U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

REPORT OF WORKSHOP 92 ON THE CORRELATION OF MARINE AND TERRESTRIAL RECORDS OF CLIMATE CHANGES IN THE WESTERN UNITED STATES.

by

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Open-File Report 92-402

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INTRODUCTION

The second annual workshop of the Correlation of Marine and Terrestrial Paleoclimatic Records Project met at Pajaro Dunes Conference Center, Watsonville, CA on April 7 through 10, 1992. The objective of the project is to construct high-resolution records of the past 150,000 yrs from paired oceanic and terrestrial responses to major climatic changes of a region that was sensitive to past climatic change - the western margin of North America. The project focus is to concentrate on the last glacial–interglacial cycle, the last deglaciation, major climate events (Isotope Stage 5e, the Younger Dryas, Termination II, mid-Holocene Hypsithermal, etc.), times of varve formation on the continental margin, and higher resolution snapshots (e.g., ENSO events, Little Ice Age, etc.) where possible. The specific objective of the workshop was to (a) review the progress of identifying and analyzing existing marine records, (b) present results of FY92 field work that collected new marine and terrestrial sections, and (c) redirect the project where necessary and focus on the analytical phase. Twenty two investigators from the USGS and several universities attended the meeting (Appendix 1).

EXISTING CORES – MARINE

A priority established at the first workshop (Gardner and others, 1991) for the Marine component of this project was to collect all existing core data from the west-coast margin that might have sedimentary records in the time window of interest. In addition, the marine group was to search for potentially valuable cores in various national repositories and to initiate a study of them. Potential cores were identified from Gorda Ridge (Oregon State Univ.), the Farallones margin (USGS), and the outer Patton Ridge (USGS) (Fig. 1).

Twenty-three cores were located, some with various climate-proxy data already generated by others, both published and unpublished, and some analyzed by the Project

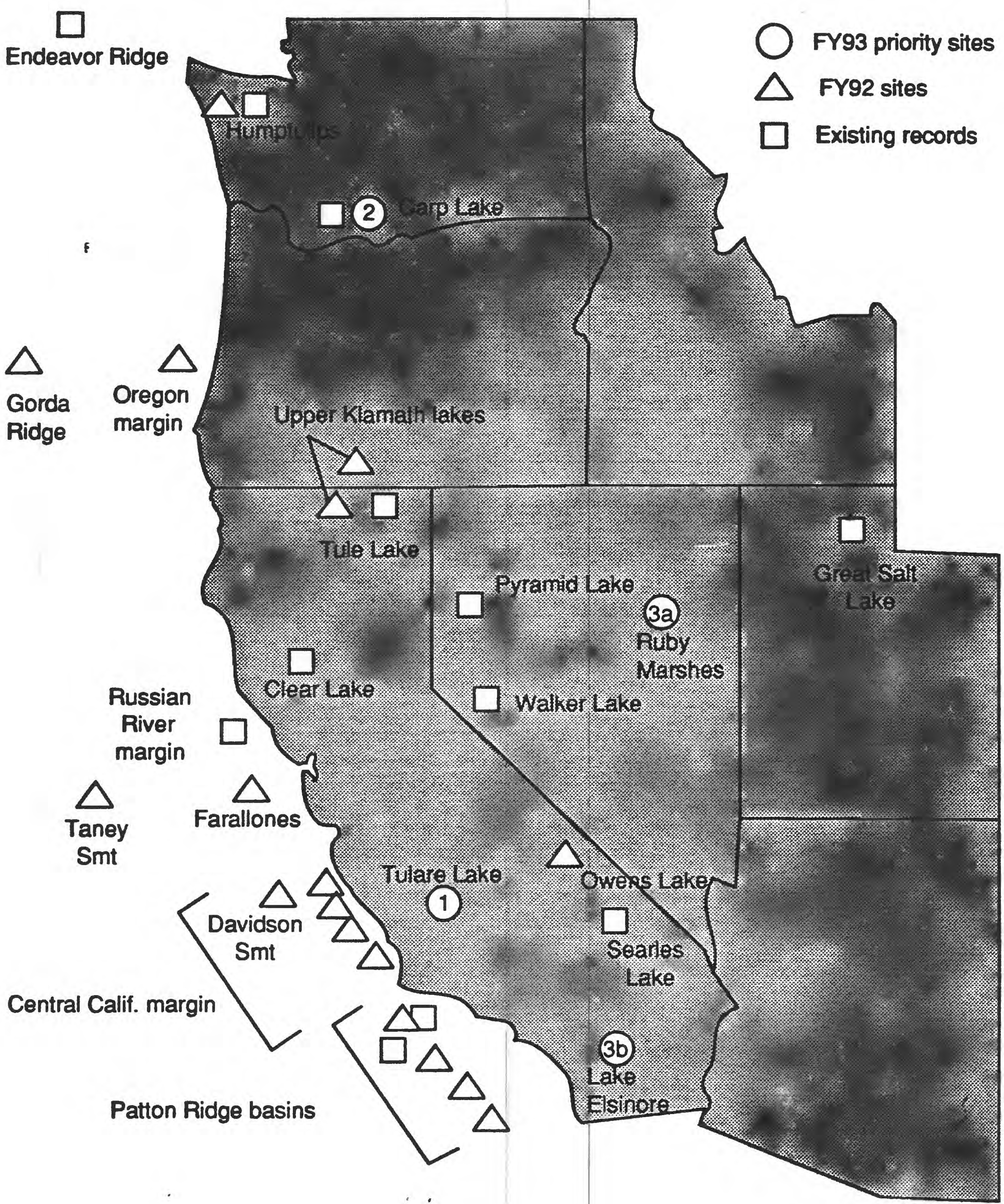

Figure 1. Locations of existing, FY92, and FY93 core sites.

Table 1. Summary of database entries

CORE	CaCO3	Corg	C-14	ISOTOPES	IG	OG	POLLEN	FORAMS	DIATOMS	RADS	NANNOS	CLAY
AHF10614				X								
END77-29	X			X								
F8-90-G21	X	X										
F8-90-G25	X	X										
F8-90-G27	X	X										
L13-81-G117	X	X	X		X				X			
L13-81-G138	X	X	X	X	X		X	X	X	X		X
PAR85-01	X		X									
PAR85-34	X		X		x							
TT17-3	X											
TT197-G330	X	X	X		X				X			
V1-80-G1	X	X	X				X	X	X		X	
V1-81-G15	X	X		X	X	X	X	X				X
V1-80-G22	X	X	X									
V1-80-G23												
V1-80-P3	X	X	X	X	X		X	X	X	X	X	X
V1-80-P4					X		X					
V1-80-P8	X	X			X		X	X				
W8709A-P13	X	X	X				X					
W8709A-P8				X			X					
Y6910-2				X			X					
Y7005-64	X			X								
Y7211-1				X			X					

Notes:
IG = ingorganic geochemistry
OG = organic geochemistry
GZ = grain size
Corg = organic carbon
silt = silt mineralogy
Rads = Radiolaria
Isotopes = O18/O16 & C13/C12
clay = clay mineralogy
refs = published data

Table 1. Summary of database entries

CORE	GZ	SILT	REFs
AHF10614			X
END77-29			X
F8-90-G21			
F8-90-G25			
F8-90-G27			
L13-81-G117			
L13-81-G138	X	X	X
PAR85-01			X
PAR85-34			X
TT17-3			
TT197-G330			
V1-80-G1	X		
V1-81-G15	X		
V1-80-G22			X
V1-80-G23			
V1-80-P3	X		X
V1-80-P4			
V1-80-P8			
W8709A-P13			X
W8709A-P8			X
Y6910-2			X
Y7005-64			X
Y7211-1			X

during FY91 and early FY92 (Table 1). A relational database of these cores was constructed using the free software Hypercard 2.1 that comes bundled with all new Apple Macintosh computers. This software was chosen because it is the only database software that does not require the user to purchase an expensive software package and will run on any color Macintosh running system 7.0 or higher. The database is entirely "point and click" and requires no manual or other aids. The use of the database follows a logical progression from (a) clicking the area you are interested in on the regional map (Fig. 2), (b) clicking the core you are interested in on the local map (Fig. 3), (c) clicking on a data file from a list (Fig. 4), and (d) reading or copying from the flat file of data displayed. The database now contains data from all 23 cores and the database will be continually updated with new cores and new analytical data as they become available. The database was distributed to all interested participants at the workshop.

EXISTING CORES – TERRESTRIAL

Tule Lake, California

The Tule Lake section is a composite section from five closely-spaced cores collected in 1983 from the Tule Lake sub-basin of the upper Klamath River basin. The section contains a nearly continuous record of lacustrine deposition for the last 3 My (Adam and others, 1989). The last 150 ky are represented in the upper 25 m of this record.

Sediment accumulated in the Tule Lake basin during the past 150 ky at an average rate of 6 ky/m, or about the same order of magnitude as anticipated deposition rates for marine cores (about 10 ky/m). The Tule Lake record can be used for marine-terrestrial paleoclimatic correlations if sample resolution is improved. Time gaps in excess of 5 ky exist between some samples; to increase time resolution to 500 years or less it will be necessary to analyze additional, intermediate samples. The Tule Lake cores are curated at the USGS in Menlo Park and are available for resampling.

