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Depth-age relationships of 25 well-dated Swiss Holocene pollen sequences archived in the Alpine Palynological Data-Base

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Abstract

Depth-age models are presented for 25 Holocene pollen sequences from Switzerland based mainly on calibrated radiocarbon dates. The pollen data from these 25 sequences are stored in the Alpine Palynological Data Base. Sediment-accumulation rates are discussed in relation to sediment type, sediment age, and elevation of the sites. The following trends are observed: 1. Peats accumulate usually faster than lake sediments; 2. During the initial 2.5 millennia of the Holocene, sediment-accumulation rates are on average low but increasing, whereas after that time they are considerably higher, and in the most recent 3 millennia somewhat increasing; 3. No relation of sediment-accumulation rates to elevation of the sites was found.

Key Words

Palynology, pollen diagrams, Holocene, dating, depth-age modelling, data-base, Switzerland.

Résumé

Titre.- Nous présentons des modèles "profondeur-âge", basés principalement sur des datations radiométriques calibrées de 25 séquences polliniques Holocènes de la Suisse. Les données polliniques de ces 25 séquences sont conservées dans une base de données: Alpine Palynological Data Base. Les vitesses de sédimentation sont examinées en relation avec le type de sédiment, l'âge du sédiment et l'altitude des sites. Les tendances suivantes sont observées: 1. Les tourbes s'accroissent habituellement plus rapidement que les sédiments lacustres; 2. Au cours des 2.5 premiers millénaires de l'Holocène, les vitesses de sédimentation sont généralement basses, mais elles ont tendance à augmenter. Par la suite, elles se maintiennent considérablement plus élevées. Pour les trois millénaires les plus récents, elles s'accroissent de nouveau quelque peu; 3. Aucune relation n'a été trouvée entre les vitesses de sédimentation et l'altitude des sites.

Mots-clés

Palynologie, diagrammes polliniques, Holocène, datation, modèles profondeur-âge, base de données, Suisse.

INTRODUCTION

A reliable chronology for pollen diagrams is a prerequisite for further research. Only when age estimates are available for all samples in a pollen diagram can we embark on estimating sediment-accumulation rates, rates of palynological change, palynological turnover, and other statistics that depend on a detailed and reliable time scale. A reliable chronology is also needed for research in which the results of pollen diagrams are integrated, such as reconstructing past vegetation patterns in time and space. An effort was made to construct depth-age models for well-dated pollen sequences in Switzerland stored in the Alpine Palynological Data Base covering the whole or much of the Holocene. In this data-base, located in Bern (Switzerland), data for pollen diagrams from the entire Alpine arc have been collected and archived since 1991. The pollen diagrams discussed in this paper are derived from sites in or very near to Switzerland. Most of them were analysed by Max WELTEN (1982a, 1982b, unpubl.), the remaining by his pupils or by students following his tradition. WELTEN wrote the dedication *Weiterbauen!* (build on!; reproduced in Figure 1 bottom right) in a copy of his 1982a publication as an encouragement to continue innovative palynology, before he died in 1984. The work presented here is one contribution to his call and is therefore dedicated to his memory; for his work and publications see Festschrift Max WELTEN edited by LANG (1984).

The term "well-dated" used in this study for the

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Fig. 1 : Location of sites
Sites are numbered 1 to 25; for additional information see Table 1.

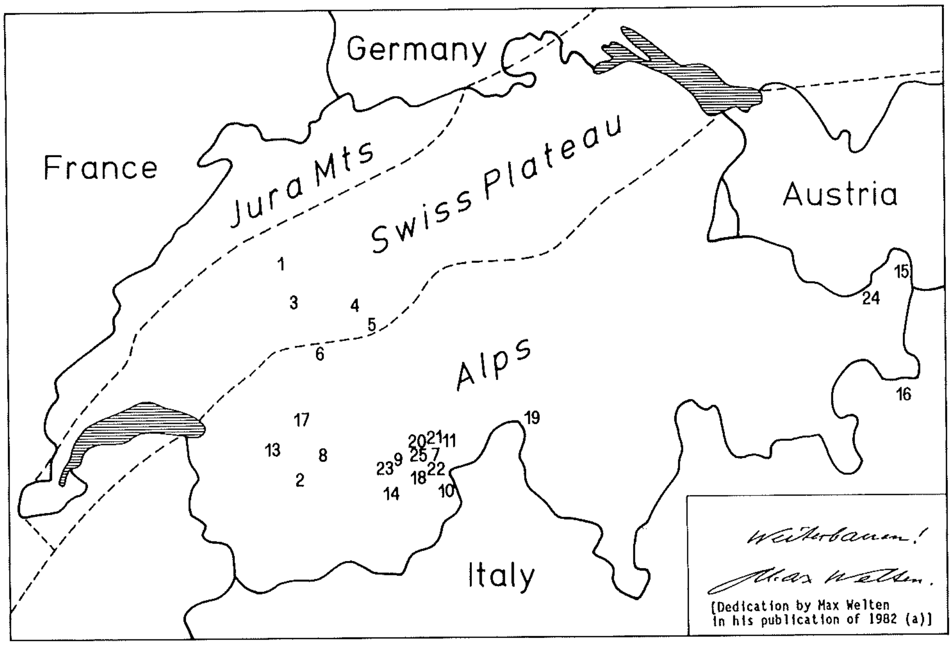


Table 1: List of pollen diagrams with depth-age model.

No. = No. of pollen diagram; diagrams are sorted on elevation
Code = One- or two-character abbreviation of name of pollen diagram
E# = Internal No. of pollen diagram in the Alpine Palynological Data Base
Site name = Name of study site
Site type :

- LGLA = lacustrine, glacial origin
- LNAT = natural open water
- TFEN = fen
- TMIR = mire
- TOWT = open-water transition mire
- TRAI = raised bog
- TVAL = valley mire

Elev. a.s.l. = elevation above sea level in m
Coring year
Corer :

- Hi = Hiller corer
- Da = Dachnowski corer
- Te = Technical coring
- Bo = Boxes (from open section)
- Sp = Spade
- Li = Modified Livingstone corer
- St = Streif corer

Water depth at the coring place was 2.7 m for site 1/Lo, whereas all other sites were not cored from open water.
Swiss coordinates = Swiss geographic coordinate system
No. Hol. Samples = Number of Holocene pollen samples in pollen diagram
No. pol. types = Number of pollen types in pollen diagram (after internal harmonisation of pollen morphology)
Original author(s): Inf. age of top-bottom = Ages of top and base of pollen diagram in conventional, uncalibrated ka yr BP as inferred by the original author(s)
Pollen analyst
Publication = Main publication(s) of the pollen diagram.

No.	Code	E#	Site name	Site type	Elev. a.s.l	Coring year	Corer	Swiss coordinates	No. Hol. samples	No. pol. types	Original author(s): Inf. age of top- bottom	Pollen analyst	Publication
1	Lo	82	Lobsigensee LQ-90	LGLA	514m	1981	St	208.800/589.500	80	117	0.0-15.0 BP	B.Ammann	Ammann&Lotter'89;Ammann'89
2	O	-3	Lac du Mont d'Orge	LNAT	640m	56/57/70	Hi	120.240/592.440	109	113	0.0-13.5 BP	M.Welten	Welten 1982a
3	Gä	5	Gänsemoos	TRAI	800m	1962	Hi	186.940/593.650	35	70	4.0-13.5 BP	M.Welten et al.	Welten 1982a; Welten 1982b
4	Li	216	Linden	TRAI	900m	1966	Hi	188.760/618.800	104	67	1.0-13.0 BP	K.Heeb	Heeb & Welten 1972
5	WU	-9	Wachseldorn Untermoos	TRAI	980m	1964/65	Bo	185.550/622.550	52	61	1.5-13.5 BP	K.Heeb	Heeb & Welten 1972
6	Ae	73	Aegelsee AE-3	TRAI	989m	1986	Li	166.260/607.960	82	85	0.0-12.5 BP	A.F.Lotter	Wegmüller & Lotter 1990
7	BN	27	Bitsch-Naters	TVAL	1030m	1956	Hi	132.240/642.500	90	88	0.5-10.0 BP	M.Welten	Welten 1982a
8	C	21	Etang d'y Cor	LNAT	1500m	1938	Hi	128.820/603.060	78	100	0.0-12.5 BP	M.Welten	Welten 1982a
9	Z	23	Zeneggen-Hellelen A	TVAL	1520m	1964	Hi	125.700/631.180	64	105	0.0-13.0 BP	M.Welten	Welten 1982a
10	GA	40	Gondo-Alpjen 2	TVAL	1635m	1964	Hi	117.910/652.000	42	92	0.0- 5.7 BP	M.Welten	Welten 1982a
11	E1	-4	Eggen ob Blatten	TVAL	1645m	1971	Hi Sp	135.650/642.400	78	92	2.0-10.0 BP	M.Welten	Welten 1982a
12	E2	49	Eggen ob Blatten 56	TVAL	1645m	1956	Hi	135.650/642.400	50	95	0.5-10.0 BP	M.Welten	Welten 1982a
13	P	16	Pillon	TVAL	1670m	1964	Hi	134.160/581.460	50	87	1.5-10.5 BP	M.Welten	Welten 1982a
14	GS	25	Grächen-See	TOWT	1710m	1973	Hi	116.180/631.370	81	90	0.0- 7.8 BP	M.Welten	Welten 1982a
15	ST	204	Schwarzsee ST	TMIR	1721m	1963	Hi	195.450/831.800	31	80	0.0-12.0 BP	M.Welten	Welten 1982b
16	D	-8	Dossaccio	TRAI	1730m	63/75/79	Hi	150.550/822.520	69	94	1.5-11.5 BP	M.Welten	Welten 1982b
17	Wb	15	Wallbach I	TFEN	1885m	1959	Hi Sp	141.780/597.200	38	87	0.0-10.3 BP	M.Welten	Welten 1982a
18	SA	39	Simplon-Alter Spittel	TVAL	1885m	1973	Hi	120.060/644.200	55	90	1.0-10.0 BP	M.Welten	Welten 1982a
19	R	-12	Robiei II	TVAL	1892m	1965	Hi Te	144.200/682.880	48	91	0.5-10.5 BP	M.Welten	Welten 1982a
20	Gr	31	Greicheralp	TVAL	1910m	1956	Hi	136.550/645.450	46	101	2.0- 5.9 BP	M.Welten et al.	Welten 1982a
21	Al	-6	Aletschwald	TVAL	2017m	56/71	Hi	137.640/645.070	57	102	0.0- 9.0 BP	M.Welten	Welten 1982a
22	H	-5	Hopschensee	TOWT	2017m	1962	Hi	122.460/645.000	36	93	0.0-13.0 BP	M.Welten	Welten 1982a
23	Bö	-13	Böhnigsee 1	LGLA	2095m	1965	Hi Da	122.600/631.600	60	149	0.5-11.0 BP	V.Markgraf	Markgraf 1969
24	M	51	Motta-Naluns	TVAL	2170m	1962	Hi Sp	188.160/815.600	54	89	1.0-10.0 BP	M.Welten	Welten 1982b
25	Ba	32	Belalp I	TVAL	2330m	1956	Hi	137.180/641.900	29	84	0.0- 6.3 BP	M.Welten	Welten 1982a

selection of pollen diagrams is naturally relative. Pollen diagrams that are sufficiently dated throughout the Holocene appear to be very scarce in the Alps. Therefore, a great effort was made in 1995 to obtain additional radiocarbon dates for selected pollen diagrams stored in the Alpine Palynological Data Base, both by AMS (Utrecht) and decay-counting dating (Bern). WELTEN (1982a), commenting on a site cored in 1938 (Etang d'y Cor; No. 8 in this paper), had expressed his regret that larger samples were not taken, the possibility of radiocarbon dating not being previewed. He took and preserved, however, small samples from many cores for later pollen analysis of intermediate levels, which were in part not used by him; many of them were used for AMS radiocarbon dating in this study.

This study presents examples of how the relationship between depth and age of Holocene lake and mire deposits can be modelled based on radiocarbon and biostratigraphic dates. It is written by and for palynologists who recognize the central importance of reliable dating and who wish to try to make one or two steps forward with palynological data that are already available, in other words to 'build on' the foundation laid by WELTEN (1982a, 1982b).

The aims of this study are to develop and present depth-age models for 25 pollen sequences that cover the entire Holocene or much of it. The data for these sequences are stored in the Alpine Palynological Data Base. Our focus is on sites from or very near to Switzerland. Pollen diagrams contributed to the Alpine Palynological Data Base by colleagues at the University of Innsbruck will be evaluated in Innsbruck where the depth-age relationships for these sequences will be modelled. The techniques of depth-age modelling used in this study are discussed here and the results obtained are evaluated.

MATERIAL AND METHODS

Table 1 gives a list of the pollen sequences for which depth-age modelling is attempted and provides some basic information about the sites and their sequences. The sites are ordered in relation to elevation, which in an Alpine mountain area is the obvious thing to do, and are consecutively numbered. Table 2 lists all the dates

Table 2: Radiocarbon dates and other dated horizons used in this study.

No. = No. of pollen diagram; diagrams are sorted on elevation
Code = One- or two-character abbreviation of name of pollen diagram
E# = No. of pollen diagram in the Alpine Palynological Data Base. For name of site, see Table 1
Type = Type of date:
- AMS = AMS radiocarbon date
- decay = Decay-counting radiocarbon date
- TOP = Biostratigraphic date: top of core
- YD/PB = Biostratigraphic date: base of Holocene
- δO18 = Oxygen-isotope transition : base of Holocene

Thickness = Vertical thickness of radiocarbon sample (if known)
Cal yr BP (calibr.) = Calibrated age of date (made with CALIB)
Use = Use of date in depth-age model:
- I = Included in model
- O = Holocene date, omitted from model
- L = Late-Glacial date, not included in model
- R = Late-Glacial date, rejected

Conv. C14 yr BP = measured radiocarbon age (conventional age)
σC13 = σC13 value in per mil going with radiocarbon measurement; c. = estimated
Lab. No. of dating :
- B-* = from Bern, "Physikalishes Institut Abt. KUP". Dates B-6477 and higher were measured in 1995-96.
- UtC-* = from Utrecht, "Vakgroep Subatomaire Physica", measured in 1995-96.

