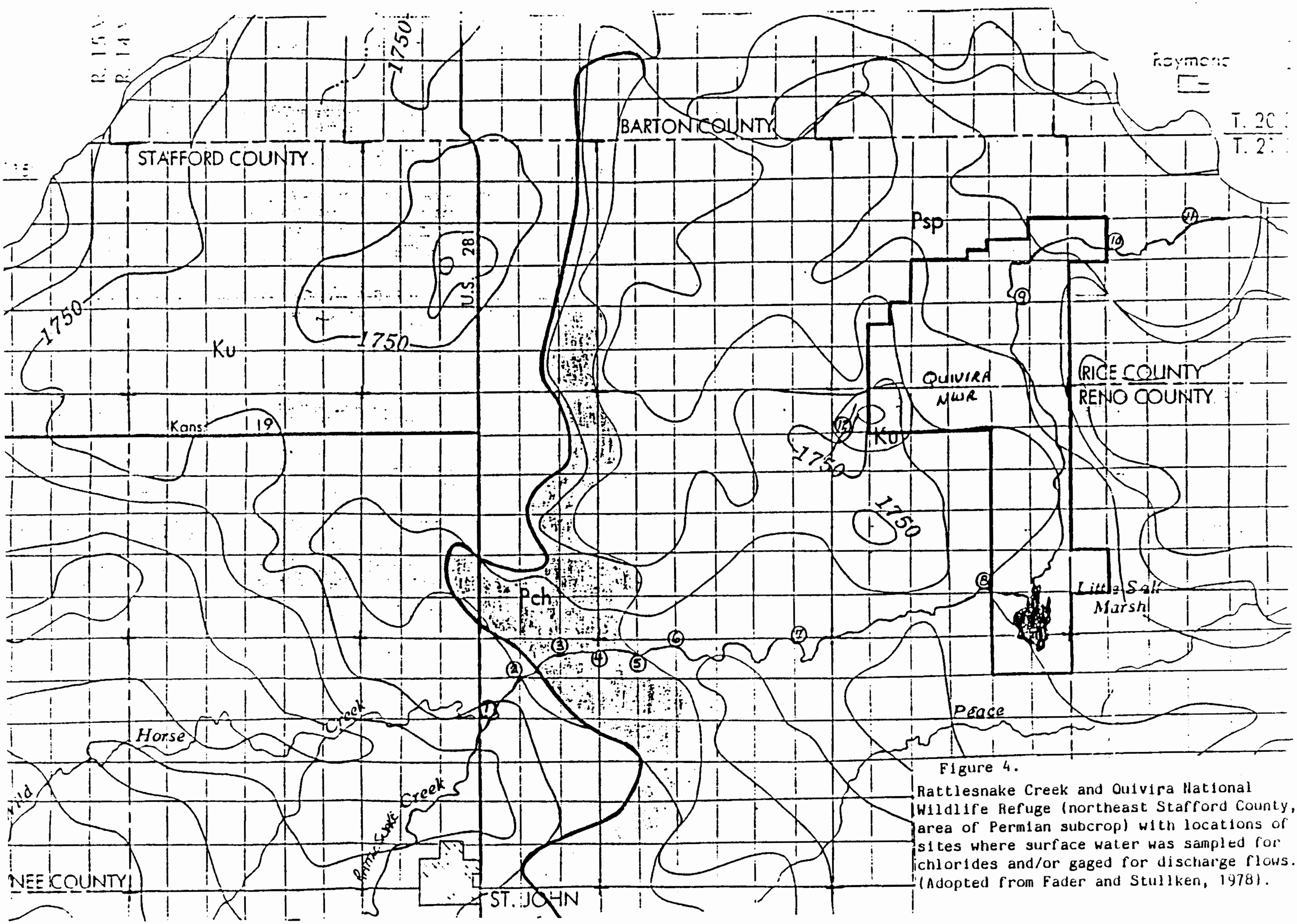


Figure 4.

Rattlesnake Creek and Quivira National Wildlife Refuge (northeast Stafford County, area of Permian subcrop) with locations of sites where surface water was sampled for chlorides and/or gaged for discharge flows. (Adopted from Fader and Stullken, 1978).

ments being taken on the GMD5-KGS water quality network wells (January, April, July, and October).