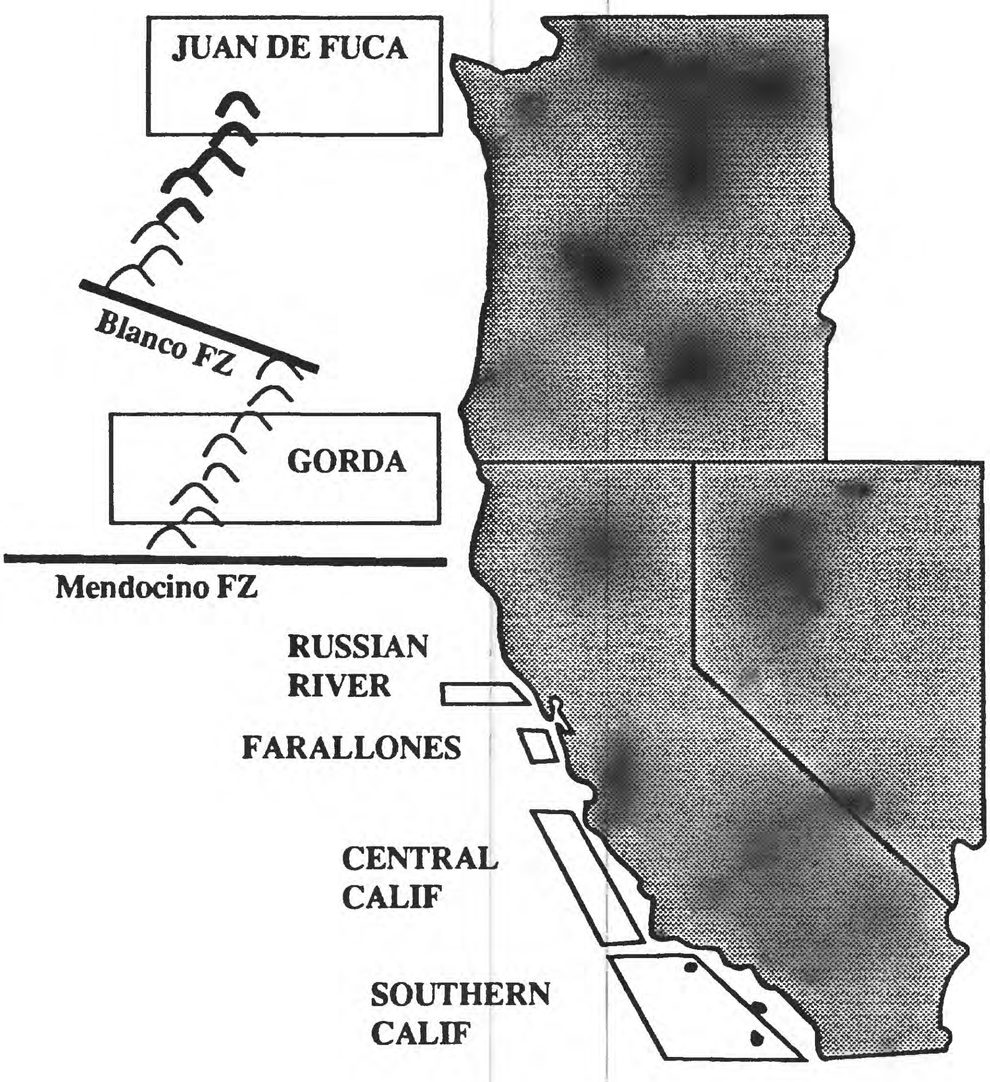

Figure 2. Database index map for offshore California, Oregon, and Washington.

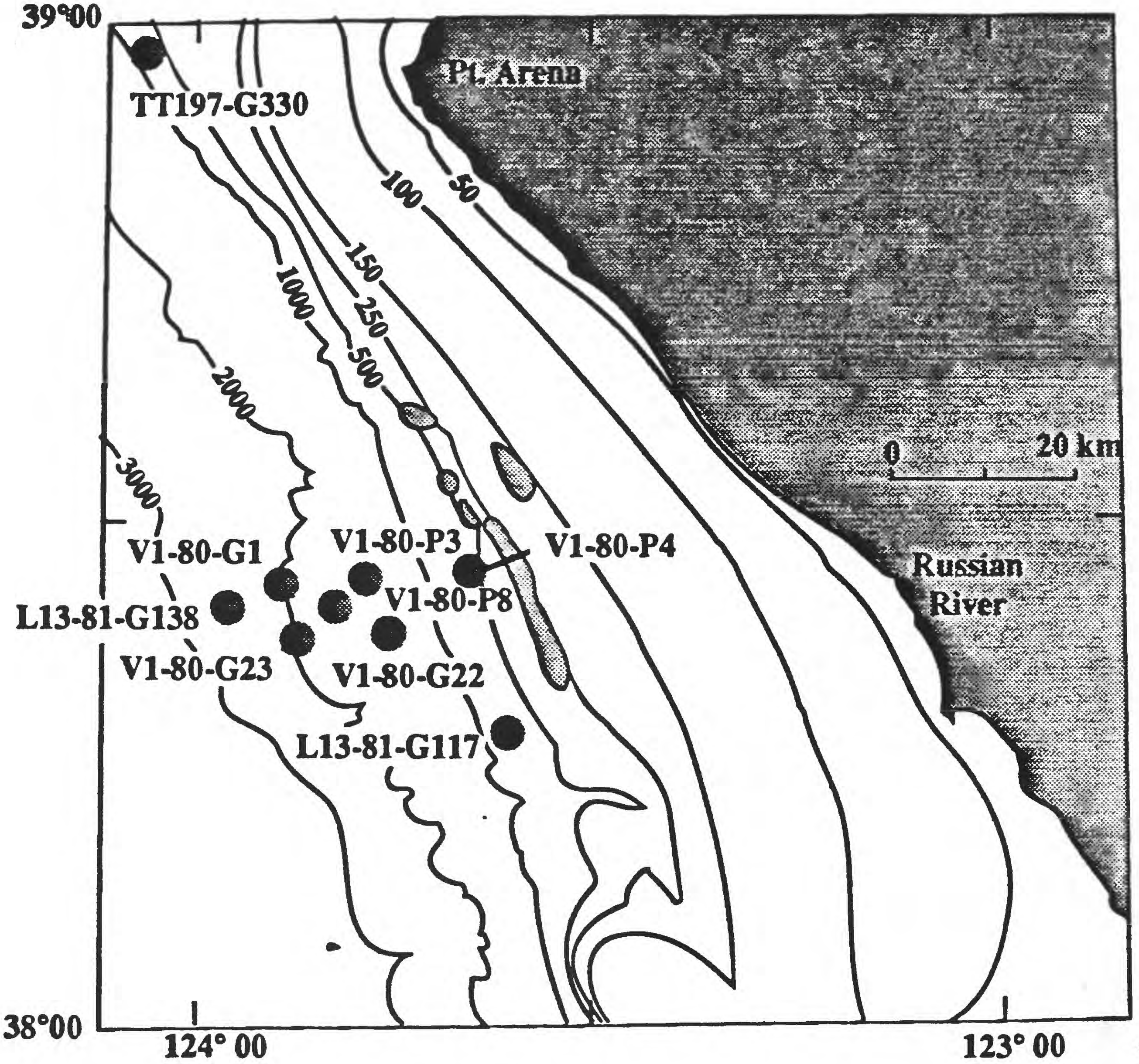

Figure 3. Database local map with core locations

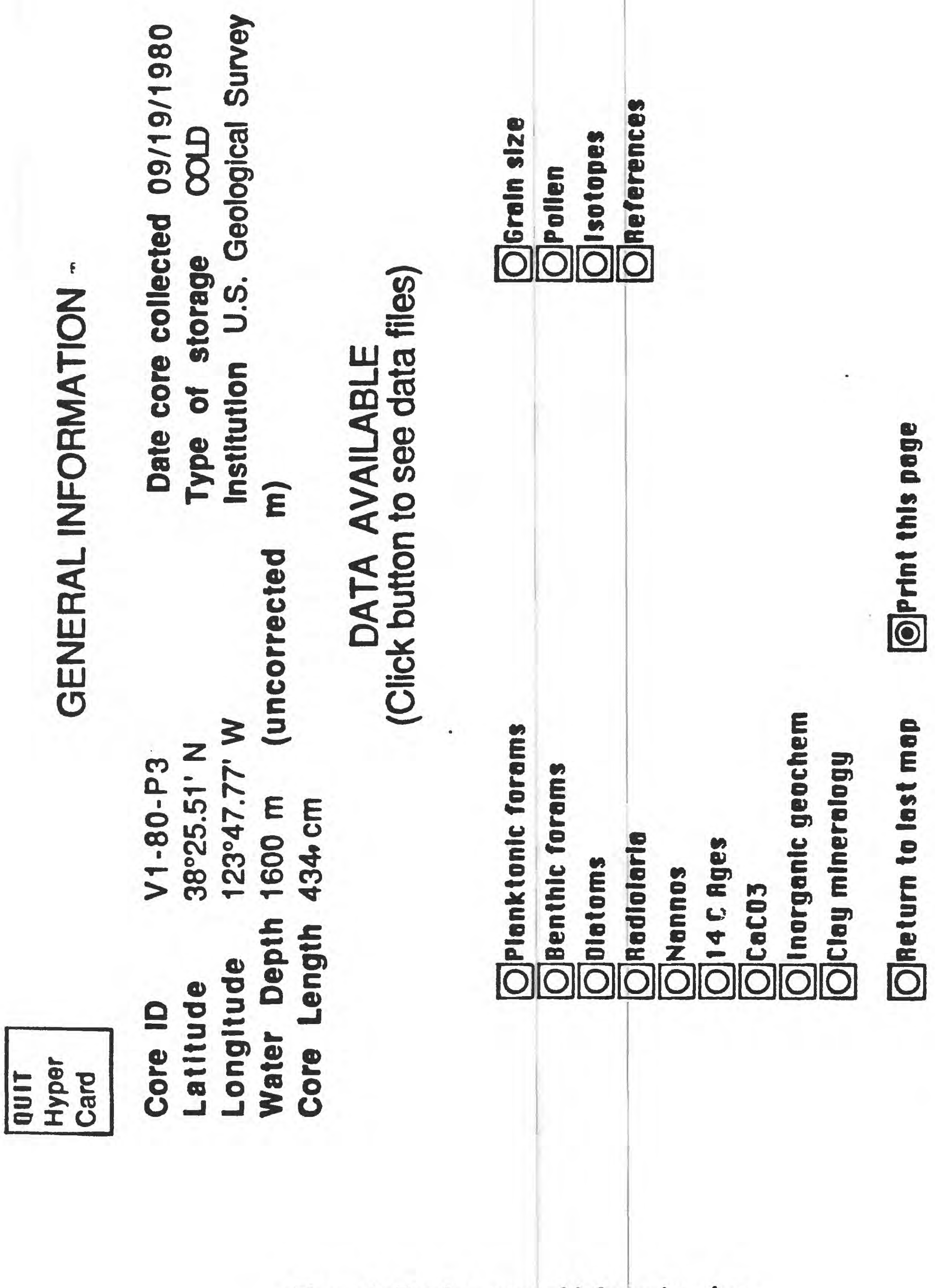

Figure 4. Database general information view.

Clear Lake, California

Core CL-73-4 is a 115-m-long core from Clear Lake, Lake County, California, that has yielded a pollen record for the past 130 ka (Adam, 1988). The oak pollen curve from that core has been interpreted as a proxy for past temperature and precipitation changes (Adam and West, 1983), and correlations with other long climate records suggest that the Clear Lake pollen record is among the most detailed records available for the last full glacial cycle, and especially for the complex changes that occurred during oxygen isotope Stage 5.