Dated material if known. Abbreviations used:
- calc. = calcareous material (including lake marl)
- decomp. = decomposed
- detr. = detritus
- Drepanocl. = *Drepanocladus*
- hyph = hyphae
- needl = needles
- possib. = possibly

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
1	Lo	82	TOP	40		-31±1	I				
1	Lo	82	AMS	97.5	5	592±52	I	590±60	-32.2	UtC-4102	mosses + fibrous plant remains
1	Lo	82	AMS	162	4	1463±54	I	1580±50	-31.9	UtC-4105	bark, leaf fragments
1	Lo	82	decay	223.5	3	1607±95	I	1690±80	-32.0	B-4314	fine-detritus gyttja
1	Lo	82	decay	244.5	3	1966±77	I	2030±60	-30.6	B-4315	fine-detritus gyttja
1	Lo	82	AMS	251.5	3	1422±74	I	1534±36	-27.1	UtC-4106	leaf fragments
1	Lo	82	decay	293.5	3	2256±96	I	2300±50	-34.3	B-4316	fine-detritus gyttja
1	Lo	82	AMS	322.5	5	1988±52	I	2044±36	-28.3	UtC-4103	seeds, twigs
1	Lo	82	decay	368	4	2797±47	I	2680±50	-33.3	B-4317	fine-detritus gyttja
1	Lo	82	decay	401.5	3	3426±47	I	3230±50	-31.8	B-4318	fine-detritus gyttja
1	Lo	82	AMS	405.5	5	3418±43	I	3200±50	-26.2	UtC-4104	mosses, seeds, bud scales
1	Lo	82	AMS	450	4	4349±63	I	3915±44	-27.2	UtC-4101	leaves, seeds, bud scales
1	Lo	82	decay	461.5	3	4692±127	I	4140±60	-34.0	B-4319	fine-detritus gyttja
1	Lo	82	decay	501.5	3	5673±70	I	4950±70	-37.7	B-4320	fine-detritus gyttja
1	Lo	82	AMS	508	2	5453±122	I	4738±45	-28.3	UtC-4108	Alnus cone, bark, fruit scale
1	Lo	82	decay	524.5	3	6132±134	I	5350±60	-33.3	B-4321	fine-detritus gyttja
1	Lo	82	AMS	553	3	6389±86	I	5610±90	-26.7	UtC-4112	plant detritus
1	Lo	82	decay	572	4	5278±182	0	4630±60	-31.6	B-4322	fine-detritus gyttja
1	Lo	82	AMS	609.5	1	7086±76	I	6180±46	-28.4	UtC-4107	twig
1	Lo	82	AMS	655	2	8239±72	I	7460±50	-29.7	UtC-4110	leaf fragments,coarse detritus
1	Lo	82	AMS	691.25	3.5	8983±218	I	8100±60	-28.6	UtC-4109	twig, leaves, seeds
1	Lo	82	AMS	728	4	9923±59	I	8910±70	-28.8	UtC-4111	coarse plant detritus, leaves
1	Lo	82	decay	731	2	10621±246	I	9500±90	-31.9	B-4323	fine-detritus gyttja
1	Lo	82	decay	744	2	12600±94	0	10670±70	-32.4	B-4037	fine-detritus gyttja
1	Lo	82	YD/PB	746		11600±50	I	10000			
1	Lo	82	decay	748	2	12718±87	0	10790±70	-31.2	B-4038	fine-detritus gyttja
1	Lo	82	decay	766	2	13389±149	L	11470±120	-32.1	B-4039	fine-detritus gyttja
1	Lo	82	LST	773.5		13138±68	L	11230±40			
1	Lo	82	decay	783	4	14206±148	L	12170±60	-33.9	B-4040	fine-detritus gyttja
1	Lo	82	decay	786	2	14219±149	L	12180±60	-34.0	B-4041	fine-detritus gyttja
1	Lo	82	decay	796	2	14958±194	L	12700±80	-32.4	B-4042	fine-detritus gyttja
1	Lo	82	decay	798	2	9418±36	R	8430±40	-29.7	B-4043	fine-detritus gyttja
1	Lo	82	decay	804	2	8290±82	R	7550±40	-28.6	B-4044	fine-detritus gyttja
1	Lo	82	decay	806	2	15813±180	L	13250±100	-29.7	B-4045	fine-detritus gyttja
1	Lo	82	decay	807.75	1.5	14603±267	R	12460±160	-30.3	B-4046	fine-detritus gyttja
2	O	-3	TOP	0		-20±1	I				
2	O	-3	decay	202		599±47	I	620±70		B-2174	detritus-gyttja+lake marl+clay
2	O	-3	decay	318		1238±54	I	1330±50		B-2175	detritus-gyttja+lake marl+clay
2	O	-3	decay	546		2617±125	I	2530±50		B-2176	detritus-gyttja+lake marl+clay
2	O	-3	decay	590		2613±139	0	2540±110		B-2157	gyttja (+clay+chalk)
2	O	-3	decay	622		3509±120	I	3290±110		B-2150	gyttja (+clay+chalk)
2	O	-3	decay	941		5965±206	I	5190±120		B-2158	gyttja (+clay+chalk)
2	O	-3	decay	981		6257±200	I	5500±150		B-2151	gyttja (+clay+chalk)
2	O	-3	decay	1184		6465±166	0	5650±150		B-84	gyttja mixed with clay + chalk
2	O	-3	decay	1227		8726±226	0	7890±170		B-2159	gyttja (+clay+chalk)
2	O	-3	decay	1270		8356±143	I	7630±100		B-2152	gyttja (+clay+chalk)
2	O	-3	decay	1304		8576±371	I	7730±240		B-83	gyttja mixed with clay + chalk
2	O	-3	YD/PB	1355		11600±50	I	10000			

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
3	Gä	5	decay	40	20	4159±67	I	3790±30	-27.5	B-6478	peat
3	Gä	5	decay	137.5	25	5781±104	I	5020±40	-30.7	B-6479	peat
3	Gä	5	decay	187		6376±96	I	5570±100		B-526	ombrotrophic peat
3	Gä	5	decay	237.5	25	7384±87	O	6530±40	-27.9	B-6480	peat
3	Gä	5	decay	335		7987±138	I	7220±120		B-527	transitional peat
3	Gä	5	decay	387.5	25	8754±191	I	7910±50	-26.0	B-6481	peat
3	Gä	5	decay	437.5	25	9934±38	I	8920±50	-23.0	B-6482	gyttja
3	Gä	5	decay	487		11069±441	I	9830±150		B-528	gyttja and dy
3	Gä	5	YD/PB	495		11600±50	I	10000			
3	Gä	5	decay	515	20	12270±207	I	10400±120	-23.6	B-6483	gyttja
3	Gä	5	LST	527		13128±68	I	11230±40			
3	Gä	5	decay	564	18	13632±174	R	11690±130	-23.8	B-6484	gyttja
4	Li	216	TOP	-50		0	I				
4	Li	216	AMS	110		1726±89	I	1820±48	-25.7	UtC-4087	twig from peat
4	Li	216	AMS	225		3510±47	I	3283±36	-28.8	UtC-4088	bark fragments from peat
4	Li	216	decay	287.5	25	4170±77	I	3810±40	-29.1	B-6486	peat
4	Li	216	decay	362.5	25	5619±28	I	4880±40	-27.2	B-6487	peat
4	Li	216	decay	462.5	25	6405±85	I	5650±50	-27.2	B-6488	peat
4	Li	216	decay	612.5	25	7484±26	I	6560±50	-28.6	B-6489	peat
4	Li	216	AMS	787.5	25	12416±103	O	10500±60	-38.7	UtC-4086	mosses from silt
4	Li	216	decay	915	10	12507±255	O	10600±200	-35.5	B-6490	gyttja
4	Li	216	AMS	997.5	5	12209±267	O	10370±140	-37.4	UtC-4085	mosses from silt
4	Li	216	YD/PB	1030		11600±50	I	10000			
4	Li	216	decay	1065	10	12300±197	O	10420±120	-27.6	B-6491.65	gyttja
4	Li	216	decay	1077.5	15	12237±308	I	10400±120	-28.5	B-6491.77	gyttja
4	Li	216	decay	1180	20	10584±378	R	9490±280	-27.9	B-6492	gyttja
5	WU	-9	AMS	10		142±142	O	190±34	-26.4	UtC-4095	seeds from peat
5	WU	-9	AMS	40		2598±121	I	2499±44	-27.4	UtC-4100	wood fragments from peat
5	WU	-9	AMS	80		3429±41	I	3233±43	-28.2	UtC-4096	twig from peat
5	WU	-9	AMS	130		4320±82	I	3878±41	-30.1	UtC-4097	bark fragments from peat
5	WU	-9	AMS	170		5832±76	I	5096±45	-28.8	UtC-4098	coarse plant fibres from peat
5	WU	-9	decay	225	30	7489±90	I	6690±100		B-924	Sphagnum peat
5	WU	-9	AMS	295		8831±153	I	8010±70	-29.4	UtC-4099	coarse detritus from peat
5	WU	-9	decay	330		9865±173	I	8950±110		B-2011	Cyperaceae peat
5	WU	-9	decay	358		10783±204	I	9680±130		B-2012	Cyperaceae peat
5	WU	-9	decay	365		10479±320	O	9400±130		B-2013	Cyperaceae peat
5	WU	-9	YD/PB	370		11600±50	I	10000			
5	WU	-9	decay	376		12460±196	L	10550±150		B-700	peat
5	WU	-9	decay	381		12106±326	L	10320±150		B-701	peat
5	WU	-9	decay	387.5	5	10193±148	R	9250±120		B-925	peat
5	WU	-9	decay	403.5	3	11238±284	R	9880±120		B-926	Cyperaceae peat
5	WU	-9	decay	411		12899±204	L	10980±200		B-702	peat
5	WU	-9	decay	426		13599±191	L	11660±150		B-703	peat
5	WU	-9	decay	430		11574±424	R	10130±110		B-921	Hypnaceae peat
5	WU	-9	decay	430		13771±202	L	11810±150		B-704	peat
5	WU	-9	decay	439		14441±245	L	12345±150		B-705	peat
5	WU	-9	decay	441		14261±233	L	12210±150		B-706	peat
5	WU	-9	decay	449		14508±228	L	12395±130		B-707	peat
5	WU	-9	decay	451		14660±259	L	12500±150		B-708	peat
5	WU	-9	decay	465		15300±246	L	12915±130		B-709	peat

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
6	Ae	73	TOP	0		-38±1	I				
6	Ae	73	decay	70		1693±135	I	1790±120		B-50	Sphagnum peat
6	Ae	73	decay	115	10	3084±128	I	2940±90	c.-27	B-5181	peat
6	Ae	73	decay	140	10	3279±62	I	3070±40	-25.6	B-5016	peat
6	Ae	73	decay	170	10	3462±90	I	3240±70	c.-27	B-5182	peat
6	Ae	73	decay	225	8	4678±142	I	4130±80	-27.0	B-5270	peat
6	Ae	73	decay	310		6311±94	I	4920±130		B-53	Sphagnum-rich detritus gyttja
6	Ae	73	decay	360	10	6241±42	I	5430±40	-27.6	B-5018	peat
6	Ae	73	decay	445	8	7140±106	I	6290±70	-29.2	B-5271	peat
6	Ae	73	decay	471.5	13	7128±97	I	6270±70	c.-27	B-5183	peat
6	Ae	73	decay	494.5	9	7383±88	I	6530±60	-28.0	B-5019	peat
6	Ae	73	decay	570	10	8286±85	I	7540±50	-29.3	B-5184	peat
6	Ae	73	YD/PB	763.75		11600±50	I	10000			
6	Ae	73	LST	801.40		13138±68	L	11230±40			
7	BN	27	TOP	0		-6±1	I				
7	BN	27	decay	135	15	908±146	I	1000±120		B-197	carr peat; no chalk
7	BN	27	decay	234	15	1639±224	I	1740±200		B-196	carr peat + wood; no chalk
7	BN	27	decay	365		2661±181	I	2600±100		B-73	peat
7	BN	27	decay	432	18	4687±147	I	4170±120		B-195	clayey gyttja; possibly chalk
7	BN	27	decay	465		6059±116	I	5280±90		B-2767	gyttja
7	BN	27	decay	505	40	6133±138	O	5350±100		B-194	clayey gyttja; possibly chalk
7	BN	27	decay	535		8172±165	I	7420±160		B-2768	gyttja
7	BN	27	decay	584		8123±186	O	7330±180		B-72	gyttja
7	BN	27	YD/PB	628		11600±50	I	10000			
8	C	21	TOP	0		12±1	I				
8	C	21	AMS	110		2379±48	I	2361±37	-31.9	UtC-4089	twig
8	C	21	AMS	230		3769±59	I	3507±41	-29.3	UtC-4090	twigs
8	C	21	AMS	340		5044±168	I	4436±41	-27.4	UtC-4091	bark fragments
8	C	21	AMS	500		6379±63	I	5619±44	-29.4	UtC-4092	Pinus needles + leaf fragments
8	C	21	AMS	620		8225±85	I	7450±60	-35.1	UtC-4093	amorphous organic material
8	C	21	AMS	730		9959±43	I	8980±60	-29.2	UtC-4094	twigs, leaf fragments
8	C	21	δO18	775		11600±50	I				
9	Z	23	TOP	0		-14±1	I				
9	Z	23	decay	113		1110±122	I	1200±100		B-637	Hypnaceae peat
9	Z	23	decay	210		1686±118	I	1775±100		B-724	peat/gyttja
9	Z	23	decay	270		2307±157	I	2320±100		B-638	Hypnaceae peat
9	Z	23	decay	387.5	25	3025±47	I	2910±30	-26.3	B-6516	peat
9	Z	23	decay	438		3314±153	I	3120±120		B-639	Hypnaceae peat
9	Z	23	decay	480		4333±177	I	3920±100		B-640	detritus gyttja
9	Z	23	decay	522.5	25	4605±177	I	4050±50	-33.0	B-6517	peat
9	Z	23	decay	562		6826±159	I	5970±120		B-723	peat/gyttja
9	Z	23	decay	622		9070±297	I	8160±130		B-641	detritus gyttja
9	Z	23	AMS	647		9441±50	I	8470±60	-30.8	UtC-4063	clay gyttja
9	Z	23	YD/PB	650		11600±50	I	10000			
9	Z	23	AMS	767		882±85	R	1010±46	-22.8	UtC-4062	clay gyttja
10	GA	40	TOP	0		-14±1	I				
10	GA	40	decay	77		1291±108	I	1400±100		B-699	Cyperaceae peat
10	GA	40	decay	192		3227±152	I	3060±120		B-630	Cyperaceae peat
10	GA	40	decay	287		4089±174	I	3740±120		B-631	Cyperaceae peat
10	GA	40	decay	387		5335±251	I	4670±130		B-632	Cyperaceae peat
10	GA	40	decay	430		6040±263	I	5310±200		B-633	gyttja