On April 6, 1992, the Rattlesnake Creek was visually surveyed from its exit of Quivira National Wilflife Refuge (east side 18-21-10, Rice County; listed on some topographic maps as Salt Creek; also located two miles upstream of the Raymond gage station), to the southwest corner of Stafford County (SW 28-25-15). Although ponding of water did occur along many stretches of the stream channel, actual flowing water was encountered only in the lower reaches (east of US 281, the area of the Permian subcrop). It should be noted, that although 1992 turned out to have above normal precipitation, this first survey was taken before any significant rainfall had begun.

The results of this survey, as well as subsequent sampling, are shown in Table 2. It is evident from this data that discharge flows, chloride concentrations, and total salt load, substancially change as the stream passes over the Cedar Hills portion of the subcrop , and as it flows eastward. It appears that more data is necessary before a clear picture of the interaction becomes apparent.

Bidleman, L.A., 1983
An Investigation into the Source of Chloride in the Arkansas River and Related Drainage Between Great Bend and Wichita: Unpublished research by Groundwater Management District #2.

Cobb, P.M., 1980
The Distribution of Mechanisms of Saltwater Intrusion in the Fresh Water Aquifer and in Rattlesnake Creek, Stafford County, Kansas: Unpublished M.S. Thesis, Department of Civil Engineering, University of Kansas, 176 pages. (Available as Kansas Geological Survey Open-File Report 80-17).

Fader, S.W. & Stullken, L.E., 1978
Geohydrology of the Great Bend Prairie, South Central Kansas: Kansas Geological Survey, Irrigation Series 4, 19 pages.

Gillespie, J.B., & Others, 1991
Geohyrdologic data for the South Fork Ninnescah River Valley and Adjacent Plains in Pratt and Kingman Counties, South-Central Kansas: United States Geological Survey Open-File Report 91-186, 55 pages.

Hargadine, G.D. & Others, 1979
Kansas Water Quality Management Plan 1978, Mineral Intrusion in Kansas Surface Waters, a summary and management report: Kansas.

Hathaway, L.R. & Others, 1978
Chemical Quality of Irrigation Waters in Ford County and the Great Bend Prairie of Kansas: Kansas Geological Survey, Chemical Quality Series #7, 41 pages.

Latta, B.F., 1950
Geology and Ground-Water Resources of Barton and Stafford Counties, Kansas: Kansas geological Survey Bulletin 88, 228 pages.

Layton, D.W. & Berry, D.W., 1973
Geology and Groundwater Resources Pratt County, South Central Kansas: Kansas Geological Survey Bulletin 205, 33 pages.

Macfarlane, J.A. & Ackerman, J., 1983
The Detection of Natural Brines by Vertical Electrical Sounding in the Great Bend Prairie, South-Central Kansas: Kansas Geological Survey Open-File Report 83-6, 24 pages.

Sophocleous, M. & McAllister, J., 1990b
Hydrologic - Balance Modeling of the Rattlesnake Creek Watershed, Kansas: Kansas Geological Survey, Ground-Water Series 11, 72 pages.

Sophocleous, M. & Perkins, S.P., 1992
Stream-Aquifer and Mineral Intrusion Modeling of the Lower Rattlesnake Creek Basin with emphasis on the Quivira National Wildlife Refuge,: Kansas Geological Survey Open-File Report 92-6, 204 pages.

Stramel, G.J., 1967
Rattlesnake Creek Study: Wichita Water Department, 31 pages.

Stullken, L.E. & Fadar, S.W., 1976
Hydrogeologic Data From the Great Bend Prairie, South Central Kansas: Kansas Geological Survey, Basic Data Series, Ground-Water Release No. 5, 50 pages.

Whittemore, D.O., 1993
Ground-Water Geochemistry in the Mineral Intrusion Area of Groundwater Management District No. 5, South-Central Kansas, Kansas Geological Survey Open-File Report 93-2.

Whittemore, D.O. & Others, 1989
Effects of Variations in Recharge on Groundwater Quality: Journal of Hydrology, 106, pages 131-145.

Young, D.O., 1993
Mineral Intrusion: Geohydrology of Permian Bedrock Underlying the Great Bend Prairie Aquifer in South-Central Kansas: Kansas Geological Survey Open-File Report 93-2.