Chewaucan Basin, Oregon

Several cores were obtained in 1986 by the USGS from the Chewaucan basin in south-central Oregon, but few analyses have been made to date. The basin includes modern Summer Lake and Lake Abert, which coalesced during the last pluvial period to form Lake Chewaucan (Allison, 1982). A 65-m core from Ana Springs, near the north end of Summer Lake, is estimated to span the interval from about 1.2 Ma to 6 ka. The core contains a thick sequence of lacustrine sediments that include abundant ostracodes. Samples for tephra and pollen were taken from this core by investigators from the University of Nevada, but no work has been completed. Two 55-m cores were taken from Upper Chewaucan Marsh; contrary to expectations, those cores contain tens of meters of dry valley-bottom sediments not consistent with the modern marsh environment. Sediments at the base of both cores include a magnetically-reversed interval that suggests an approximate age of 900 ka.

Owens Lake

A 278-m core from Owens Lake, Inyo County, California, was taken by the USGS in 1952. Preliminary assessment of microfossils in the core (Smith and Pratt, 1957) shows diatoms and ostracodes that indicate cyclic alternation between fresh throughflow lake conditions and saline, probably closed-basin conditions during the past 600+ ky. Six episodes of fresh, overflowing lake conditions during the past 600 ky suggest the 100 ky cycles of orbital eccentricity that are presumed to force climate change recorded by marine systems (e.g., Wright, 1989). These preliminary have led to the current (April-May 1992) effort to recover an additional core from Owens Lake.

Searles Lake

A long core from the Searles Lake playa has been extensively studied (e.g., Smith, 1983) and includes a record of the past 3.2 My. Deposition during that interval alternated between lacustrine and dry-playa phases, with the result that few paleoclimatic tools provide results throughout the core. The Searles Lake record is one of the most important records in the western U.S., but its position in the rain shadow of the Sierra Nevada and the discontinuous record of the biostratigraphy make it difficult to establish unequivocal correlations with other areas.

Tulare Lake

The sediments of Tulare Lake, in Kings and Tulare Counties, California, contain evidence of past lakes that were maintained by favorable climatic conditions and impounded by outwash dams across the axis of the San Joaquin Valley (Atwater and others, 1986). The deposits contain pollen, diatoms, and ostracodes that reflect the extent and chemistry of the ancient lakes and indicate the past presence of a wide variety of lacustrine and marsh environments.

CORES COLLECTED DURING FY92 – MARINE

USGS cruise F2-92 was conducted along the California margin from March 11 to March 30, 1992 using the RV FARNELLA (Gardner and Dean, 1992). Fifty-four piston cores were collected, with an average of about 7 m of recovery per core and a range of lengths from 2.5 to 10 m. In addition, nine gravity cores were collected that range in length from 1.2 to 5.5 m (see Table 1 for a summary of the cores). The total amount of sediment recovered in these 63 cores is 380 m. The cores were collected from Taney

Seamount, Davidson Seamount, the Santa Lucia margin, and the Patton Ridge margin (Figs. 5 and 6). The sediments from the seamounts were collected from the carbonate lysocline but smear slides show that siliceous and calcareous biogenic components (diatoms, Radiolaria, nannofossils, and Foraminifera) are abundant. These cores represent the pelagic signal from this region, uncontaminated by any hemipelagic dilution or strong margin chemical events. The cores from the margin are all from hemipelagic settings and contain both pelagic and terrigenous components. These cores have the potential for valuable marine–terrestrial correlations.

Each core was analyzed aboard ship for p-wave velocity, wet bulk density, and magnetic susceptibility at 1-cm intervals, and water content has been calculated for each core at 1-cm intervals. In addition, each core was split, imaged in 24-bit color, described visually and microscopically from smear slides taken for each lithology. A digital graphic core log was made for each core from a compilation of the visual core description and smear-slide data. The cores were sampled at 30-cm intervals for calibration of water content and for shear strength. The cores were all stored in a refrigerated locker aboard ship and have been transferred to the refrigerated core locker at the Deer Creek facilities of the Branch of Pacific Marine Geology.

The continental margin cores fall into two groups; those that have subsurface laminations, and those that do not have subsurface laminations. Our investigations of the margin off northern California allowed us to predict that the strength of the oxygen-minimum zone (OMZ) in this region fluctuated during the past 50 ka and that at times the OMZ was strong enough to eliminate bioturbating organisms from mixing the seasonal signal and thus to preserve varves; Gardner and Hemphill-Haley, 1986; Anderson and others, 1987; 1989; Dean and others, 1991). We hypothesized that by mapping the present-day OMZ we should be able to locate cores off the Santa Lucia margin that also

Table 2. Summary of core recovery.

ID	water depth	recovery	comments
			GRAVITY CORES
G1	3045 m	0.80 m	(Taney Smt) green fossiliferous clay above ash!
G2	3310 m	5.50 m	(base of Davidson Smt) green clay
G3	1120 m	3.28 m	same station as P2 – left unopened for geotech
G4	617 m	1.40 m	sandy clay
G5	807 m	3.70 m	green clay with laminations
G6	968 m	1.2 m	sand; bent barrel
G7	620 m	2.32 m	silty clay with distinct laminae in sect. 1
G8	675 m	3.3 m	green clay with some laminations
G9	777 m	2.23 m	fine sand
			PISTON CORES
P1	1330 m	3.61 m	green silty clay
P1 TW	1330 m	0.38 m	left unopened
P2	1120 m	4.16 m	green silty clay
P2 TW	1120 m	0.57 m	left unopened
P3	799 m	5.75 m	green clay with laminations
P3 TW	799 m	0.41 m	left unopened
P4	915 m	9.00 m	green clay w/H_2S
P4 TW	915 m	0.44 m	left unopened
P5	1005 m	8.61 m	green clay with hints of microbioturbated laminae
P5 TW	1005 m	0.48 m	left unopened
P6	1045 m	7.32 m	green clay
P6 TW	1045 m	0.48 m	left unopened
P7	1010 m	7.32 m	very sandy green clay. Section 2 to bottom all flow-in
P7 TW	1010 m	0	no recovery
P8	1329 m	2.58 m	very sandy with glauconite(?) crusts and clasts
P8 TW	1329 m		left unopened
P9	867 m	4.50 m	green clay
P9 TW	867 m	0.32 m	left unopened
P10	595 m	5.86 m	green clay
P10 TW	595 m	0.57 m	left unopened
P11	733 m	5.82 m	laminated silty clay
P11 TW	733 m	0	no recovery
P12	595 m	2.52 m	green clay
P12 TW	595 m	0.55 m	no recovery
P13	575 m	5.64 m	green clay
P13 TW	575 m	0.53 m	left unopened
P14	630 m	5.29 m	lost top ~1 m from liner implosion. Laminations
P14 TW	630 m	0.44 m	left unopened

Table 2 (cont.). Summary of core recovery.

ID	water depth	recovery	comments
P15	585 m	8.70 m	top section messed up by liner implosion
P15 TW	585 m	0.00 m	no recovery
P16	580 m	6.54 m	green silty clay w/ **laminated-bioturbated cycles**
P16 TW	580 m	0.40m	left unopened
P17	564 m	7.76 m	green silty clay w/ one sandy turbidite
P17 TW	564 m	0.35 m	left unopened
P18	584 m	5.06 m	green silty clay with **laminae** in sect. 2, 3, and 4
P18 TW	584 m	0.0 m	no recovery
P19	850 m	4.28 m	green clay with sand turbidites
P19 TW	850 m	0.53 m	left unopened
P20	815 m	5.21 m	green silty clay with some **laminae** in sect. 2 and 1.6 m of flow-in below the lamina
P20 TW	815 m	0.15 m	left unopened
P21	735 m	5.68 m	green silty clay with **laminae** in sect. 1 and 2, and 70 cm of flow-in
P21 TW	735 m	0.5 m	left unopened
P22	675 m	7.94 m	green silty clay
P22 TW	675 m	0.5 m	left unopened
P23	768 m	8.0 m	green silty clay with faint hints of **laminations**
P23 TW	768 m	0.56 m	left unopened
P24	795 m	5.23 m	oil (?)-stained sand
P24 TW	795 m	0	no recovery
P25	2096 m	7.54 m	green clay with dark/light cycles
P25 TW	2096 m	0.35 m	left unopened
P26	1730 m	5.68 m	green silty clay with dark/light cycles
P26 TW	1730 m	0.57 m	left unopened
P27	1615 m	4.31 m	green clay w/light-colored sands
P27 TW	1615 m	0.54 m	left unopened
P28	1790 m	4.22 m	green clay with sandy turbidites
P28 TW	1790 m	0.55 m	left unopened
P29	1475 m	6.19 m	green clay w/ H_2S
P29 TW	1475 m	0.45 m	left unopened
P30	1412 m	2.93 m	sandy turbidites
P30 TW	1412 m	0.30 m	left unopened
P31	608 m	5.70 m	green **laminated** clay
P31 TW	585 m	0.55 m	left unopened
P32	583 m	8.94 m	green **laminated** clay
P32 TW	583 m	0.50 m	left unopened
P33	575 m	6.23 m	green clay with **laminated**-bioturbated cycles
P33 Tw	575 m	0.0 m	no recovery
P34	610 m	6.68 m	green clay with bioturbation cycles and faint **laminations** at the base of section 3 and in section 4
P34 TW	610 m	0.53 m	left unopened

Table 2 (cont.). Summary of core recovery.