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
11	E1	-4	TOP	0		-21±1	I				
11	E1	-4	decay	36		2549±173	I	2490±100		B-2546	peat
11	E1	-4	decay	48		2937±140	I	2840±110		B-2547	peat
11	E1	-4	decay	92		4623±190	I	4080±100		B-2548	peat
11	E1	-4	decay	107		4211±217	I	3850±140		B-2572	
11	E1	-4	decay	136		5063±183	I	4450±40	-27.3	B-6514	peat
11	E1	-4	decay	149		2847±95	0	2730±100		B-2591	
11	E1	-4	decay	181		6245±195	0	5490±140		B-2573	
11	E1	-4	decay	215		5667±77	I	4930±80	-24.0	B-6515	peat
11	E1	-4	decay	240		5965±206	I	5190±120		B-2550	peat
11	E1	-4	decay	260		6414±115	I	5630±110		B-2551	peat/gyttja
11	E1	-4	decay	290		6972±177	I	6080±100		B-2552	peat/gyttja
11	E1	-4	decay	321		7838±96	I	7070±100		B-2553	gyttja
11	E1	-4	decay	340		8149±157	I	7360±130		B-2554	gyttja
11	E1	-4	decay	370		9805±231	I	8890±220		B-2555	gyttja
11	E1	-4	AMS	395		10647±225	I	9525±87	-19.4	UtC-4248	Carex seeds
11	E1	-4	AMS	420		8504±78	0	7801±64	-27.3	UtC-4247	wood fragments
11	E1	-4	YD/PB	425		11600±50	I	10000			
12	E2	49	decay	60	20	2557±177	I	2500±100		B-201	decomp.Carex peat;hardly chalk
12	E2	49	decay	115		3746±157	I	3490±120		B-970	
12	E2	49	decay	140	20	4400±166	I	3970±110		B-200	peat; very little chalk
12	E2	49	decay	217		6049±121	I	5250±80		B-199	peat
12	E2	49	decay	290		6638±140	0	5840±120		B-971	
12	E2	49	decay	320	20	7837±115	I	7080±120		B-198	Carex-Hypn.peat;possibly chalk
13	P	16	decay	62.5	25	2432±273	I	2350±100		B-2419	Hypnaceae peat
13	P	16	decay	112.5	25	3500±121	I	3270±100		B-2418	Hypnaceae peat
13	P	16	decay	162.5	25	4779±201	I	4270±100		B-2417	Hypnaceae peat
13	P	16	decay	187.5	25	5444±131	I	4700±100		B-2416	Hypnaceae peat
13	P	16	decay	237.5	25	6333±126	I	5550±110		B-2415	Hypnaceae peat
13	P	16	decay	262.5	25	6883±131	I	6040±110		B-2414	Hypnaceae peat
13	P	16	decay	312.5	25	8940±264	I	8080±130		B-2413	Hypnaceae peat
13	P	16	decay	337.5	25	9733±146	I	8760±100		B-2412	Hypnaceae peat
13	P	16	decay	360	20	9819±161	I	8870±120		B-2411	Hypnaceae peat
13	P	16	YD/PB	384		11600±50	I	10000			
14	GS	25	TOP	0		-23±1	I				
14	GS	25	decay	70	20	857±67	I	950±60		B-2581	peat/gyttja
14	GS	25	decay	140	20	2249±94	I	2270±70		B-2582	peat/gyttja
14	GS	25	decay	227	40	2643±135	I	2600±60		B-2583	peat/gyttja
14	GS	25	decay	380	40	4283±126	I	3880±70		B-2584	peat/gyttja
14	GS	25	decay	516	55	5772±115	I	5010±80		B-2585	peat/gyttja
14	GS	25	decay	630		6463±152	I	5660±120		B-2602	peat/gyttja
14	GS	25	decay	680	40	7829±87	0	7050±90		B-2586	peat/gyttja
14	GS	25	decay	737		7679±206	I	6830±200		B-2603	peat/gyttja
14	GS	25	decay	827	45	6960±206	0	6080±180		B-2587	peat/gyttja
14	GS	25	decay	880	40	8144±148	I	7360±90		B-2588	peat/gyttja
14	GS	25	decay	1033	33	8224±93	0	7440±90		B-2589	peat/gyttja
14	GS	25	decay	1083	25	8273±90	0	7520±90		B-2590	gyttja
15	ST	204	TOP	0		-13±1	0				
15	ST	204	decay	148		231±231	I	280±80	-28.4	B-3174	peat
15	ST	204	decay	185	20	7519±42	0	6720±40	-28.2	B-6477	peat
15	ST	204	AMS	300		4319±88	I	3880±60	-28.6	UtC-4075	peat
15	ST	204	decay	341		7326±65	I	6460±80	-31.6	B-3173	gyttja
15	ST	204	decay	400	50	9819±163	I	8870±130	c.-25	B-3068	gyttja
15	ST	204	YD/PB	438		11600±50	I	10000			
15	ST	204	decay	441		11338±328	I	10020±130	c.-25	B-3172	clay-gyttja

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
16	D	-8	decay	212.5	25	3714±116	I	3450±80	c.-25	B-3072	peat
16	D	-8	decay	412.5	25	5661±77	I	4910±80	c.-25	B-3073	peat
16	D	-8	decay	587.5	25	7998±71	I	7220±60	c.-25	B-3074	peat
16	D	-8	decay	691.5		8774±183	I	7960±130	-31.0	B-3175	gyttja
16	D	-8	decay	786		9175±192	I	8190±130	-30.1	B-3176	gyttja
16	D	-8	YD/PB	857.5		11600±50	I	10000			
17	Wb	15	TOP	0		-9±1	I				
17	Wb	15	decay	8		142±129	0	130±100		B-364	peat
17	Wb	15	decay	30		836±91	I	930±100		B-365	peat
17	Wb	15	decay	60		1223±83	I	1320±80		B-366	peat
17	Wb	15	decay	100		1553±137	I	1660±100		B-367	peat
17	Wb	15	decay	130		5044±212	I	4380±120		B-368	peat
17	Wb	15	decay	155		6266±151	I	5500±120		B-369	peat
17	Wb	15	decay	170		7263±168	I	6410±150		B-370	peat
17	Wb	15	decay	190		7622±146	I	6820±150		B-371	peat
17	Wb	15	decay	207		8145±165	I	7360±160		B-372	peat
17	Wb	15	decay	221		8801±188	I	8000±120		B-373	peat
17	Wb	15	AMS	250		8807±141	0	7966±42	-26.5	UtC-4060	clayey gyttja
17	Wb	15	YD/PB	285		11600±50	I	10000			
17	Wb	15	AMS	295		13013±70	L	11100±50	-25.1	UtC-4061	clayey gyttja
18	SA	39	AMS	30		2653±103	I	2577±35	-28.0	UtC-4082	bark fragments from peat
18	SA	39	AMS	100		3715±90	I	3432±41	-25.6	UtC-4084	Bryophyte stems + Carex seeds
18	SA	39	decay	129		3738±101	I	3490±80		B-2577	peat/gyttja
18	SA	39	AMS	180		5442±119	I	4696±38	-28.5	UtC-4081	thin twigs from peat
18	SA	39	decay	230		6544±124	I	5750±100		B-2578	peat/gyttja
18	SA	39	AMS	255		7890±57	0	7126±48	-27.0	UtC-4083	bark fragments from peat
18	SA	39	decay	327		7915±155	I	7140±140		B-2579	peat/gyttja
18	SA	39	decay	377	40	9052±323	I	8160±200		B-2580	peat/gyttja
18	SA	39	AMS	402		9975±43	I	9000±60	-26.1	UtC-4080	clay gyttja
18	SA	39	AMS	424		11200±215	I	9900±60	-19.9	UtC-4079	clay gyttja
18	SA	39	AMS	430		11502±358	I	10100±70	-21.2	UtC-4078	clay gyttja
18	SA	39	YD/PB	432		11600±50	I	10000			
19	R	-12	TOP	0		-15±1	I				
19	R	-12	decay	77		1394±104	I	1480±100		B-2604	peat
19	R	-12	AMS	187.5	25	1346±42	0	1466±52	-25.6	UtC-4245	Carex seeds from peat
19	R	-12	decay	230		4710±133	I	4210±80		B-2606	gyttja
19	R	-12	decay	237	25	4937±102	I	4350±80		B-2614a	
19	R	-12	decay	275		5673±175	I	4920±90		B-2605	peat
19	R	-12	decay	338		6473±155	I	5680±110		B-2614b	
19	R	-12	AMS	387.5	25	6315±79	0	5496±47	-25.6	UtC-4246	twigs from sandy gyttja
19	R	-12	decay	450		8033±88	I	7260±100		B-2607	gyttja
19	R	-12	decay	512		8934±264	I	8070±130		B-2612	gyttja
19	R	-12	decay	537		9401±139	I	8480±110		B-2613	gyttja
19	R	-12	decay	565		9985±289	I	9000±140		B-2614	gyttja
19	R	-12	YD/PB	625		11600±50	I	10000			
20	Gr	31	decay	92.5	15	3802±113	I	3530±90		B-2002	Cyperaceae peat
20	Gr	31	decay	177.5	15	4342±182	I	3940±100		B-2003	Cyperaceae peat
20	Gr	31	decay	240	20	5041±204	I	4380±120		B-2004	Hypnaceae peat
20	Gr	31	decay	340	20	6174±244	I	5420±230		B-2005	Hypnaceae peat
20	Gr	31	decay	412.5	15	6405±104	I	5630±100		B-2006	Hypnaceae peat

No.	Code	E#	Type	Depth (cm)	Thick -ness	Cal yr BP (calibr.)	Use ?	Conv. C14 yr BP	δC13	Lab. No. of dating	Dated material
21	Al	-6	TOP	0		-21±1	I				
21	Al	-6	decay	35		1001±63	I	1100±70		B-2885	peat
21	Al	-6	decay	75		1690±114	I	1780±80		B-2886	peat
21	Al	-6	decay	135		2634±144	I	2590±80		B-2887	peat
21	Al	-6	decay	195		4171±174	I	3800±80		B-2888	peat
21	Al	-6	decay	255		6310±107	I	5530±100		B-2889	peat
21	Al	-6	decay	315		7824±95	I	7050±100		B-2428	peat/gyttja
21	Al	-6	decay	370		8821±170	I	8010±110		B-2429	peat/gyttja
21	Al	-6	decay	410	30	7019±162	0	6140±150		B-78	gyttja, some clay
22	H	-5	TOP	0		-12±1	I				
22	H	-5	decay	97		608±53	I	660±80		B-634	clayey gyttja
22	H	-5	decay	137.5	25	2002±104	I	2050±70	-26.7	B-6485	gyttja
22	H	-5	decay	201		3460±111	I	3230±100		B-669	gyttja
22	H	-5	decay	246		5156±423	I	4500±300		B-635	clayey gyttja
22	H	-5	decay	277.5		5773±156	I	5040±150		B-635E	
22	H	-5	decay	328		4476±317	0	3970±120		B-636	clayey gyttja
22	H	-5	AMS	345		7340±50	I	6488±42	-26.6	UtC-4077	twig from sandy gyttja
22	H	-5	decay	390		8581±363	I	7730±180		B-610	gyttja
22	H	-5	decay	405		9984±294	I	9000±150		B-609	gyttja
22	H	-5	decay	406		10633±332	I	9530±250		B-530	clayey gyttja
22	H	-5	YD/PB	418		11600±50	I	10000			
22	H	-5	decay	490		12219±443	R	10430±250		B-529	clayey gyttja
22	H	-5	decay	494		14783±324	I	12580±200		B-608	gyttja
22	H	-5	AMS	595		8959±229	R	8080±60	-25.6	UtC-4076	sandy gyttja
23	Bö	-13	TOP	0		-15±1	I				
23	Bö	-13	decay	385	30	5455±128	I	4740±100		B-786	Sphagnum+Drepanocl+fungal hyph
23	Bö	-13	decay	485	40	6880±120	I	6030±100		B-785	detr.gyttja+Larix-+Pinus leavs
23	Bö	-13	decay	545	25	8818±166	I	7990±110		B-784	algal gyttja with Pediastrum
23	Bö	-13	YD/PB	565		11600±50	I	10000			
23	Bö	-13	decay	593	29	12301±246	I	10430±150		B-782	algal gyttja with Pediastrum
24	M	51	decay	28		1421±92	I	1530±100		B-531	Hypnaceae peat
24	M	51	decay	50		1974±135	I	2020±100		B-532	Hypnaceae peat
24	M	51	decay	81		2672±176	I	2620±100		B-533	Hypnaceae peat
24	M	51	decay	120		4285±138	0	3890±100		B-534	wood (Salix)
24	M	51	decay	130		4285±138	I	3890±100		B-535	Hypnaceae peat
24	M	51	decay	142		4676±147	I	4130±100		B-536	wood (Salix)
24	M	51	decay	160		5052±199	I	4400±100		B-537	wood (Salix)
24	M	51	decay	174		5274±291	I	4580±200		B-538	Hypnaceae peat
24	M	51	decay	192		5665±190	I	4900±120		B-539	wood (Salix)
24	M	51	decay	230		6619±137	I	5820±120		B-541	Hypnaceae peat
24	M	51	decay	248		7042±132	I	6170±120		B-542	Hypnaceae peat
24	M	51	decay	265		8164±148	I	7400±120		B-543	Hypnaceae peat, some sand
24	M	51	decay	276		8876±267	I	8030±120		B-544	Hypnaceae peat, some sand
24	M	51	YD/PB	299		11600±50	I	10000			
25	Ba	32	TOP	0		-6±1	I				
25	Ba	32	decay	62.5	15	1837±105	I	1920±90		B-205	Carex peat; possibly chalk
25	Ba	32	decay	92.5	15	4724±144	I	4240±80		B-204	Carex peat; possibly chalk
25	Ba	32	decay	122.5	15	6619±137	I	5820±120		B-203	decomp.Carex peat;possib.chalk
25	Ba	32	decay	147.5	15	7024±139	I	6130±110		B-202	decomp. Carex peat; some chalk

available in the study sites for depth-age modelling. Figure 1 shows the locations of the sites.

Time period
The depth-age models presented are based on the Holocene dates; Late-Glacial dates close to the Late-Glacial - Holocene boundary are occasionally included if they are relevant (Table 2). The results (ages and sediment-accumulation rates of pollen samples) are presented for the entire Holocene, occasionally extending slightly into the Late-Glacial (*e.g.* Fig. 3-1).