Table 1 Chloride concentrations (measured in mg/l) of water samples from wells in northeast Stafford Co.

LOCATION	DATE	CL (mg/L)
SW 2-21-12	06/19/91	68
SE 2-21-12	07/10/90	44
	06/19/91	49
SE 5-21-12	06/18/90	79
	07/13/90	85
	06/28/91	86
	09/19/91	83
	04/30/92	82
NE 6-21-12	05/20/89	54
	07/25/90	121
	06/07/91	28
SW 9-21-12	06/14/90	67
	07/18/90	87
	08/09/90	90
NE 11-21-12	06/19/90	165
	05/22/91	173
	06/28/91	208
	08/01/91	290
	08/16/91	225
	05/06/92	263
NW 11-21-12	06/19/90	26
SW 11-21-12	06/26/90	173
	04/30/92	88
SW 14-21-12	07/10/90	48
	06/07/91	64
NW 15-21-12	06/14/90	18
	06/26/90	49
	07/25/90	107
	05/21/91	22
	06/21/91	46
	08/01/91	113
	05/06/92	35
SE 15-21-12	06/26/90	195
	07/13/90	263
	08/09/90	304
	06/21/91	58
	08/01/91	295
NE 16-21-12	06/14/90	85
	06/26/90	122
	08/09/90	202
	06/21/91	131
	08/01/91	180
	05/06/92	108
NE 17-21-12	06/28/90	55
	08/09/90	74
	09/11/90	75
	06/28/91	57
	05/06/92	65
SE 17-21-12	06/28/90	148
	09/19/91	160
	04/30/92	163
SW 19-21-12	03/16/90	990
NE 23-21-12	06/26/90	181
	06/21/91	167
S2 23-21-12	08/01/91	195
NE 26-21-12	06/26/90	86
	08/16/91	142
SW 26-21-12 (a)	08/27/90	161
SW 26-21-12 (b)	08/27/90	163
SW 27-21-12	06/18/90	126
	07/09/90	130
	07/25/90	129
	08/27/90	134
	06/21/91	126
	06/28/91	137
	08/01/91	118
	08/16/91	121
	05/06/91	146
SE 27-21-12	06/18/90	177
	06/28/90	225
	07/09/90	270
	07/25/90	250
	08/27/90	303
	06/21/91	246
	08/01/91	214
	08/16/91	301
	08/30/91	320
	05/06/92	215

Table 1 Chloride concentrations (measured in mg/l) of water samples from wells in northeast Stafford Co.

LOCATION	DATE	CL (mg/L)
NE 28-21-12	06/18/90	125
	07/09/90	94
	08/27/90	226
	06/21/91	147
	08/01/91	222
	08/16/91	219
SE 28-21-12	06/18/90	68
	07/10/90	78
	07/25/90	98
	05/21/91	69
	06/21/91	73
	06/28/91	91
	08/01/91	120
	08/16/91	125
	04/30/92	82
NE 32-21-12	06/29/90	242
	07/10/90	220
	08/09/90	385
	08/27/90	480
	05/21/91	387
	06/21/91	517
	08/01/91	441
NW 33-21-12	10/01/91	160
NE 34-21-12 (a)	06/18/90	12
	07/09/90	139
	07/25/90	213
	08/27/90	235
	06/07/91	104*
	06/21/91	38*
	08/01/91	222*
	04/30/92	47*
	*May represent mixture of a & b	
NE 34-21-12 (b)	06/18/90	27
	07/09/90	27
	08/27/90	47
SW 1-21-13	07/13/90	133
	09/19/91	20
	04/30/92	138
SE 10-21-13	06/28/90	274
	09/11/90	320
	08/01/91	213
	08/16/91	172
	04/30/92	310