ID	water depth	recovery	comments
P35	680 m	0.0	entire core destroyed by imploded liner and homogenization of sediment by water in the liner
P35 TW	680 m	0.0	no recovery
P36	655 m	8.26 m	green clay
P36 TW	655 m	0.56 m	left unopened
P37	660 m	8.40 m	homogeneous green clay
P37 TW	660 m	0.50 m	left unopened
P38	660 m	8.82 m	geotechnical core, left unopened
P38 TW	660 m	0.56 m	left unopened
P39	845 m	6.69 m	green clay with microbioturbated **laminations**
P39TW	845 m	0.44 m	left unopened
P40	760 m	8.60 m	green clay with **laminations**
P40 TW	760 m	0.25 m	left unopened
P41	640 m	8.71 m	homogenous green clay with gas cracks below 4.9 m
P41 TW	640 m	0.52 m	left unopened
P42	725 m	8.49 m	homogeneous green clay with **laminations** in sect. 4
P42 TW	725 m	0.55 m	left unopened
P43	855 m	8.16 m	green clay with sandy turbidites
P43 TW	855 m	0.47 m	left unopened
P44	610 m	8.26 m	homogeneous green clay. Liner implosion
P44 TW	610 m	0.45 m	left unopened
P45	705 m	8.61 m	homogeneous green clay with **laminations** in sect. 2, color, and microbioturbation cycles at base. Liner implosion
P45 TW	705 m	0.46 m	left unopened
P46	795 m	7.03 m	green clay with **laminations**
P46 TW	795 m	0.55 m	left unopened
P47	870 m	8.02 m	homogeneous green clay
P47 TW	870 m	0.54 m	left unopened
P48	624 m	6.09 m	homogeneous green clay
P48 TW	624 m	0.52 m	left unopened
P49	720 m	7.23 m	green clay with well-defined **laminations**
P49TW	720 m	0.15 m	left unopened
P50	720 m	8.59 m	geotechnical core, left unopened
P50 TW	720 m	0.43 m	left unopened
P51	775 m	8.56 m	green clay with bioturbation cycles & **laminations**
P51 TW	775 m	0.52 m	left unopened
P52	865 m	8.13 m	green clay
P52 TW	865 m	0.56 m	left unopened
P53	3320 m	8.16 m	siliceous green clay
P53 TW	3320 m	0.29 m	left unopened
P54	3305 m	9.97 m	siliceous green clay
P54 TW	3305 m	0.0 m	small amount of mud in core catcher; sampled for Forams and Diatoms

have preserved m isobaths, so we planned a series of cores to traverse across this zone, but starting shallower and ending deeper than the present-day OMZ. This distribution of cores would allow us to determine the spatial and temporal distribution of the paleoOMZ and the history of the California Current system. The outcrop area of Santa Lucia Bank (Fig. 5) was broader than we expected so we were unable to sample transects in this region. However, we were able to collect an excellent suite of cores, 19 of which have well-preserved varves.

The varves typically occur as a basal layer of Foraminifera that resembles a rapidly extinguished fauna that could not escape a sudden decrease in oxygen content. Directly above the Foraminifera layer is a sequence of alternating light and dark millimeter-thick laminations that appear identical to the varves found off northern California (Gardner and Hemphill-Haley, 1986; Anderson and others, 1989). The laminations typically are capped by a zone of abundant horizontal *Chondrites* burrows, then vertical *Chondrites*, followed by *Planolites* burrows and heavy mottling. The laminations were consistently found 4 to 5 m subbottom, which, using the chronostratigraphy recently developed for core V1-81-G15 on Patton Ridge, suggests an age of about 40 to 50 ka. This estimate of the timing of these laminated, low-oxygen events is very preliminary, and numerous AMS ^{14}C dates will be required to firmly establish the timing and degree of correlation of these events. The appearance, thickness, bioturbation facies, and water depth of occurrence, all suggest that these laminations are indeed varves.

Many of the cores that do not have preserved laminations show a very distinctive cyclicity of bioturbation styles similar to what was found in the laminated cores on this cruise and off northern California (Anderson and others, 1989). Progressing younger, thoroughly bioturbated sediment becomes more mottled with large *Planolites* burrows, then small, vertical *Chondrites* burrows, then small horizontal *Chondrites*. Continuing, the reverse sequence of bioturbations occurs, going from horizontal to vertical

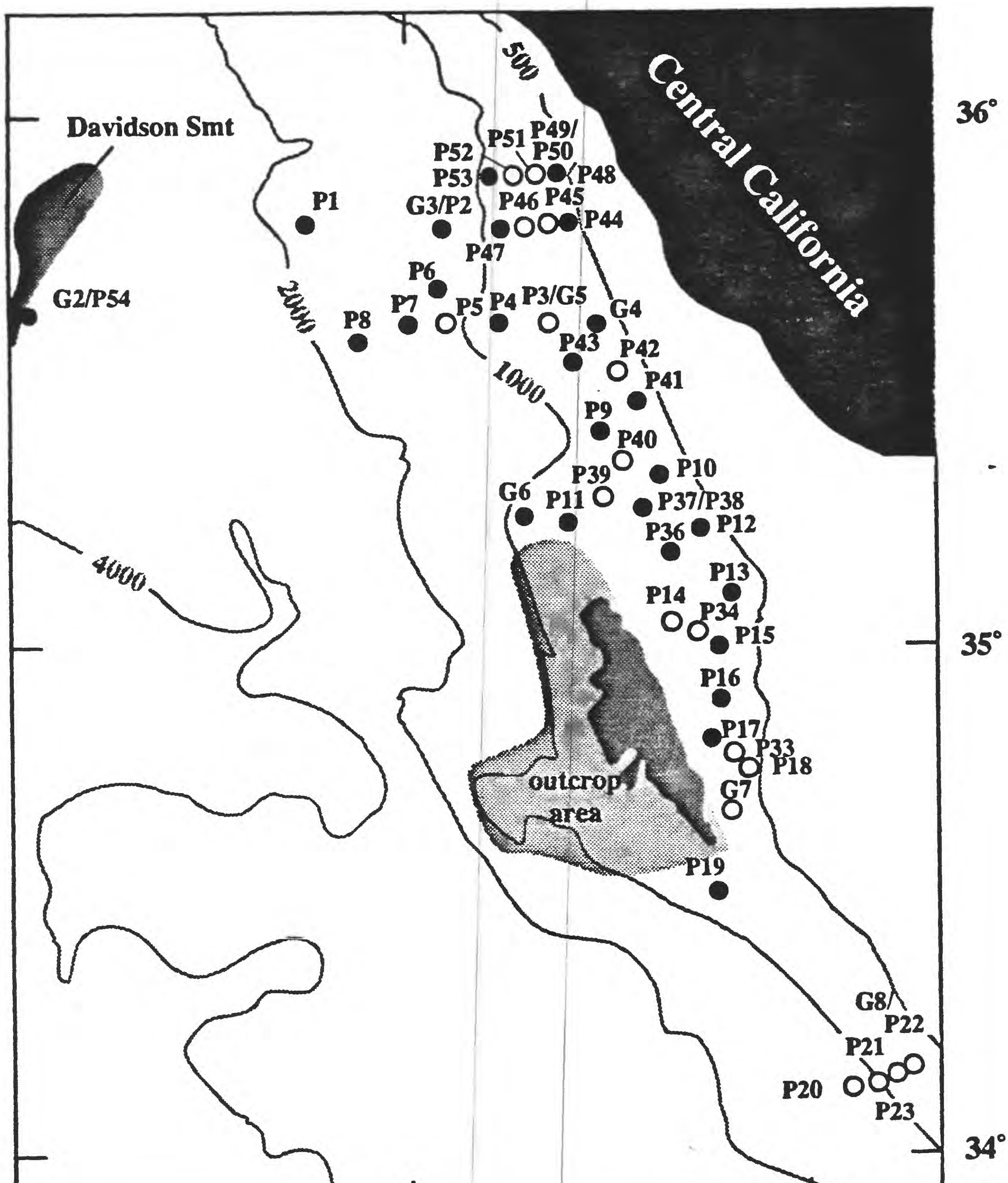

Figure 5. Map of central California margin coring locations, cores with laminations shown as open circles.

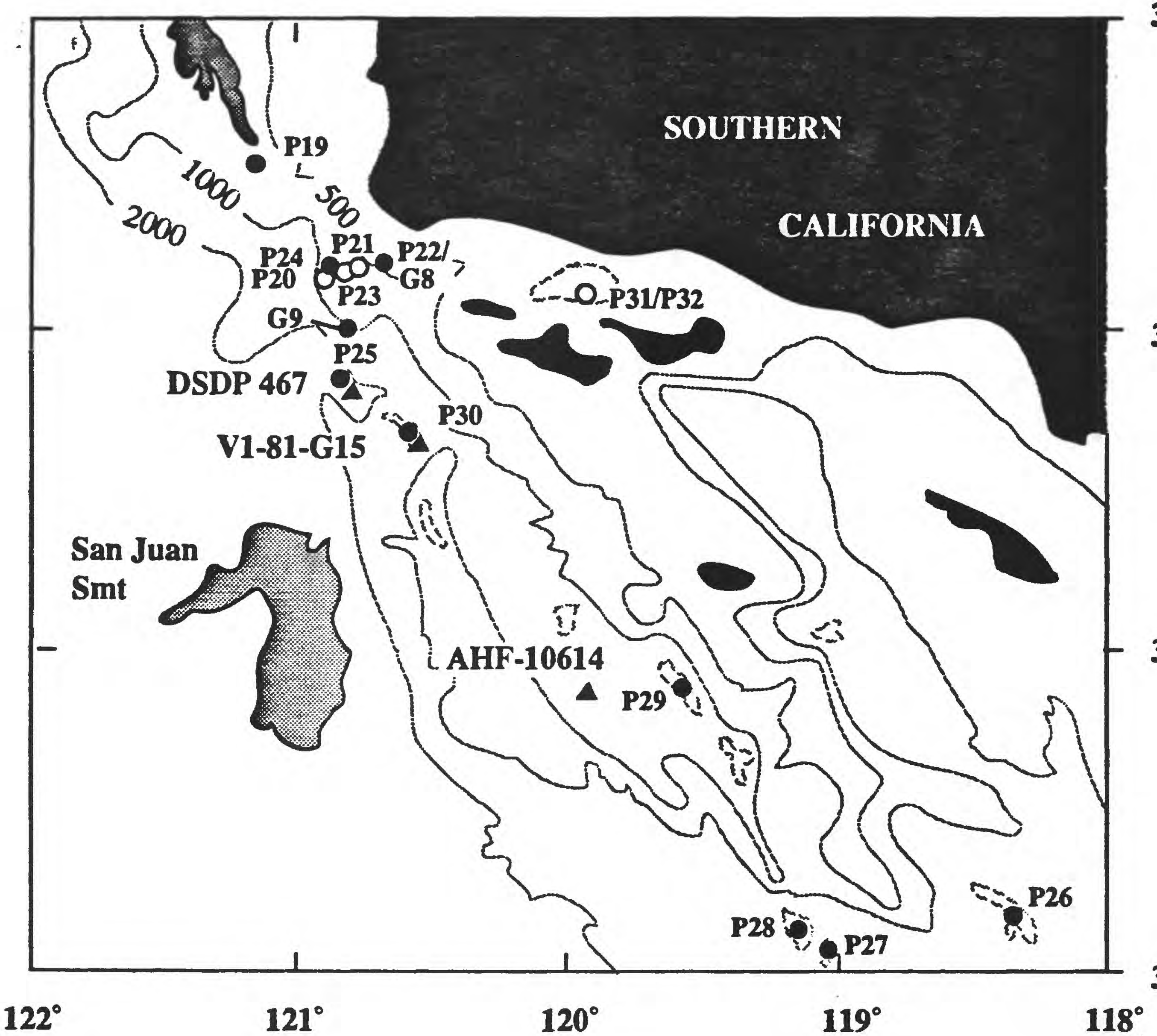

Figure 6. Coring sites in Patton Ridge basins, cores with laminations shown as open circles.