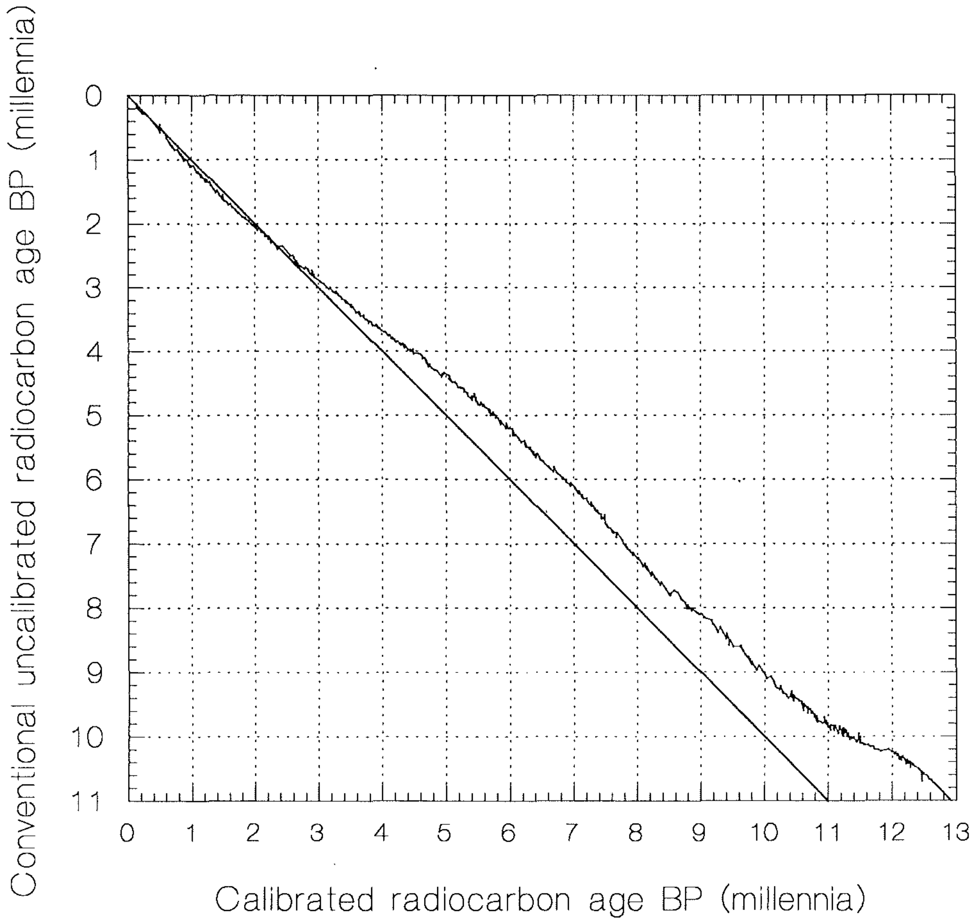
Dates available
Three types of dates are available for depth-age modelling: radiocarbon dates (both decay counting and AMS), the occurrence of the Laacher See Tephra (in the Late-Glacial), and biostratigraphic dates. Biostratigraphic dates are based on the pollen assemblage and include, if appropriate, the surface of the sediment (dated to the year of sediment sampling) and the beginning of the Holocene (11600 ± 50 cal yr BP). Depths are those indicated in the original publications.

Additional dates
At the time we started this project we were surprised by the small number of pollen diagrams that were well-dated for the entire Holocene or Late-Glacial. Both WELTEN's (1952) skillfully drawn and now famous vegetation diagrams depicting for the Holocene the relation between major altitudinal zonation in vegetation and time and AMMANN & LOTTER's (1989) detailed Late-Glacial chrono-zonation of biostratigraphies in the Swiss Plateau had left us with the impression that a large number of well-dated pollen diagrams existed. However, this was not the case. WELTEN's Holocene vegetation diagrams are based mainly on pollen diagrams that are radiocarbon-dated for only part of the sequence and that he correlated by eye. AMMANN & LOTTER's Late-Glacial chrono-stratigraphy is based on two well-dated lowland pollen diagrams only. A reasonable number of well-dated pollen diagrams for studying geographical patterns in palynological data is a main aim of the research programme of the Alpine Palynological Data Base. We therefore felt that additional radiocarbon dating on existing pollen diagrams would be essential, not only to obtain a reasonable number of pollen diagrams dated throughout but also in order to check the many points of biostratigraphic correlation made by WELTEN and to refine his time scales. Additional radiocarbon dating has been carried out in 1995 and 1996 (58 AMS dates; 31 decay-counting dates), and we feel that with relatively little effort and cost the value of the data stored in the Alpine Palynological Data Base has been increased enormously. The chronology of 13 out of 25 pollen diagrams presented here depends partly or mainly on these additional radiocarbon dates.

Statistical modelling and graphical display
The depth-age relationships presented in this study are based on two kinds of statistical models: linear interpolation of sample ages between dates, and polynomial functions with 2 to 6 terms of the type $y = a + bx + cx^2 + dx^3$ etc., where y is the estimated age, and x is sediment depth. Two different computer programs were used for implementation. In the first step, the PC program APDB written by Steve JUGGINS (1994) was used. This program fits a curve through the dates based on the selected model and displays the results on the monitor as a printable graph with sediment depth and modelled age as the X- and Y-axes; the dates and the samples are shown with different symbols. Dates can be excluded from the model by flagging them on the graph; a continuous graphic display permits experimentation with the inclusion or exclusion of certain dates and with different models. This helped us to select a suitable chronology for each pollen sequence. After this, the program PSIMPOLL (BENNETT, 1993) was used for estimating confidence intervals of sample ages using the model selected in APDB. Results were printed using SYGRAPH (WILKINSON, 1990); each graph includes ages and confidence intervals of samples and ages and standard deviations of dates plotted against depth. The chronology inferred by the original author(s) is added to each graph.

Calibration of radiocarbon years
For depth-age modelling, we can use the radiocarbon dates expressed as uncalibrated radiocarbon years, so-called conventional radiocarbon years BP, or alternatively we may choose to calibrate the dates before any depth-age modelling. At first consideration, the use of uncalibrated radiocarbon years may seem preferable. Advantages over the use of calibrated dates are (1) convenience, because it saves the effort of calibrating the dates, (2) the smaller standard errors of the dates, because calibration inevitably increases the error, (3) comparability with much of the palynological literature, in which dates and interpolated ages are most commonly given as uncalibrated ages, and (4) the depth-age model might be more simple, because it involves less data manipulation.
However, the latter is not true. Depth-age models based on uncalibrated radiocarbon dates are actually more complex than those based on calibrated dates. This can be seen in Figure 2, showing the complex relationship between calibrated and uncalibrated radiocarbon years. A peat or lake deposit with a constant sediment-accumulation rate throughout the Holocene would produce a linear depth-age relationship using calibrated

Fig. 2 : Calibrated years BP versus conventional uncalibrated years BP
The curve shows the relation between calibrated and uncalibrated radiocarbon age BP and is constructed from all dates listed in Table 2. A straight line X=Y is drawn for comparison.



ages, but with uncalibrated ages the curve would theoretically have a shape reflecting the relationship between calibrated and uncalibrated dates shown in Figure 2. In practice, however, sufficient dating control to reproduce all these wiggles in the depth-age relationship is never available to a palynologist. The consequence of these wiggles is that the duration (in calendar years) of radiocarbon years changes throughout the Holocene. This implies that sample ages interpolated in some way between uncalibrated radiocarbon dates do not have a fixed duration in calendar years; they therefore can not be usefully calibrated. We conclude that depth-age models based on uncalibrated radiocarbon ages are unnecessarily complex and that the modelled ages have such a complex relationship to calendar years that their meaning is unclear. Therefore, calibration of radiocarbon dates before depth-age modelling is essential.

We use the traditional abbreviation "BP" for conventional, uncalibrated radiocarbon years before AD 1950 (STUIVER & POLACH, 1977), occasionally adding "ka" (millennia: ka BP), whereas calibrated ages are indicated with "cal yr BP" (calendar years before AD 1950) or cal ka BP (millennia before AD 1950).
Dates were calibrated by CALIB version 3.0.3c (STUIVER & REIMER, 1993) using their method B (probability distribution) and 1σ (1 standard deviation). TAYLOR *et al.* (1996) provide a good, readable explanation of the history, techniques, and implications of calibrating radiocarbon dates. For the Laacher See Tephra we calibrated the radiocarbon age 11230 ± 40 BP given by HAJDAS *et al.* (1995) to 13138 ± 68 cal yr BP rather than accepting the ages 12350 ± 135 cal yr BP and 12201 ± 224 cal yr BP based on counts of annually laminated sediments of Soppensee and Holzmaar suggested by these authors. All ages in this study are calibrated, including those of the inferred

chronologies of the original author(s). Table 2 lists all dates for the pollen sequences available for depth age-modelling and their calibrations.

According to BENNETT (1994) the use of calibrated radiocarbon ages has one major disadvantage in depth-age modelling, as numerical methods for estimating confidence intervals for interpolated calibrated radiocabon ages are not yet available due to the statistical complexity of the estimated errors of calibrated radiocarbon years; such errors do not follow a normal distribution. In spite of this and in the absence of an alternative, we use the standard errors of the calibrated radiocarbon dates and assume a normal distribution in the modelling as a first approximation.

Reliability of depth-age models

The reliability of our depth-age models depends on the reliability and quality of the dates, on the sediment characteristics, and on the statistical model used. In the sites studied here, radiocarbon dates may differ from the ages of the associated pollen assemblages for various reasons:

1. Hard-water effects, resulting in radiocarbon dates that are too old. This might be the case if the surrounding bedrock contains old carbon, for example limestone, or when the sampled sediment contains lake marl. We might not have been aware of this when there is heterogeneity in the bedrock near the site. Sediment samples for AMS dating consisted of terrestrial macrofossils whenever possible. Otherwise undefined organic material was used if macrofossils were not available.
2. Admixture of roots or other young material in the sediment, resulting in dates that are too young. This might explain some dates that are apparently too young in shallow peat deposits.
3. Contamination during coring, usually down-core transport of sediment resulting in dates apparently too young. Many sites studied here were cored by Max WELTEN with a Hiller corer (WELTEN, 1982a, 1982b). With this equipment, special care is necessary to avoid contamination of the sediment with shallower material, especially at greater coring depths. Down-core contamination might also explain most of the improbably old records of *Juglans* and *Castanea* pollen grains (before *ca.* 2500 cal yr BP).
4. History of storage of the cored material. This is a problem for the radiocarbon datings carried out in 1995 and 1996 on stored material (See Table 2). Individual samples of most sites studied here were preserved for possible later research, rather than as complete cores. The later research envisioned for small samples certainly did not include radiocarbon dating, as the AMS method was unknown at the time. The greater part of these samples were wrapped in wet or moist condition in paper of journals (large samples) or of telephone-books (small samples), some in plastic bags, packed together in larger bags in cardboard boxes and stored in a dark, dusty, un-refrigerated room. We carefully cleaned the samples for dating from paper fibres (all samples) and washed them with distilled water in order to remove any carbon diffused from the paper (AMS samples), but contamination at some stage of packing and storing can not be excluded. Contamination with younger carbon seems more probable than with older carbon, but we can not be sure of this.
5. Measuring errors might result in erronous radiocarbon ages. We have no reason to suspect this, but we can not exclude it.

Another factor influencing the reliability of depth-age models is sediment characteristics, especially short-term fluctuations in sediment-accumulation rates and the presence of hiatuses. Depth-age relationships can be modelled well if changes in sediment-accumulation rates are gradual and enough dates are available to track them. In some sites, however, these changes are thought to be abrupt and in a few sites there are good reasons for recognizing hiatuses in the sediment (periods of non-sedimentation). This is often related to sediment lithology, consisting partly of peat and partly of lake deposits. This problem can in some cases be resolved by modelling separately different sections of the pollen diagram.

The reliability of radiocarbon dates measured by decay counting is reduced when sediment-accumulation rates are low and not constant. This situation is for many sites inferred by the original authors for the first few millennia of the Holocene. Sediment accumulation is inferred to be very low in the Preboreal at many sites, increasing gradually or abruptly mostly around 9-7 cal ka BP. Low sediment accumulation leads to radiocarbon samples covering a large time span, especially in the early days of radiocarbon measurement when larger samples were required than today and especially when cored with a Hiller corer (as was frequently done by WELTEN, 1982a, 1982b) resulting in narrow sediment cores. The vertical thickness of radiocarbon samples was unfortunately mostly not indicated in the older days, but when known it was frequently 25 cm or more (Table 2), which might cover more than a millennium. This causes inaccuracy when sediment-accumulation rates are not constant, because it makes uncertain the exact level for which the date is valid.

PRESENTATION

The results for each site are shown in Figures 3-1 to 3-25, containing the following sections:

1. A pollen diagram including a simplified lithology, selected pollen types, the new chronology as an additional scale on the far left, and dotted lines showing the original chronology. Pollen morphology is harmonized to a level common to all pollen diagrams in order to provide concise and comparable pollen diagrams for all sites; this is inevitably a low level with only a few pollen types. All pollen and spores of non-aquatic vascular plants counted are included in the pollen sum; only obligate aquatics are excluded. Marsh plants are included.
2. A graph showing both the accepted depth-age model (called "new chronology" in this study) and that of the original author(s) (called "original chronology").
3. A graph showing the sediment-accumulation rate estimated for each pollen sample.

RESULTS

Results of the depth-age modelling are summarized in Table 3. Comments on individual pollen sequences are presented below.

Pollen diagram 1/Lo (Lobsigensee LQ-90), 514 m (Fig. 3-1)

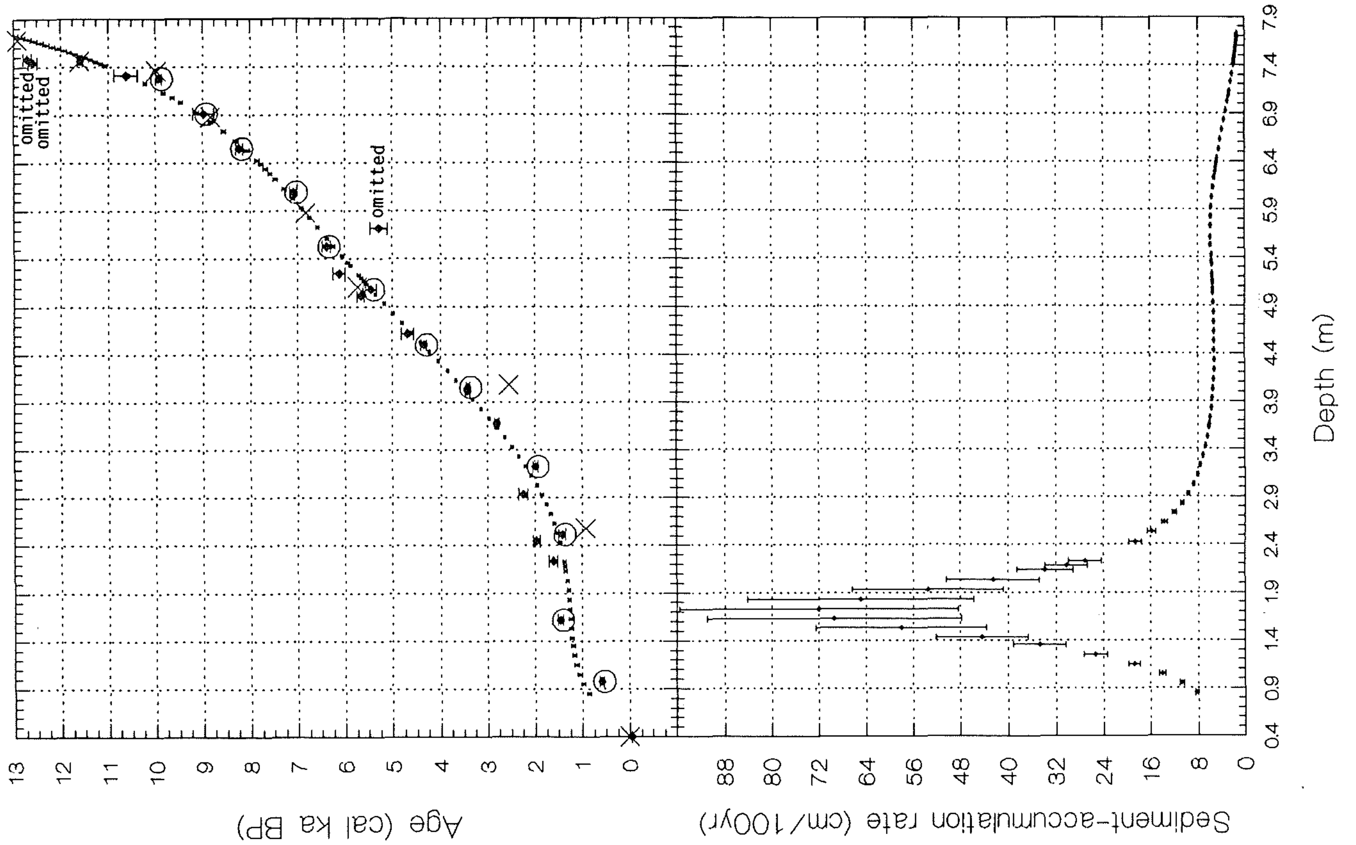
The new chronology might be only moderately successful for the last 2.5 ka because the dates are scattered away from the depth-age curve and because of the sinoid bends in the depth-age curve causing excessively increased sediment-accumulation rates between 1 and 2 cal ka BP. Drawing a straight line between the dates at the top (40 cm) and at 368 cm (*ca.* 2.8 cal ka BP) might be as good as the curve presented, resulting in a more moderate increase of sediment-accumulation rates in the upper *ca.* 2.5 ka. Such an increase may have been caused by increased erosional input due to human activity since Roman times (AMMANN, 1989).