LOCATION	DATE	CL (mg/L)
NE 13-21-13	09/14/90	290
	06/28/91	302
	08/01/91	301
	08/30/91	323
	09/06/91	201
NE 15-21-13	07/11/90	149
	07/25/90	160
	04/30/92	133
SE 24-21-13	05/06/92	260
NE 26-21-13	08/16/91	122
NW 26-21-13	05/06/92	134
NW 27-21-13	06/29/90	135
	07/17/90	136
	09/11/90	155
	04/30/92	137
NE 28-21-13	08/01/91	159
SW 4-22-11	04/30/92	64
SW 5-22-11	04/30/92	147
(Artesian)	07/13/92	140
	10/01/92	137
	03/26/93	150
NW 9-22-11 (Artesian)	01/28/92	79
SE 28-22-11(a)	05/15/90	106
SE 28-22-11 (b)	05/15/90	9
SW 31-22-11	04/07/92	6750
SE 1-22-13	08/27/90	520
	09/11/90	460
	05/06/92	362
SS 3-22-13	06/18/90	113
	07/13/90	149
	08/27/90	181
	09/11/90	187
	06/28/91	140
	07/25/91	195

Table 1 Chloride concentrations (measured in mg/l) of water samples from wells in northeast Stafford Co.

LOCATION	DATE	CL (mg/L)
SE 10-22-13	07/09/90	23
	07/24/90	30
	08/27/90	41
	06/28/91	25
	08/01/91	37
	05/06/92	20
NW 11-22-13	07/09/90	133
	07/25/90	198
	08/08/90	264
	08/27/90	130
	06/28/91	180
	08/01/91	457
	08/16/91	348
	05/06/92	99
NE 13-22-13	07/28/92	10
NW 13-22-13	09/06/88	550
	06/28/90	64
	07/09/90	378
	08/09/90	518
	08/27/90	350
	06/21/91	197
	06/28/91	326
	04/30/92	208
SW 13-22-13	07/09/90	206
	09/11/90	365
	06/28/91	213
	04/30/92	185
SE 14-22-13	07/09/90	333
	08/09/90	275
SE 27-22-13	02/16/93	9
NE 5-23-10	04/10/92	250
SW 5-23-10	04/10/92	1960
NW 6-23-10	07/18/89	3500
SE 7-23-10	09/09/92	620
SE 21-23-11	02/09/90	305
SW 5-23-12 (a)	08/19/88	346
SW 5-23-12 (b)	08/19/88	820
SE 6-23-12	08/19/88	50
NE 36-23-12	06/21/91	205
SW 4-24-11 (a)	12/10/90	110
SW 4-24-11 (b)	12/10/90	155
NE 6-24-11	07/26/91	800
SW 11-24-12	02/18/92	220

Table 2 Surface water chloride concentrations and discharge data from Rattlesnake Creek

		10-18-91	4-6-92	7-13-92	10-1-92	3-26-93
1. SW 10-23-13	= CL		80	44	65	52
	= CFS		NO FLOW PONDED	5.12	0.84	LARGE (a) FLOW
2. SE 3-23-13	= CL	310	124	76	130	65
	= CFS	FLOW	FLOW			
3. ES 2-23-13	= CL		950	496	975	276
	= CFS					
4. ES 1-23-13	= CL	1460	1490	856	1660	660
	= CFS	FLOW				
5. ES 6-23-12	= CL	1990	1750	1028	2000	790
	= CFS	FLOW	4.86	11.12	3.53	31.89
6. ES 5-23-12	= CL	1980				
	= CFS	SMALL FLOW				
7. WS 1-23-12	= CL	2340	1810	900	2090	850
	= CFS	PONDED	5.25	11.95	2.88	34.94
8. SW 26-22-11	= CL		2020	1124	2520	1080
	= CFS	DRY	(6.40)b	(25.00)b	(3.80)b	
9. SS 23-21-11	= CL					1070
	= CFS	DRY	DRY	DRY	VERY SMALL FLOW	LARGE FLOW
10. WS 17-21-10	= CL		7030	6900	8200	1770
	= CFS					
11. WS 15-21-10	= CL					
	= CFS	(0.53)c	(2.70)c	(8.80)c	(2.20)c	
12. NW 7-22-11 (d)	= CL		1650	1480	2350	1520
	= CFS		FLOW	FLOW	FLOW	FLOW

(a) CONSTRUCTION IN STREAM PREVENTED MEASURING FLOW
(b) USGS ZENITH STATION
(c) USGS RAYMOND STATION
(d) DATA IS FROM SMALL, UNNAMED SURFACE (?ARTESIAN) FLOW