Chondrites, then large *Planolites* and finally homogeneous sediment. This describes an idealized sequence; several sections show all these bioturbation facies, but other sections show only part of the sequence. The cores also apparently record cycles in abundance of siliceous and calcareous biogenic components; periods of time when siliceous productivity was dominant (strong upwelling) alternating with periods when more calcareous productivity dominated (more subtropical conditions). These cycles are suggested from the examinations of smear slide and will be investigated over the next few months by laboratory measurements of calcium carbonate and biogenic silica. The new cores will allow us to correlate the timing of the bioturbation cycles with the timing of the laminations and the biogenic cycles to produce a history of oceanographic changes in this region.

The north-south California-margin transect was extended to the Mexican-US border by coring all of the small basins of the west-facing Patton Ridge (Fig. 6). The basins include the Cortes Basins, Tanner Basin, and several unnamed basins, one of which was the location of DSDP Site 467. In addition, we took the time to collect two cores from Santa Barbara Basin because we need material from a reference section that many people have already worked on. Core coverage of the continental margin of the western U.S. now extends from the US - Canadian border on the north to the US - Mexican border on the south (Fig. 1).

CORES COLLECTED DURING FY92 – TERRESTRIAL

Six sites near Klamath Falls (Fig. 7) were selected for intermediate-depth coring in FY92. Nine cores were recovered, with an overall recovery rate of 86% (Table 2). Magnetic susceptibility logs for the best cores from each site are shown in Figures 8 through 13. Susceptibilities vary by at least three orders of magnitude. Systematic fluctuations of susceptibility with depth are clearly present, but it would be premature to attempt correlations or interpretations of the susceptibility curves until other aspects of the cores are analyzed.

Table 2. FY92 terrestrial cores drilled

Core	Maximum depth (m)
Buck Lake, Core 1	42.0
Buck Lake, Core 2	6.5
Butte Valley, Core 1	102.0
Caledonia Marsh, core 1	16.0
Grass Lake, core 1	1.5
Grass Lake, core 2	31.0
Round Lake, core 1	51.0
Wocus Marsh, core 1	24.0
Wocus Marsh, core 2	53.0

The Klamath cores are discussed below in terms of two groups: (1) cores from large subbasins tectonically, hydrologically, and/or limnologically related to the Klamath Basin proper, and (2) cores from smaller, independent basins nearby.

Cores from large basins

Wocus Marsh, at an elevation of about 1265 m, is located in a large embayment along the southwestern margin of Upper Klamath Lake. The site consists of reclaimed lake bottom, and is now used for agriculture. Before reclamation, the basin was a shallow marsh. The Wocus Marsh section extends to a depth of 51.86 m. Combined recovery for cores 1 and 2 was over 90%. Drilling at Wocus Marsh did not reach the base of the sediments, but was stopped in order to leave adequate time for other sites.

Both the lithology of the cores and the geography of the upstream basin suggest that the Wocus Marsh record includes glaciolacustrine clays derived from the Mountain Lakes Wilderness Area just west of Upper Klamath Lake, and also from glaciers on the now-absent Mt. Mazama. Sediments in the cores include fine-grained, inorganic silts and clays of probable glacial origin, as well as other silty units, algal muds, and peats. Several conspicuous tephra layers have been submitted for identification, including four near the middle of the section (21 to 24 m depth) and two near the base (48 to 50 m). Identification of these tephra will permit correlation with the sections at Tule Lake and

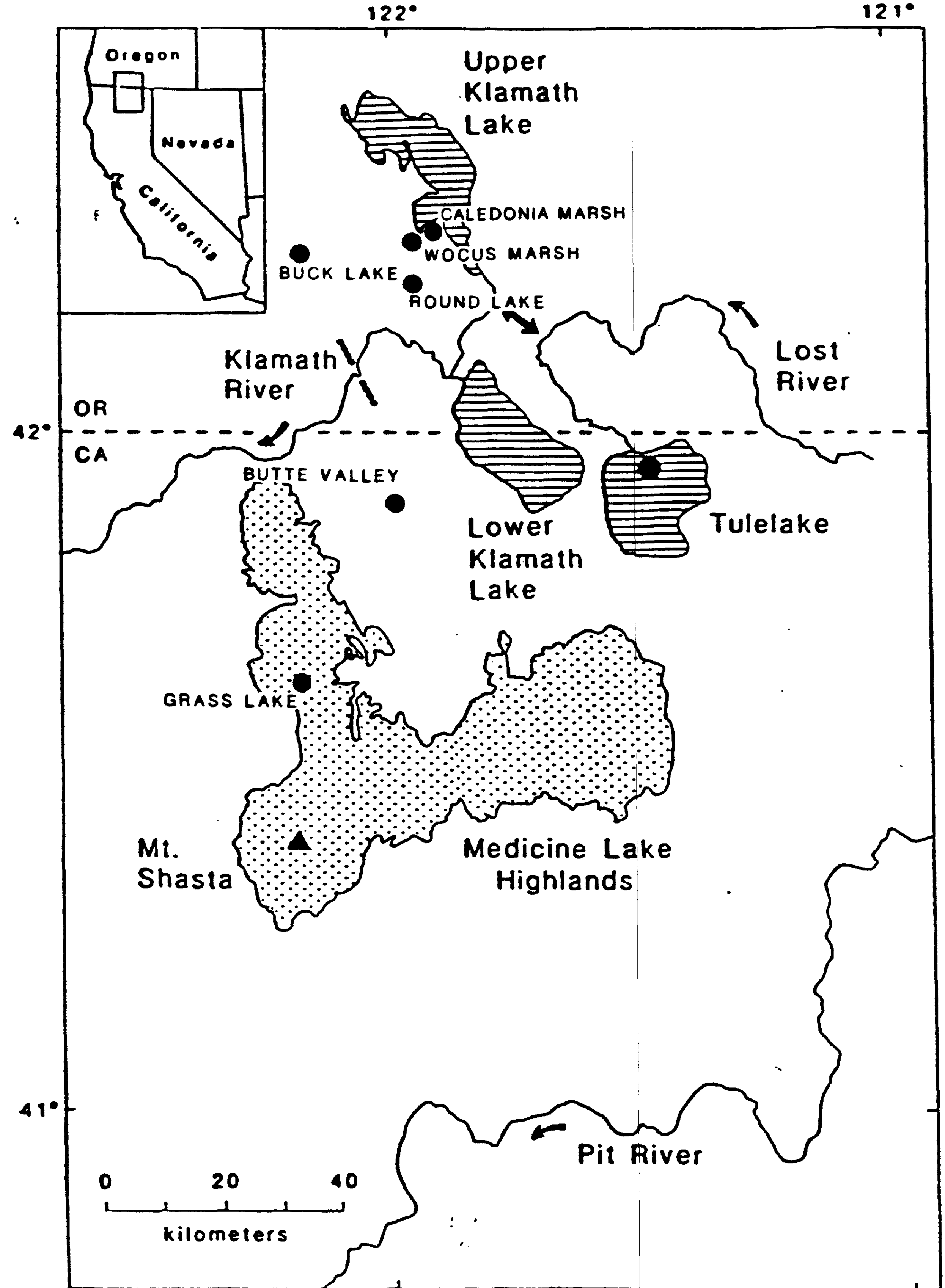

Figure 7. Map of terrestrial sites drilled during FY92.

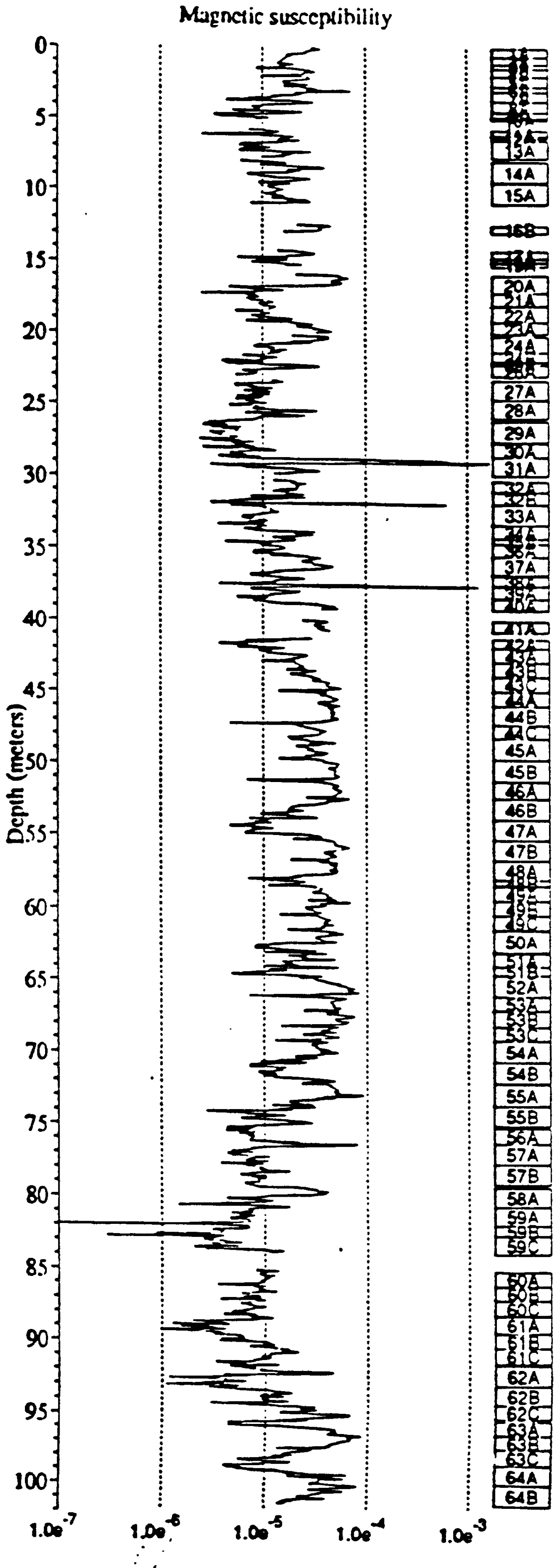

Figure 8. Magnetic susceptibility log of Butte Valley, Core 1.