AMMANN (1989) inferred a hard-water effect of a few hundred years in the decay-counting dates measured on bulk samples. On the other hand, hard-water effects might be absent in the AMS dates measured mostly on terrestrial macro-fossils. A visual comparison between AMS dates (marked on the graph by circles) and decay-counting dates suggests, however, that hard-water effects are small.

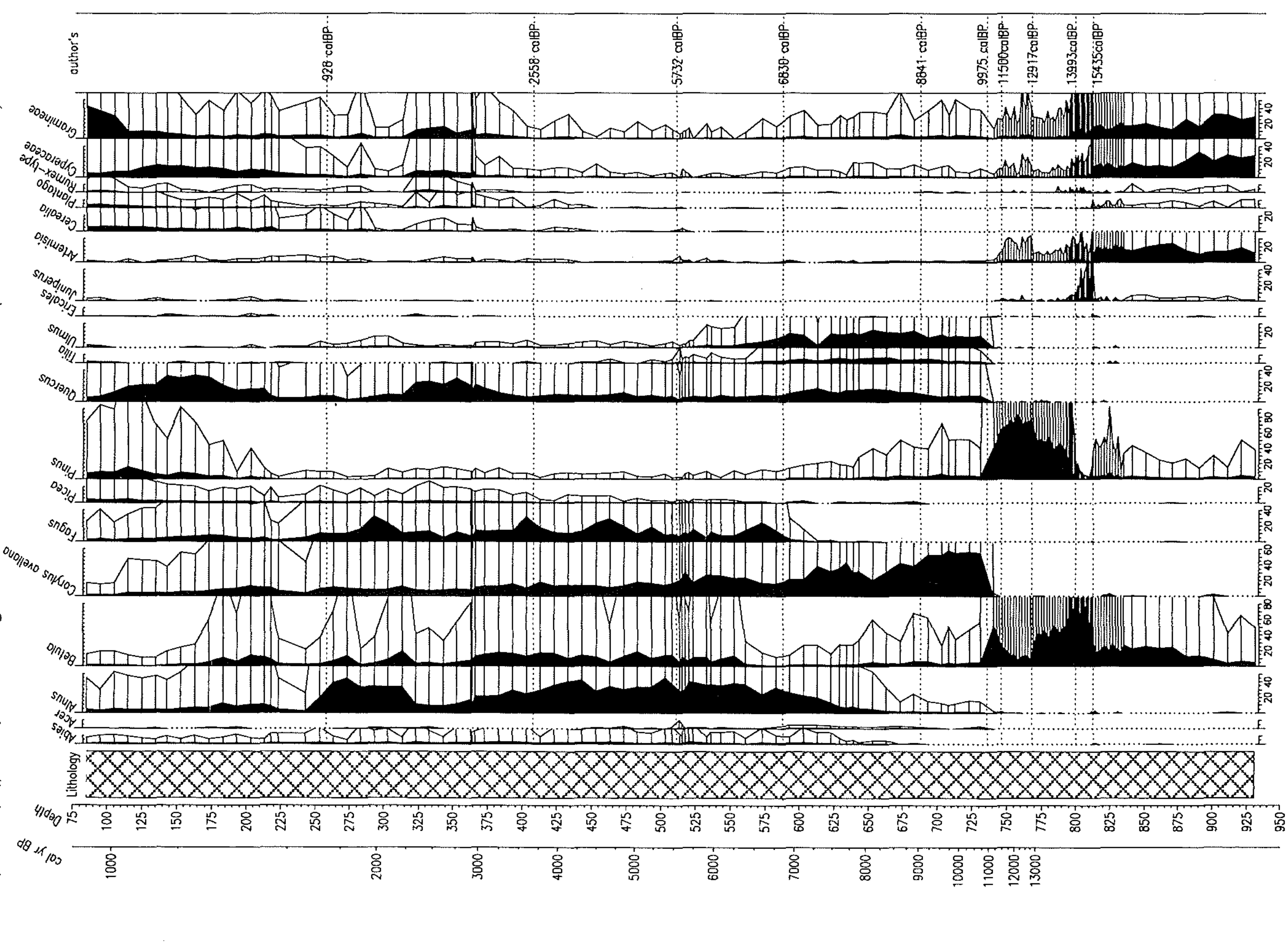
However, hard-water effects may play a role in the two dates (748 cm, 744 cm) taken from sediments just below and just above the base of the Holocene (746 cm) giving calibrated ages of 1.3-1.4 cal ka older than the base of the Holocene. A slight hard-water effect may have pushed the dates just below the plateau of constant C14 age at this position (*ca.* 10000-10300 BP).

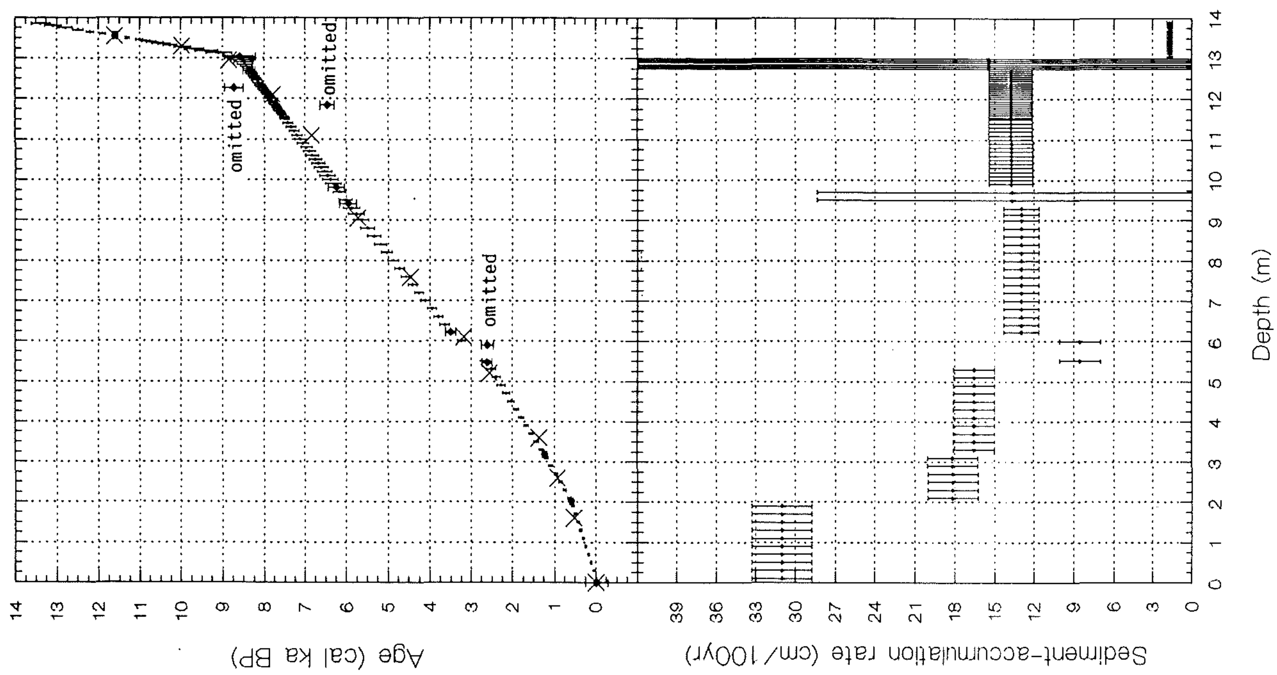
The new chronology suggests increasing sediment-accumulation rates up to *ca.* 7 cal ka BP, followed by approximately constant rates, and a renewed increase after *ca.* 3 cal ka BP.

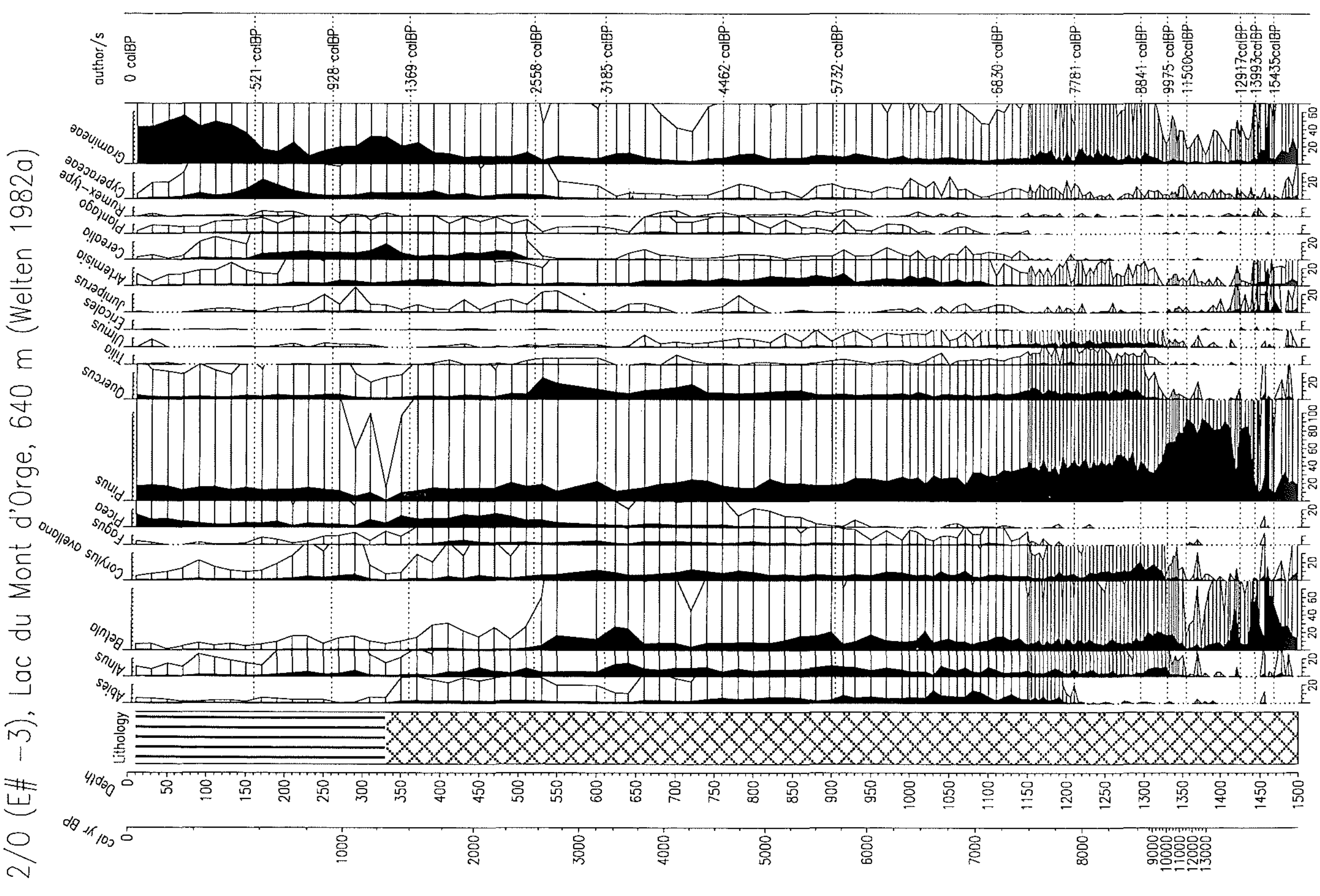
Fig. 3-1 to 3-25 : Depth-age models and sediment-accumulation rates of studied sites.
Left: Summary pollen diagram. The time scale to the left represents the "new chronology" modelled in this study. The time scale on the right represents the "original chronology" of the original author(s). All ages are calibrated. The simplified lithology (left) indicates peat (vertical lines) and lake sediments and clay (cross-hached).
Right: Depth-age relationship (top) and sediment-accumulation rates (bottom). The *X-axis* of both graphs represents sediment depth (excluding water depth in case of a lake).
Depth-age graph (top right):
The *Y-axis* represents calibrated radiocarbon years BP.
Biostratigraphic and radiocarbon dates are represented with solid diamonds with error bars indicating 1σ standard deviation of the ages, as follows:
The dates omitted from the model are marked as such.
Pollen samples are represented by small diamonds with error bars showing confidence intervals. The sequence of samples follows the depth-age curve modelled.
The *inferred chronology* of the original author(s) is indicated with large crosses. They mostly represent Firbas regional zone boundaries, in a few cases site-zone boundaries.
AMS dates are marked with circles around the dates in Fig. 3-1 only.
Sediment-accumulation rates (bottom right):
The *Y-axis* represents sediment-accumulation rate in cm per 100 year.
Pollen samples are represented by small diamonds with error bars showing confidence intervals.