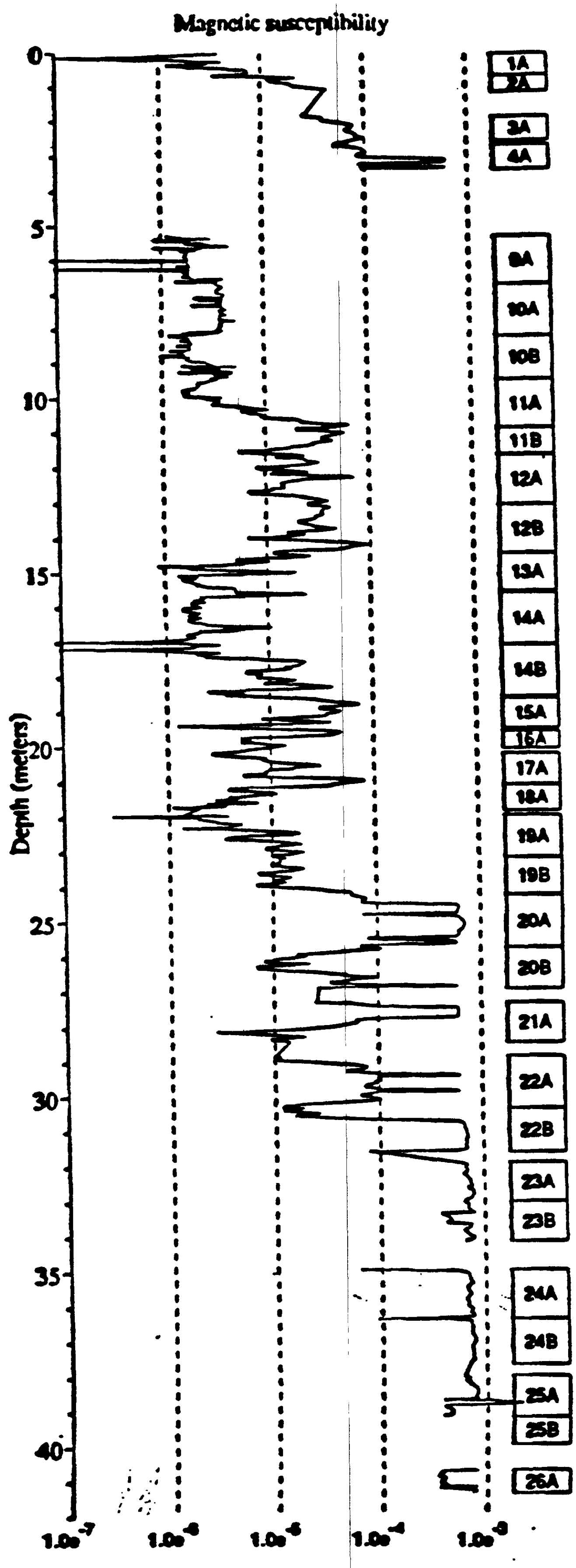

Figure 9. Magnetic susceptibility log of Buck Lake, Core 1.

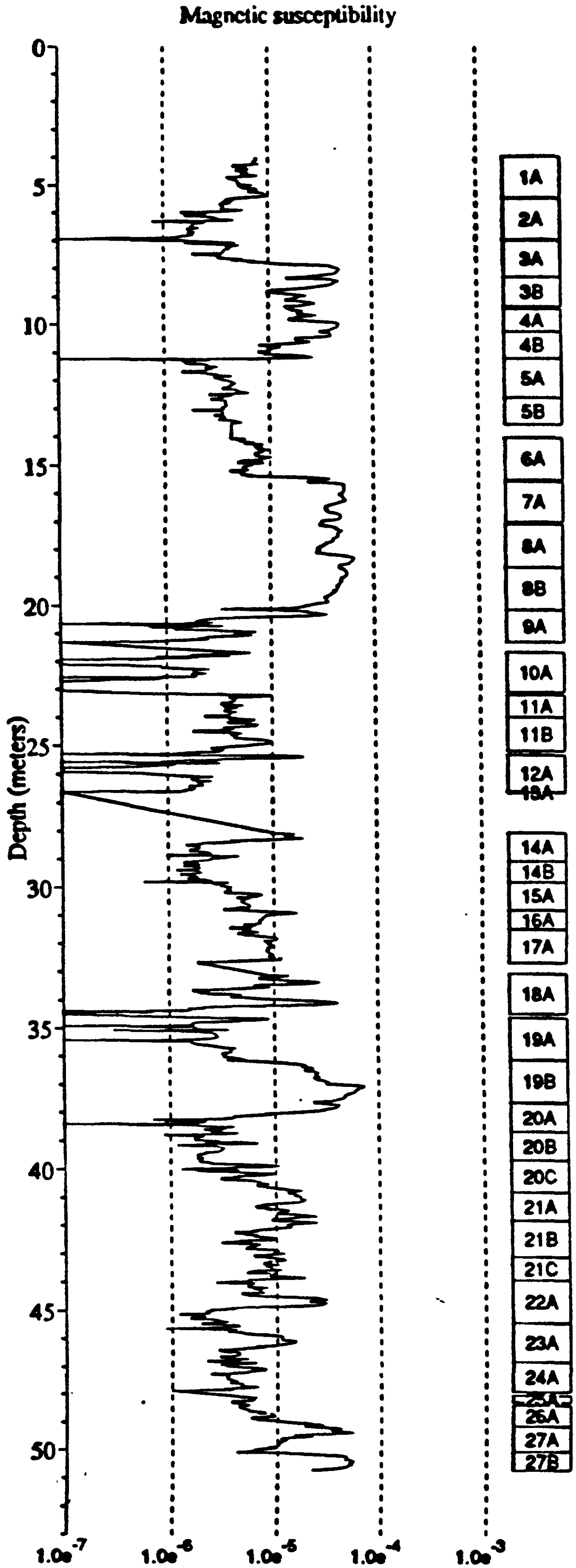

Figure 10. Magnetic susceptibility log of Wocus Marsh, Core 2.

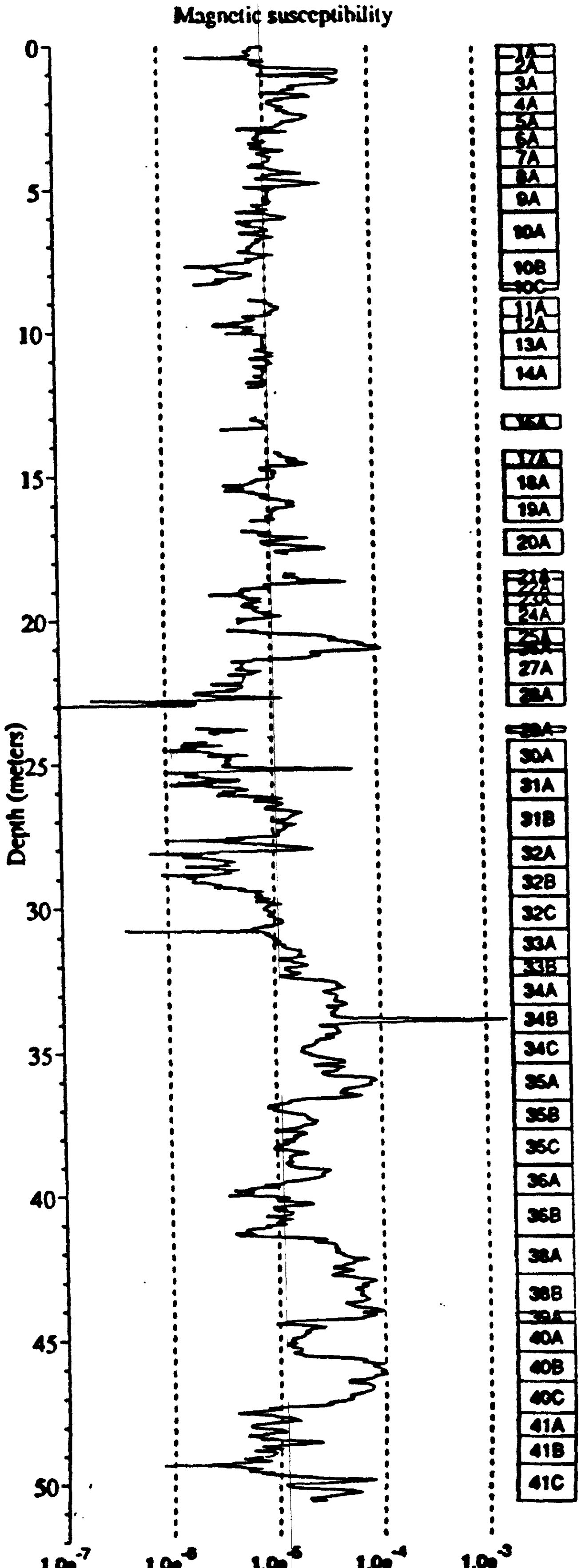

Figure 11. Magnetic susceptibility log of Round Lake, Core 1.

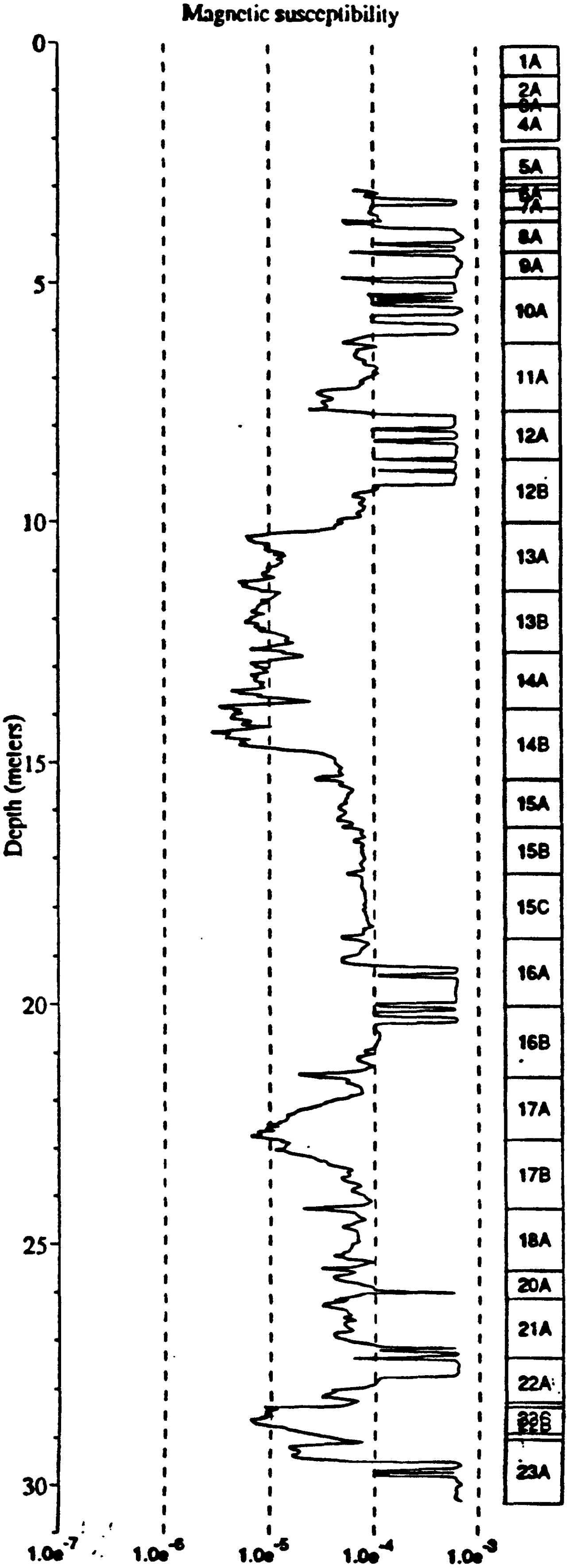

Figure 12. Magnetic susceptibility log of Grass Lake, Core 2.