1/Lo (E# 82), Lobsigensee LQ-90, 514 m (Ammann 1989)




Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
omitted
omitted


2/0 (E# -3), Lac du Mont d'Orge, 640 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author/s
0 calBP
521 calBP
928 calBP
1369 calBP
2558 calBP
3185 calBP
4462 calBP
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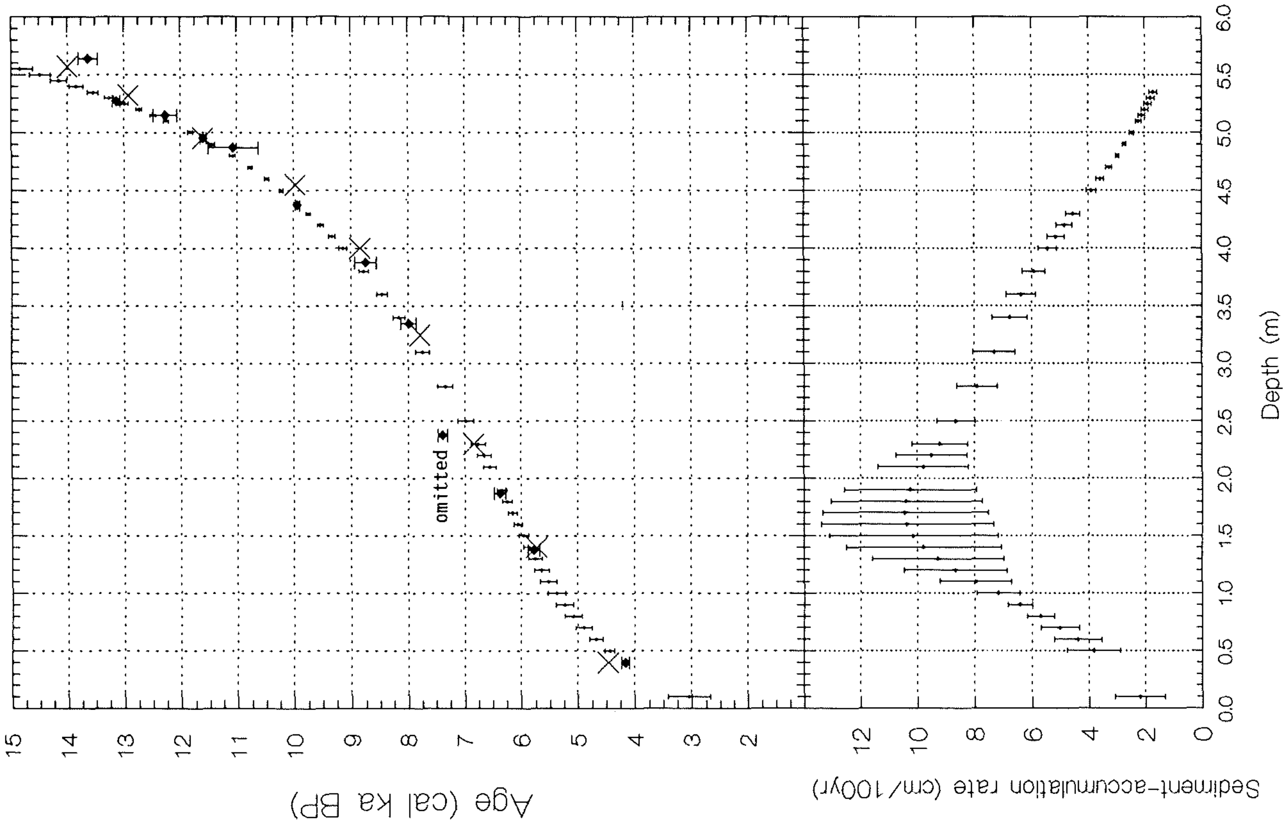
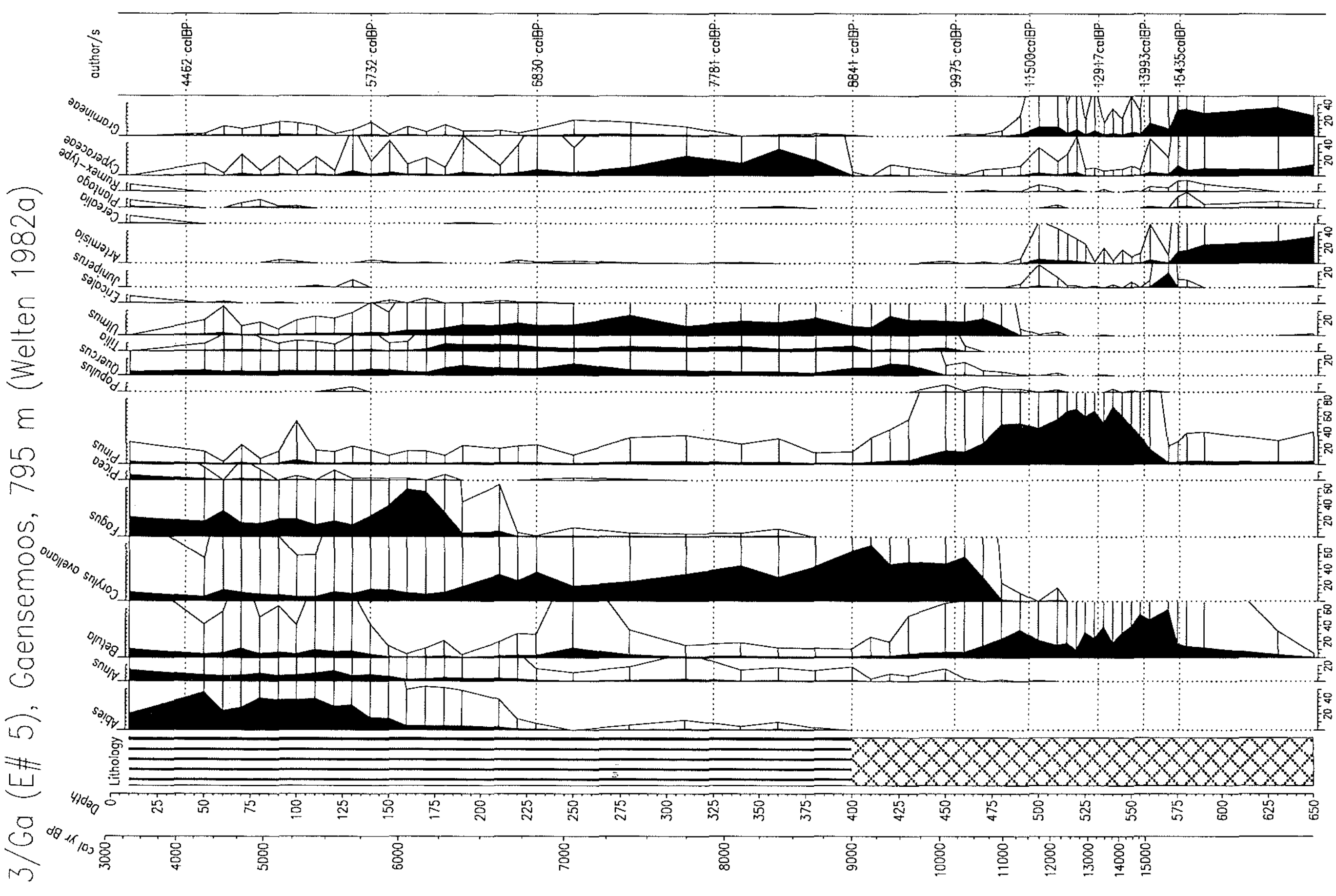
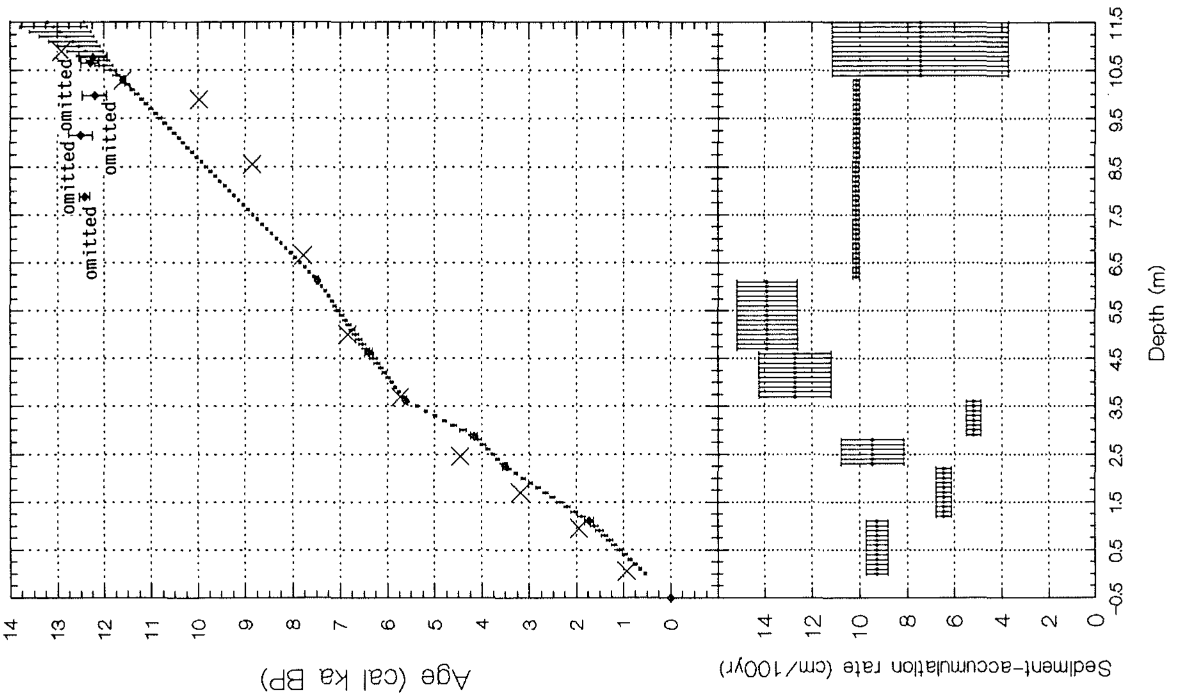
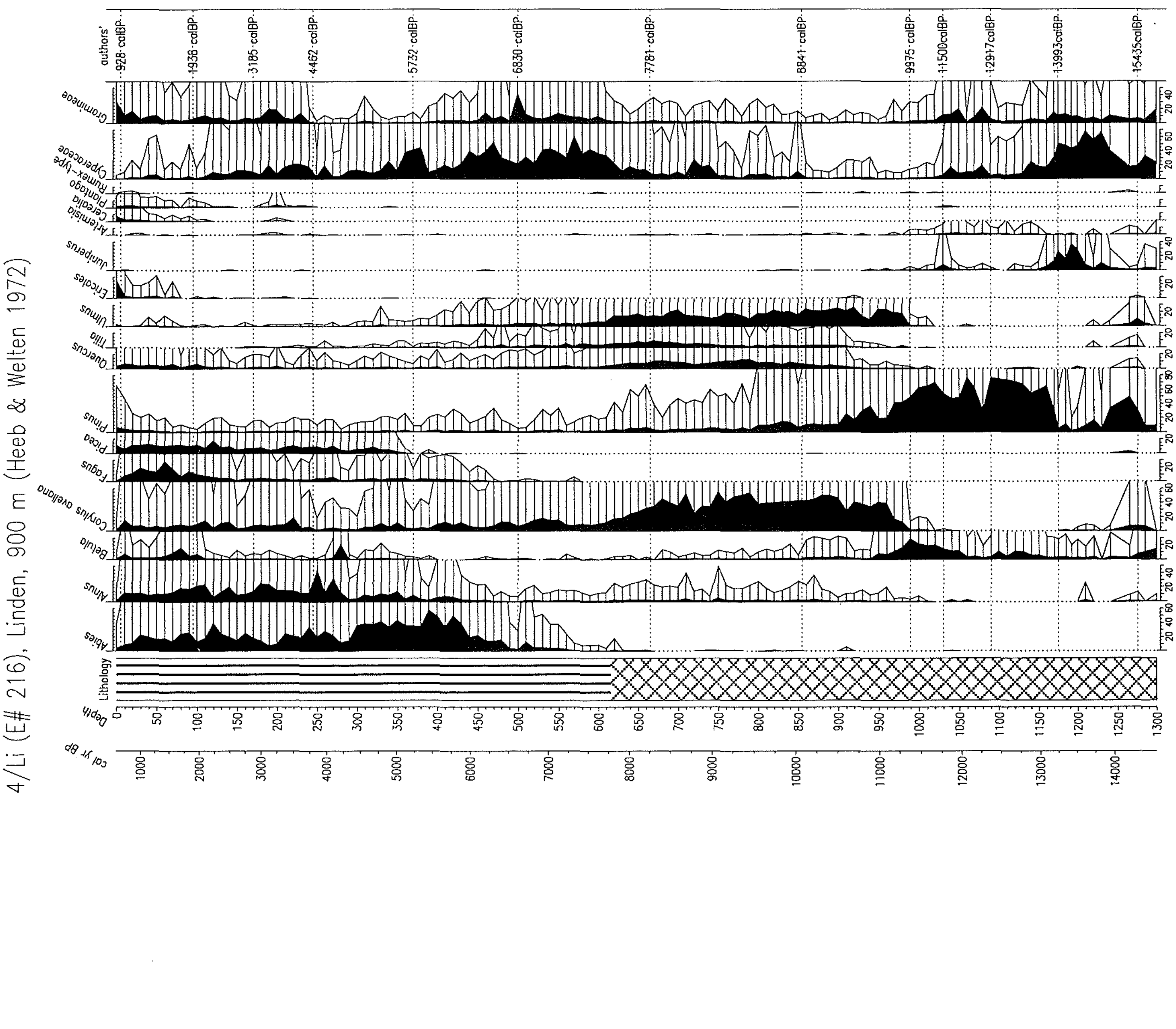
13993calBP
15435calBP


Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted


3/Ga (E# 5), Gaensemoos, 795 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Populus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author/s
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11503calBP
12917calBP
13993calBP
15435calBP


Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
omitted
omitted
omitted


4/Li (E# 216), Linden, 900 m (Heeb & Welten 1972)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
authors'
928 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
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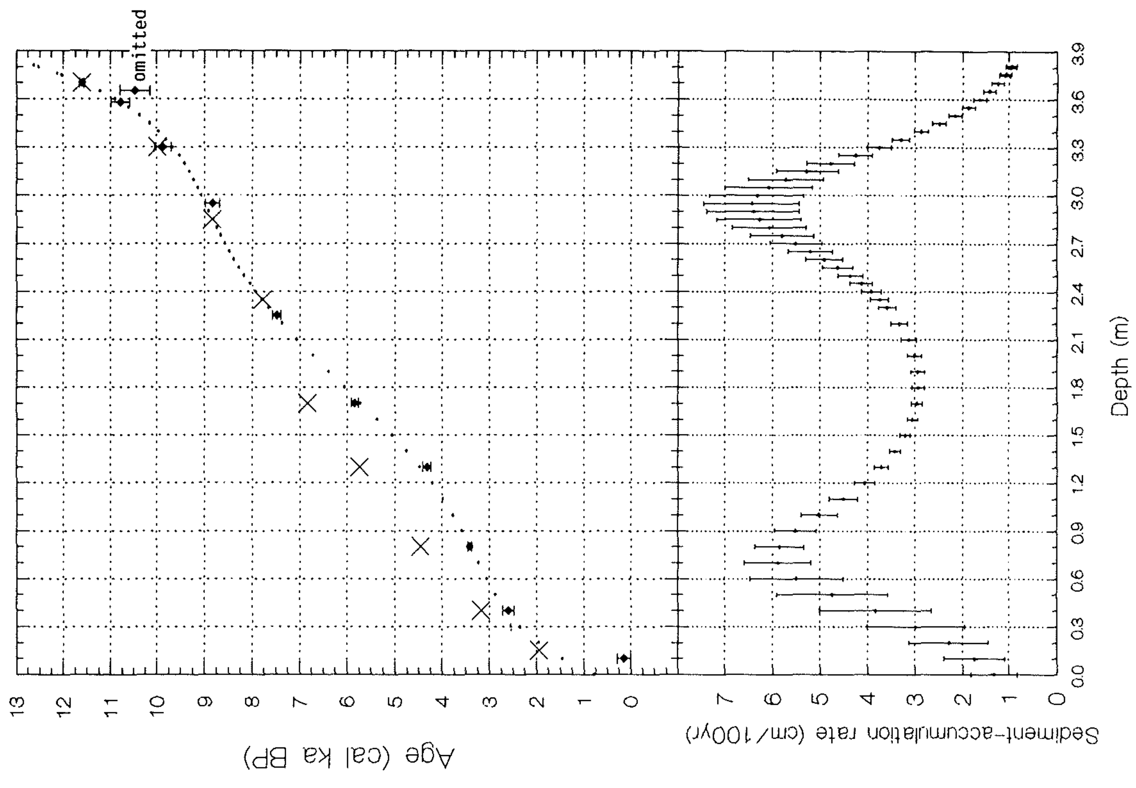
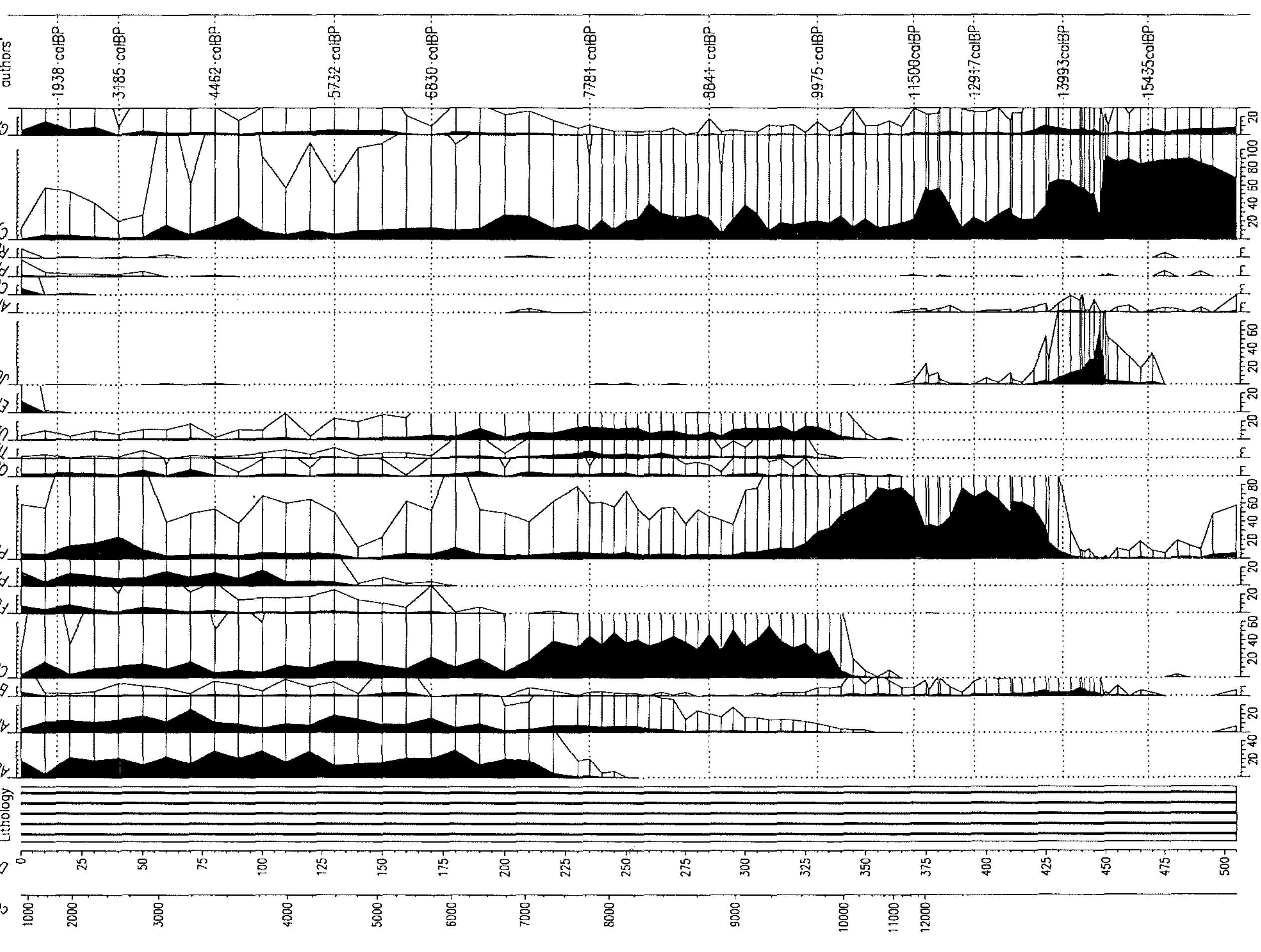
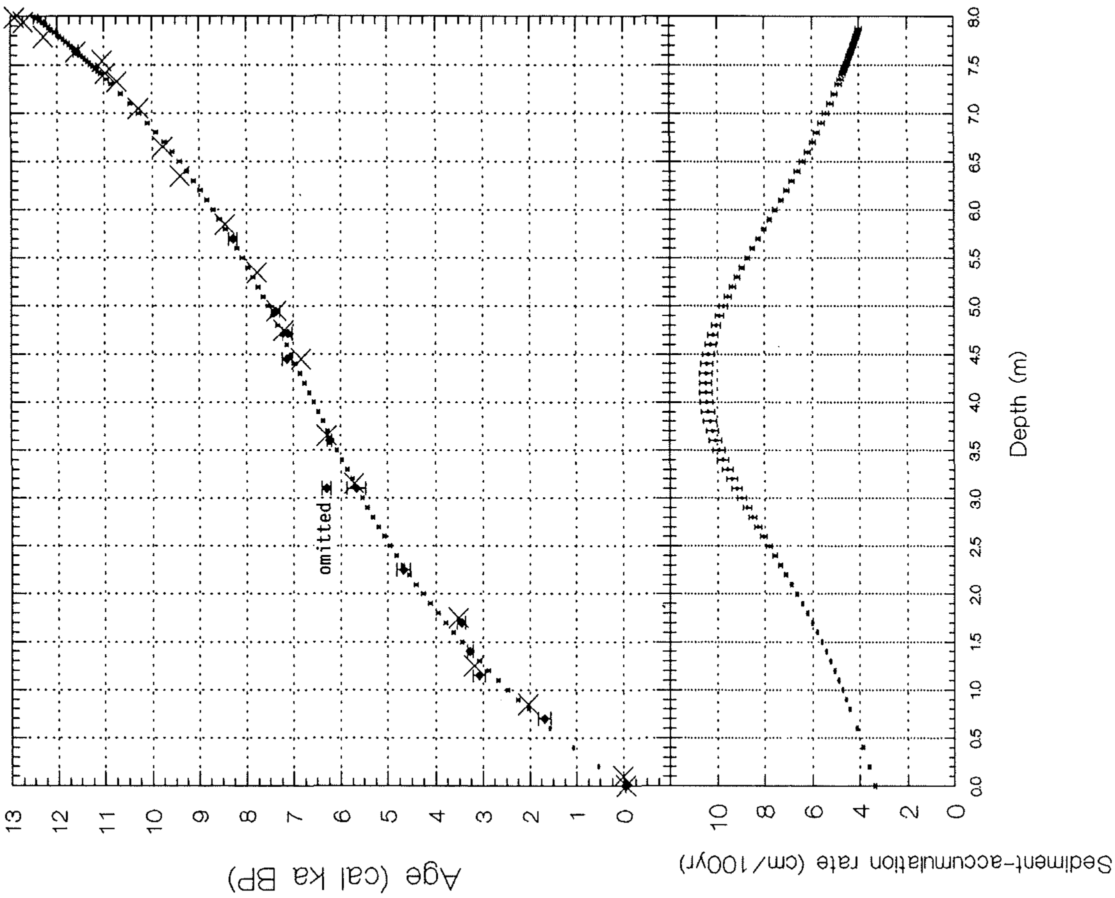
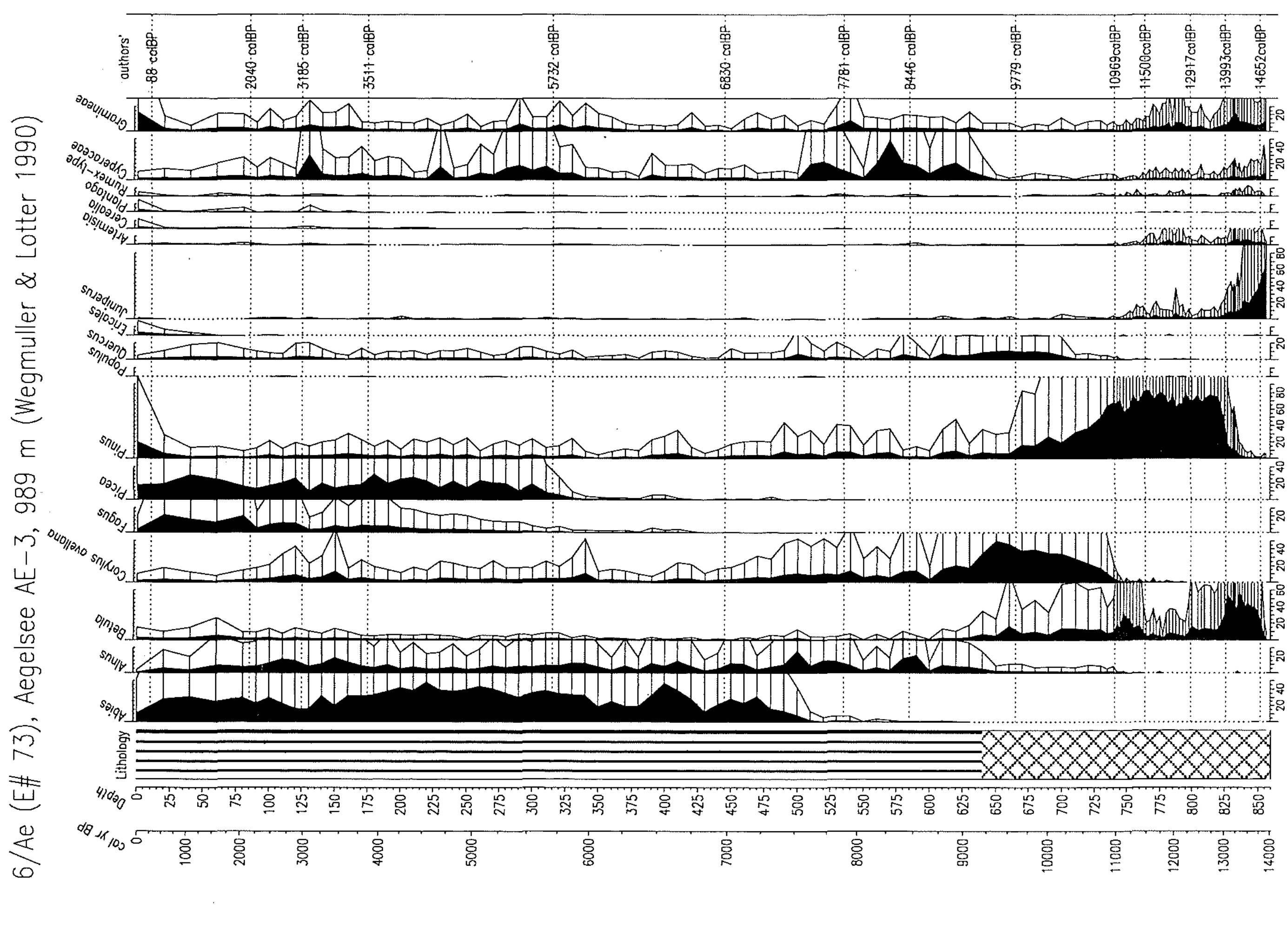
13993calBP
15435calBP



5/WU (E# -9), Wachseldorn Untermoos, 980 m (Heeb & Welten 1972)




Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted


6/Ae (E# 73), Aegelsee AE-3, 989 m (Wegmuller & Lotter 1990)
Cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Populus
Quercus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
authors'
88 calBP
2040 calBP
3185 calBP
3511 calBP
5732 calBP
6830 calBP
7781 calBP
8446 calBP
9779 calBP
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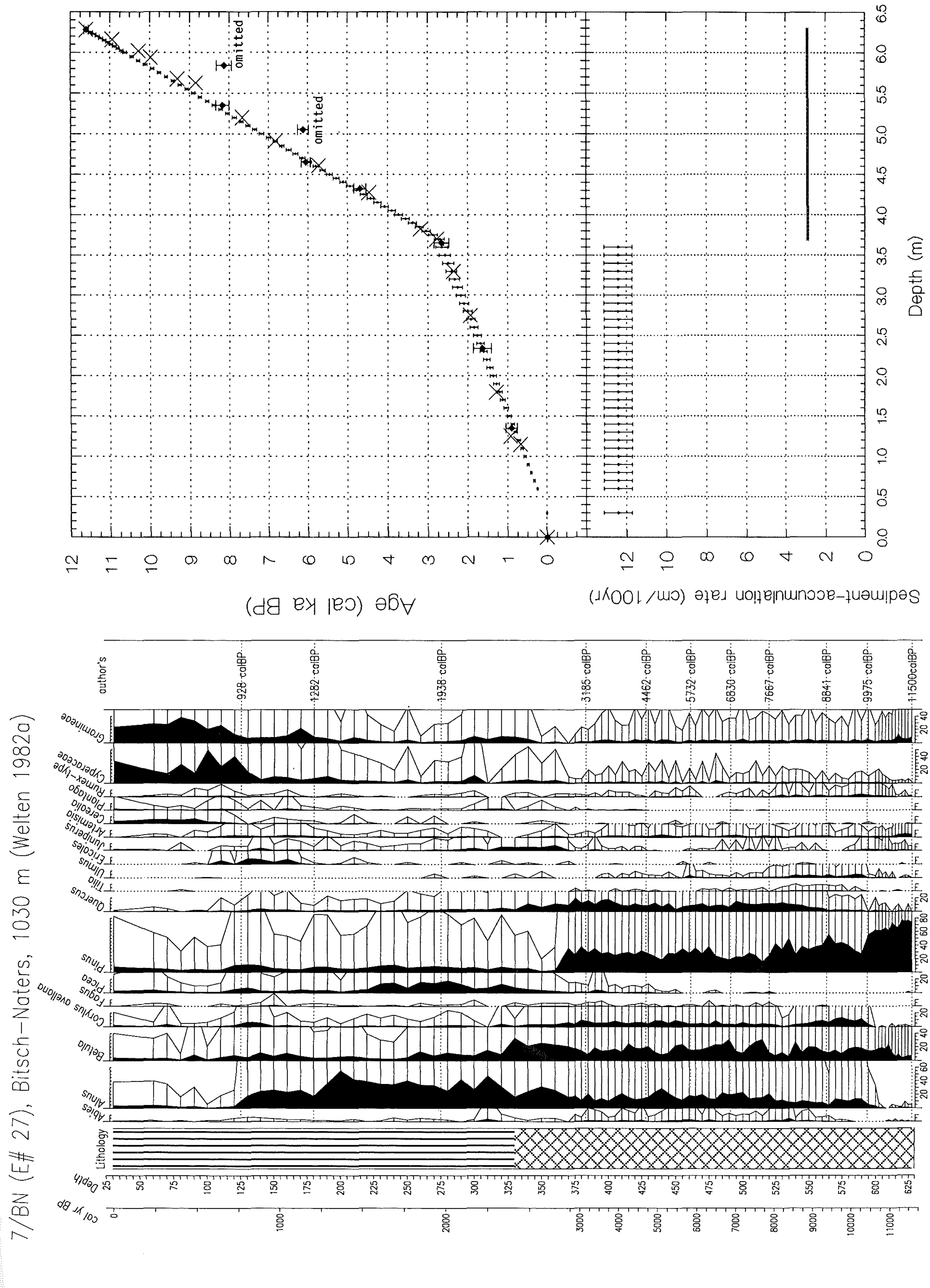
13993calBP
14652calBP