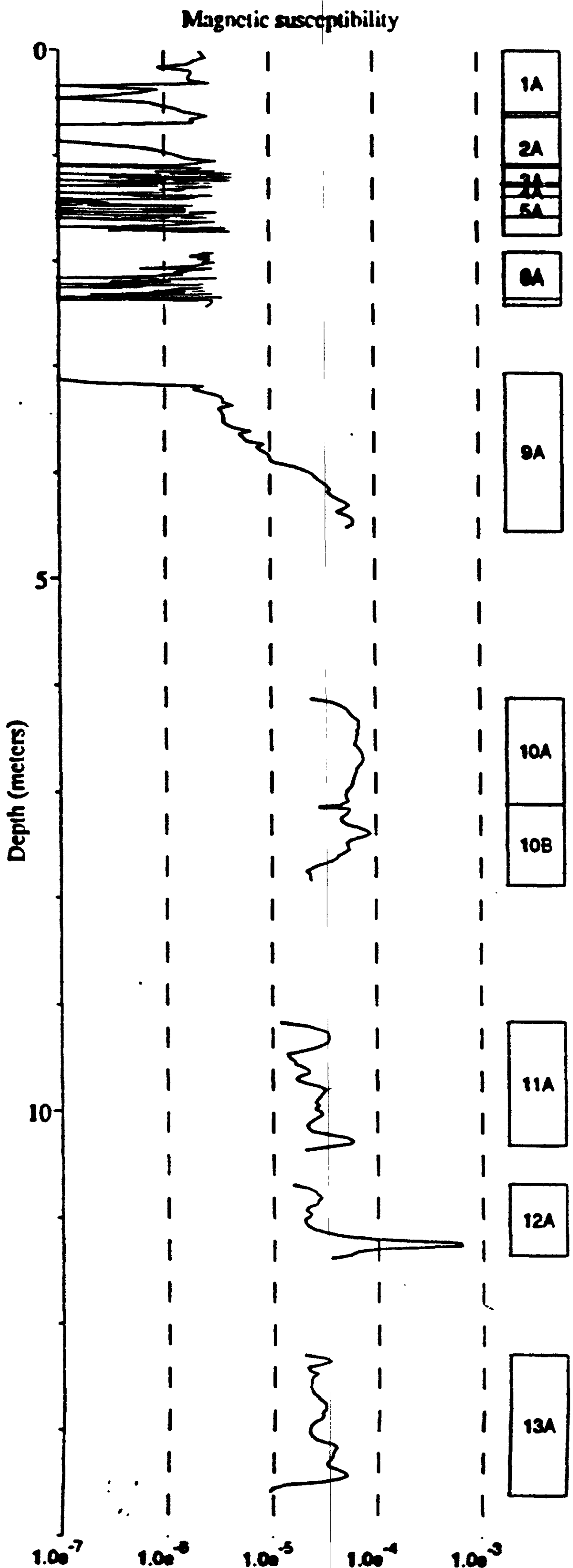

Figure 13. Magnetic susceptibility log of Caledonia Marsh, Core 1.

Summer Lake. Diatoms from near the base of the core indicate an age of 1.3 Ma by correlation to the Tule Lake record.

Caledonia Marsh is a large polder reclaimed from the main body of Upper Klamath Lake, about 5 km north of the Wocus Marsh site. It was chosen to evaluate whether the Wocus Marsh connection to Klamath Lake had been cut off at times in the past. The coring was not successful because we encountered seeping artesian water at a depth of only 16 m. We could not have cored deeper with our equipment without the possibility of creating a permanent (and unwanted) spring. The artesian water also led to problems with core recovery higher in the section; total recovery at this site was only about 65%.

The lithology of the available sediments from Caledonia Marsh consists of highly organic fibrous peats above a depth of about 6 m and interbedded muds and silty muds below that depth. A single siliceous tephra layer from a depth of 7.7 m has been submitted for identification. Better recovery of the upper part of the section might be possible using a Livingston piston corer.

An interesting feature of the Caledonia Marsh cores is the smoothed character of the paleomagnetic susceptibility curve compared to the curves for the other sites (Fig. 9). The very jagged curve above a depth of 3 m is an artifact caused by overlapping depths recorded for Shelby tubes, but the curves for core slugs 9 to 13 are much less "jumpy" than similar cores from other sites, as though the data had been passed through a low-pass filter.

Butte Valley

The Butte Valley hydrologic system is apparently not connected to the Lower Klamath Lake system, from which it is separated by a prominent narrow ridge. The floor of Butte Valley lies at an elevation of 1292 m, about 50 m higher than Lower Klamath Lake. A thin deposit of mixed gastropod shells and gravel representing an ancient shoreline is exposed east of the town of Dorris about 15 to 20 m above the valley floor, well above the present sill level, which suggests some tectonic activity since the (unknown) time the shoreline formed. The valley is probably still tectonically active. Unlike the Lower Klamath and Tulelake basins, Butte Valley appears to be hydrologically closed. Solutes are thus conserved in the basin except when it is full enough to overflow. Water well logs indicate the common presence of fish remains and shells beneath the valley floor. The site was selected for drilling because the hydrologic contrast with the Tule Lake basin offered the chance to recover a better record of calcareous fossils, especially ostracodes, than was recovered at Tule Lake.

The core recovered from Butte Valley extended to a depth of 102 m with 92% recovery. Numerous silicic tephra layers are present in the core and have been sampled and submitted for identification. One layer already identified is the Rio Dell Ash (1.45 Ma) which occurred at a depth of 58 m. Linear extrapolation suggests that the base of the core could be about 2.5 Ma, indicating that sedimentation rates in Butte Valley are slower by a factor of 2.7 than those at Tule Lake. Ostracodes near the base of the core indicate a Pliocene age.

Preliminary analysis of the diatoms in the Butte Valley core suggest that alkaline, shallow marsh conditions have prevailed for the past 1 to 2 My. Some levels with freshwater diatoms (e.g., *Cyclotella bodanica* and *Stephanodiscus niagarae*) could correlate with lake highstands in the Klamath Lake Basin and/or with periods of overflow into the Klamath drainage. However, if the Rio Dell Ash is correctly identified in the Butte Valley core, it suggests that the Butte Valley and Tule Lake paleoenvironments at that time were quite different, with Tule Lake dominated by *Stephanodiscus niagarae* and Butte Valley a shallow, alkaline marsh.

Smaller, independent basins

The Tule Lake, Wocus Marsh, Caledonia Marsh, and Butte Valley cores all represent huge drainage basins that lie mostly well to the east of the Cascade Range. Because we hope to use pollen as a tool for correlation with marine cores, we also wanted to obtain cores that represent the forest vegetation of the Cascades. The large-basin cores are suitable for palynologic comparison with marine cores because they represent the integrated vegetation of large areas, but much of the vegetation in the large basins represents the rain-shadow ecosystems east of the Cascades, and is unlikely to be represented by a clear pollen signal in the marine record. We therefore searched for long-term depositional sites within the Cascades forests, as close to the oceans as we could find. The Grass Lake and Buck Lake sites were selected. We also took a core from Round Lake to serve as a local pollen record in close proximity to the Wocus Marsh large-basin core.

Round Lake is a closed basin at an elevation of 1299 m located about 6 km southwest of Wocus Marsh. Because the basin has a limited drainage area and no overflow, it can provide an estimate of the degree to which the Wocus Marsh core reflects local changes versus changes elsewhere in its large drainage area.

A single core was taken at Round Lake to a depth of 51 m, when circulation of drilling mud was lost. The lithology of the core shows a major change in the basin environment at a depth of ~25 m. Below that depth, the basin was occupied by an open-water lake that deposited about 25 m of lacustrine muds. Above that depth, the lake was ephemeral at best, and the sediments consisted of very tight clays that were difficult to core. Tephra are present in the lacustrine sediments, but none were seen in the tight clays. Identification of the tephra from the lower part of the section will enable us to correlate the Round Lake record with the other cores so we can evaluate the nature of the change that caused sedimentation to shift so dramatically at Round Lake.

Buck Lake lies just east of the crest of the Cascade Range at an elevation of 1505 m, well within the mixed coniferous forest. The lake was drained and converted to pastureland about 1940. The lake bottom is irrigated each summer from large springs that emerge at the west end of the lake, and the ground surface is relatively soft. Because of the soft ground we were forced to drill fairly near the eastern edge of the lake, rather than risk losing the drill rig. The core we took extended into the local volcanic bedrock at a depth of 42 m.

The stratigraphy of the Buck Lake core consists of about 30 m of lacustrine clays at the top, underlain by about 10 m of volcanic debris flow deposits and then by fresh basalt. Some rounded stream gravels were encountered at a depth of 3 to 4 m. The lacustrine clays have a reddish, somewhat oxidized, appearance, but the appearance of well-preserved horizons of moss stems at some levels indicates that the oxidation must have taken place prior to deposition. The levels with moss laminae are dominated by *Tetracyclus lacustris,* a diatom that lives in cool to cold and very fresh water (i.e., mountain lakes). Other parts of the core are characterized by *Cyclotella ocellata*, or by *C. kutzingiana* and *Aulacoseira distans*, all consistent with oligotrophic fresh and cool water. The few pollen samples counted indicate significant changes in the vegetation surrounding the lake through time, including the replacement of *Abies* (fir) by *Picea* (spruce) at some levels. Detailed studies of the magnetic and paleomagnetic properties of the core are in progress. The core includes at least 15 silicic tephra samples that have been submitted for identification. Depending on the sedimentation rate and the age of the lacustrine part of the core, this site may be important for documenting the Quaternary history of the forest ecosystems along the crest of the Cascades.

Grass Lake, at an elevation of 1540 m, is the highest-elevation site cored. The basin lies just east of the crest of the Cascades about 27 km north of Mt. Shasta. The deposits are impounded by a lava flow that blocked drainage to the east. The site was a lake during historic time, but was drained into the underlying highly permeable basalts by a dynamite explosion that disrupted the sediment cover.

We recovered a 30-m core at Grass Lake with a recovery of over 98%. Sediments consisted of interbedded fine sand, silts, and muds to a depth of 29.5 m, underlain by about 1 m of volcaniclastic breccia. Tephra layers were rare; only two have been submitted for identification, and one of those was not identifiable.

ANALYSES TO BE RUN ON NEW CORES - MARINE

The recovery of 380 m of sediment on the 1992 coring cruise, together with previously existing cores, provides the project with a unparalleled opportunity to examine the high-resolution record of paleoceanographic changes of the California Current system. However, collecting the various proxy indicators requires an enormous analytical effort. We are undaunted by the effort, but worried about available manpower and time constraints. Ignoring, for the moment, manpower and time constraints (see section below), we propose to perform the analyses outlined in Table 3 on selected cores.

To reiterate, our overall focus is to correlate, with the tightest temporal constraints we can provide, the marine and terrestrial records. The correlations will require, in some instances, common proxies in the two types of data (e.g., pollen in marine and terrestrial cores). In other instances, different proxies will be developed to investigate a common

Table 3. Analyses and objectives to be run on marine cores.

ANALYSIS	INTERVAL	PURPOSE
$CaCO_3$ / C_{org}	5 cm	stratigraphy, carbon budget
Sulfur	20 cm	redox studies for upwelling
XRD	20	clay mineralogy
biogenic SiO_2	5 cm	stratigraphy, upwelling
Rock-Eval (H-index)	20 cm	marine/terrestrial inputs
$\delta^{18}O$ & $\delta^{13}C$	5 cm	global stratigraphy; paleotemperature
$\delta^{13}C_{org}$	20 cm	marine/terrestrial inputs
$\delta^{15}N_{org}$	20 cm	paleoproductivity
ICP (major and trace elements)	20 cm	paleoenvironments
XRF (major elements)	20 cm	fill in from ICP
pollen	10 cm	marine–terrestrial tie
diatoms	10 cm	surface paleoceanography
Radiolaria	10 cm	subsurface paleoceanography
nannofossils	10 cm	calcareous paleoceanography
Foraminifera	10 cm	paleo-sea-surface temperatures
magnetics	unknown	stratigraphy
tephra	continuous	correlation & absolute age
AMS ^{14}C	as required	absolute dating

parameter. An example is using planktonic Foraminifera faunas in marine cores and lacustrine diatom floras from the terrestrial records to generate sea-surface and lake temperatures, respectively. With the two responses chronostratigraphically correlated at a high precision, the oceanic forcing and continental responses can be evaluated. Consequently, high-resolution analyses are the foundation of the project and will consume the next several years.

ANALYSES TO BE RUN ON NEW CORES – TERRESTRIAL

Analyses in progress for the Klamath Lakes cores include magnetic properties, logging of lithology, and sampling for tephra, pollen, diatoms, bulk elemental geochemistry, and macrofossils, where appropriate. Personnel and budget constraints will limit the number of cores that can be examined in detail. We hope to extend the amount of work on the cores through collaborations with academic researchers; a list of present collaborators is shown in Table 4.

Table 4 Analyses and objectives to be run on terrestrial cores

RESEARCHER	INSTITUTION	INTEREST
Kathy Whitlock	Univ. of Oregon	Palynology
Kathryn Hakla	Univ. of Pittsburgh	Palynology, Grass Lake
Ken Verosub	UC Davis	Paleomagnetism
Gerald Smith	Univ. of Michigan	Fish remains

REPRIORITIZED FY93 SITES - MARINE

Because of the success of the FY92 marine coring, we do not anticipate any need for additional marine coring. We will continue to be on the lookout for data from any cores, published or unpublished, from the west coast margin and will include them in our database.

REPRIORITIZED FY93 SITES – TERRESTRIAL

Based on the available records and new Klamath Lakes cores, the remaining high-priority terrestrial sites were discussed and reprioritized for potential drilling in FY93. The new priorities for undrilled terrestrial sites are shown on Figure 1 as circled sites and are listed, in order of priority, below:

1. Tulare Lake, CA
2. Carp Lake, WA
3a. Ruby Marshes, NV
3b. Lake Elsinore, CA

These sites would each represent the terrestrial side of an east-west marine-terrestrial transect and are considered crucial to the long-term success of this project.

Tulare Lake, in the southern San Joaquin Valley, includes a lens of Quaternary sediment over 1000-m thick, well beyond the scope of this project. It should be possible to select a drill site where a 100 to 200 m core would penetrate through the base of the Corcoran Clay and the Brunhes-Matuyama boundary, which would provide a firm paleomagnetic datum for correlation with the marine record. Drilling by Atwater and others (1986) encountered natural gas at a depth of only 40 feet, so blowout prevention equipment will be necessary even for a shallow core.

Carp Lake, in south-central Washington, occupies a maar crater in a volcanic field that is roughly 1 My old. Work by Kathy Whitlock has recovered cores to a depth of about 20 m using manually-driven equipment, and those cores extend back in time an estimated 80 to 100 ky. The site is the northernmost known possibility for a record extending back through the last interglacial period in the interior western U.S. It seems likely that a drill rig on a barge or raft could significantly extend the Carp Lake record.

Ruby Marshes, in east-central Nevada, lie in a closed basin that was never flooded by the great pluvial lakes, but did receive runoff from the glaciated Ruby Mountains. The site should provide a good record of the interior Great Basin during the last glacial cycle and might enable the Project to correlate the Pacific marine record with the climatic history of the continental interior.

Lake Elsinore occupies a fault-bounded basin relatively near the ocean in southern California. A river flows through the basin, and there is some question whether the basin deposits are well suited to paleoclimatic analyses. If the deposits are suitable, the site would provide a southern extension of the land record to correlate with marine cores taken from the Patton Ridge margin. We are investigating the history of the Lake Elsinore basin to determine its suitability for coring.

ANTICIPATED PROBLEMS

As mentioned above, manpower and time are the two largest concerns looming in the immediate future. We will begin the analytical work immediately, with the available manpower, and will investigate student help and student interns as an interim stop-gap measure. Next fiscal year we will ask for more manpower and analytical time.

Another anticipated problem concerns unequal archiving and curating of the marine and terrestrial cores. The two types of cores are fundamentally different; marine cores are soft and continuous and taken in liners for ease of handling, whereas terrestrial cores are often fragile, discontinuous, and unlinered, which makes initial handling difficult. The problem lies in the amount of and thoroughness of archiving done in the field. Onboard ship, time is taken for initial core logging (p-wave velocity, wet bulk density, and magnetic susceptibility), splitting into two sections, digitally imaging in color, fully describing both visually and microscopically, and analyzing for ephemeral properties (water content and shear strength). Complete logs of each core are completed by the end of the cruise. Sampling for most proxy variables is done at the Deer Creek laboratories of PMG.

At the drill site, terrestrial cores are left unsplit but the surface is scraped for a crude lithological description. The cores are then sent back to the lab for magnetic susceptibility measurements and then await various investigator's requests for subsamples. Clearly, the two types are handled very differently, and there should be more attention paid to the logging, description, and curation of the terrestrial cores.

Part of the problem with adequate field logging of terrestrial cores lies in the lack of a clean workplace and a shortage of personnel. Drilling for the Klamath Falls cores was handled with a science crew of five and three drillers. Computer equipment could not be taken to the drill sites because a reasonably dust-free workspace was not available. In addition, funding for the effort did not arrive in time to purchase all of the equipment and integrate it before we went in the field. It would have been possible to set up a separate lab in rented quarters, but an additional one to three people would have been required to provide adequate staffing of both the drill rig and the field lab. A request for a truck in which to construct a field lab was not approved for FY92.

Ideally, the continental drilling program should have facilities at the drill site similar to those available at sea: stable electrical power, a clean air-conditioned environment for a computer, uniform lighting for photography, microscopes, etc. If a USGS Global Change Program drilling effort will continue for a number of years, such a lab should be seriously considered. A pre-existing mobile lab would eliminate many of the problems that now arise when a field operation must be set up during the brief time between provision of funding and the onset of drilling. However, setting up such a lab will require a significant investment of both personnel time and money.

A common database should be developed combining the marine and terrestrial data generated on this project. We need one central person to manage the database, to enter new data sent in by various investigators, and to keep track of what core subsample was collected by whom, when, and for what purpose. Separate marine and terrestrial databases have been started (Gardner and Adam) and each investigator probably will store his or her own analytical data in files of some type, most of which probably will be digital. What concerns us is that there is no database being developed that can combine all the marine and terrestrial data (maps of locations, lists of analytical data, lists of samples taken for various purposes, analytical results, lists of reports published on the data, etc).

During the first Workshop in early 1991, we strongly endorsed the concept of a Project Curator who would help keep uniform curation of all the new marine and terrestrial cores and manage the database. This concept was not carried out in practice, and we do not have a person tasked to do this important job. One solution for a common project database is to use the Branch of Pacific Marine Geology (PMG) community computer (a networked Sun SparcStation running under UNIX). This computer has a number of phone modems and can be accessed by anyone at no charge. PMG is willing to let the database reside on this computer, but the database must be maintained by a curator. Once a Project Curator is clearly identified, PMG and Project personnel can work with them to develop the database design.

Another problem that will certainly have to be faced is the refrigerated core storage for all of the Project material. Presently, all the marine cores and the Owens Lake cores are all stored at the Deer Creek refrigerated core-storage facility of PMG. The remaining terrestrial cores are presently stored in a refrigerated van at the Menlo Park Main Center. Neither of these storage facilities is a long-term solution; PMG probably will be relocated at University of California Santa Cruz as early as 1995, and room is scarce at the Main Center. Refrigerated vans can be located at the USGS Marine Facilities in Redwood City, CA but each van requires about $4000 in electrical hook-up charges and there is no room or equipment at MARFAC for examining or sampling the cores. The Denver Core Research Center, under the direction of the Branch of Sedimentary Processes, has volunteered space for refrigerated core storage adjacent to the National Ice Core Repository Facility presently under construction. This solution has many advantages; abundant space, a full-time curatorial staff, large layout areas for examining and sampling cores, cameras, digital imaging, microscopes, etc. There are no real disadvantages to this solution, and we hope to use the Denver Core Research Center as the permanent repository.

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