7/BN (E# 27), Bitsch-Naters, 1030 m (Welten 1982a)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
omitted
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
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4462 calBP
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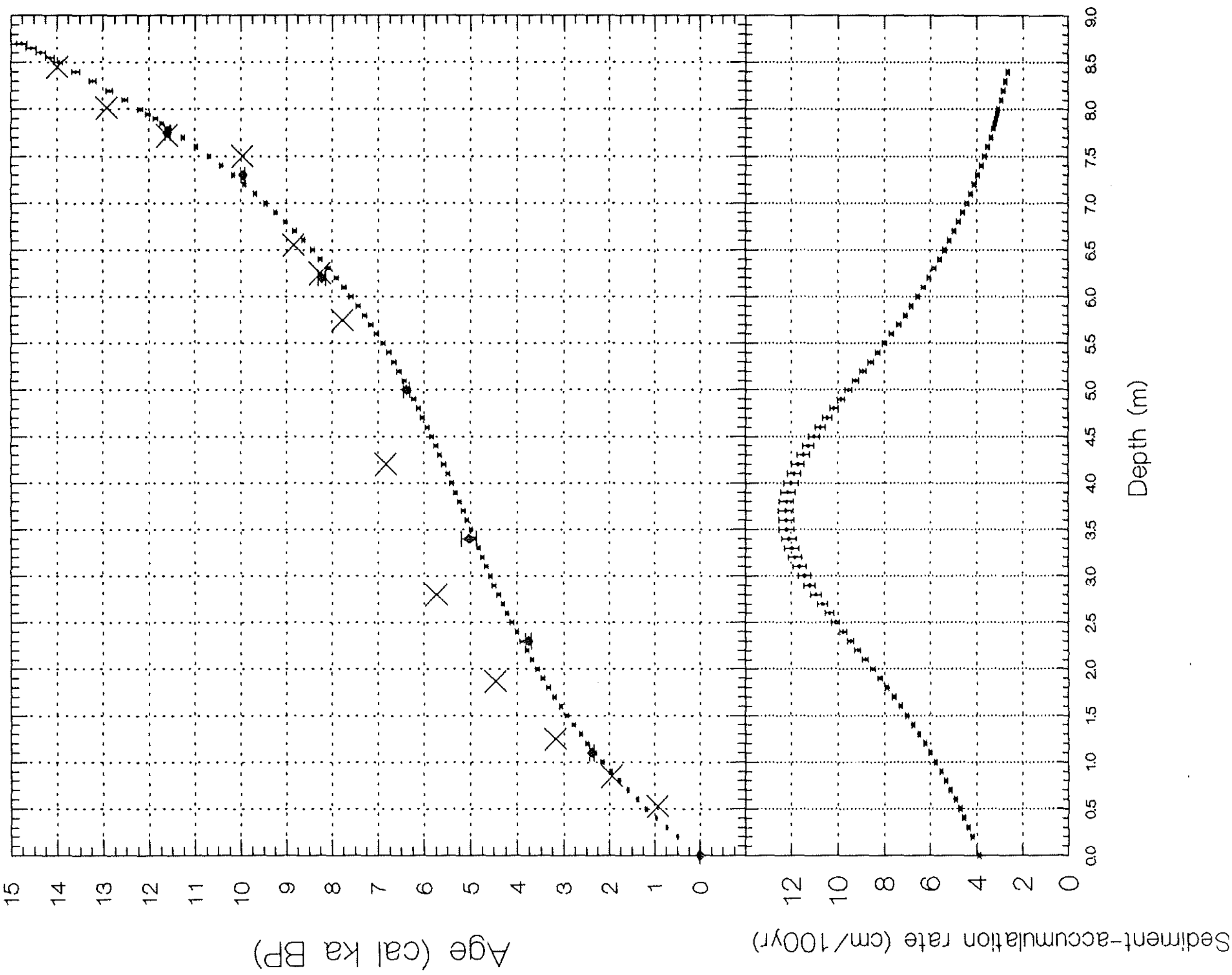
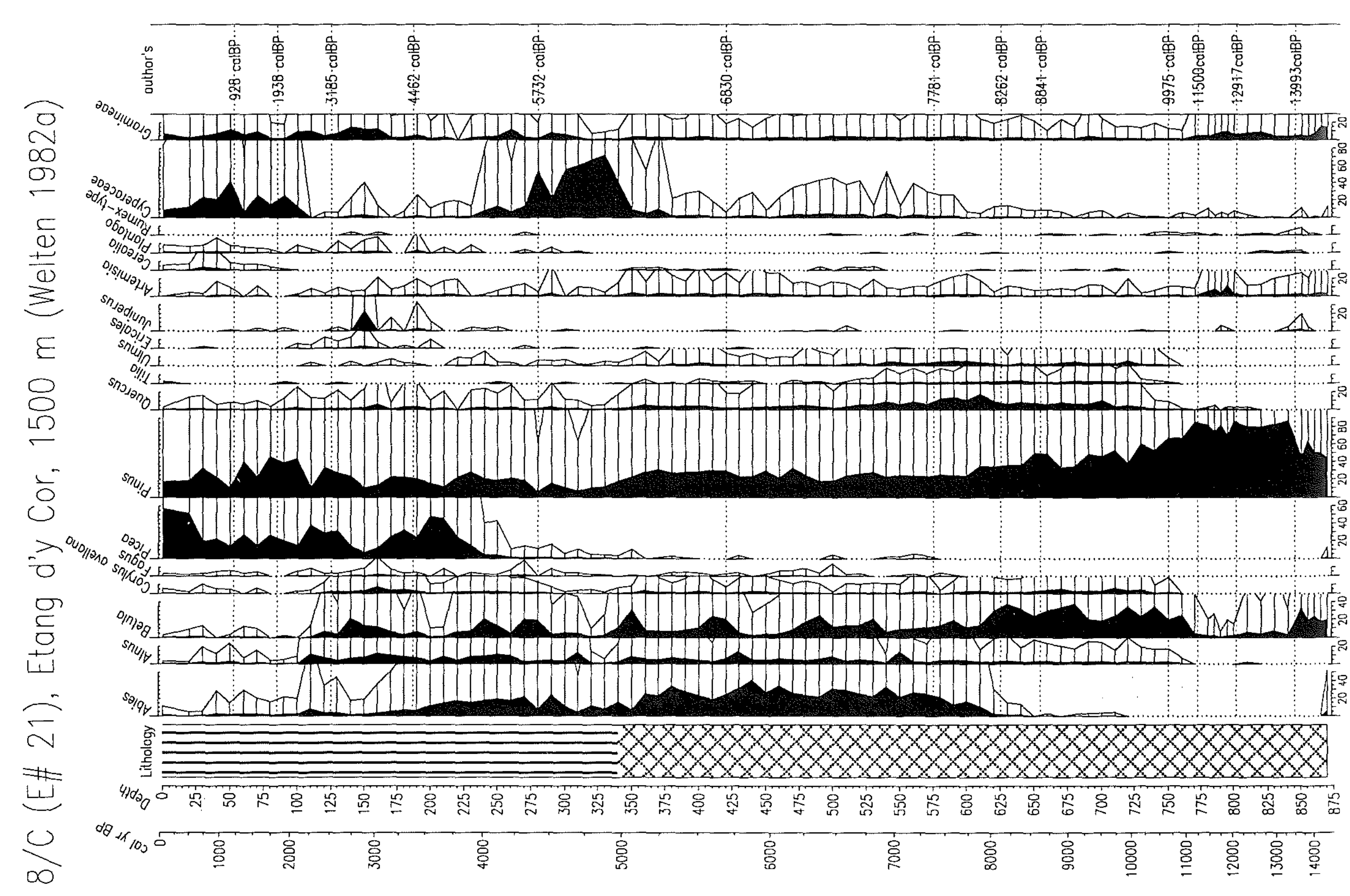
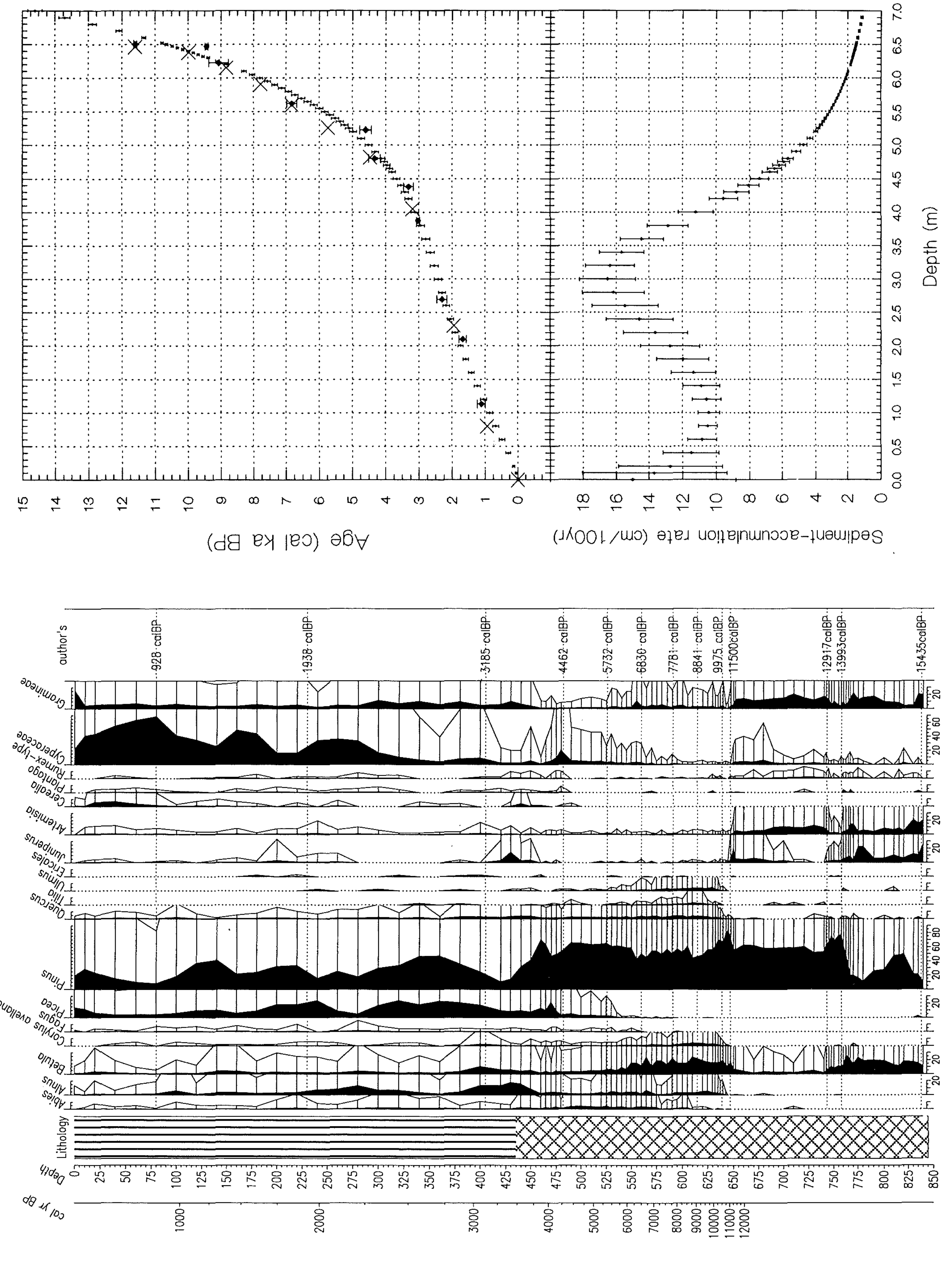
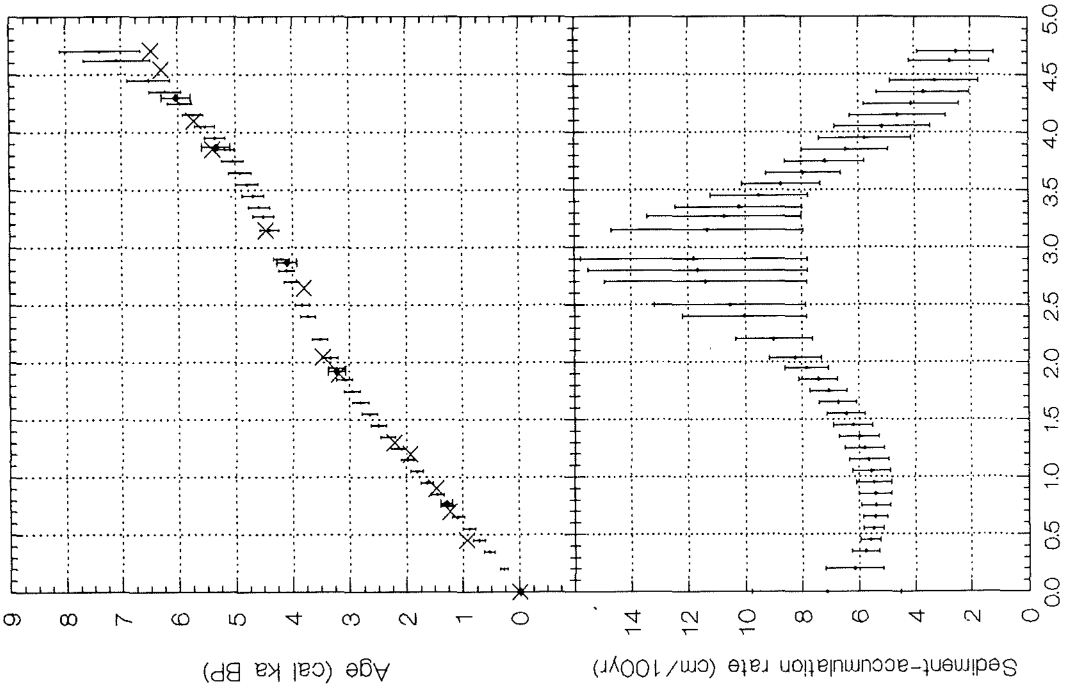
11500calBP

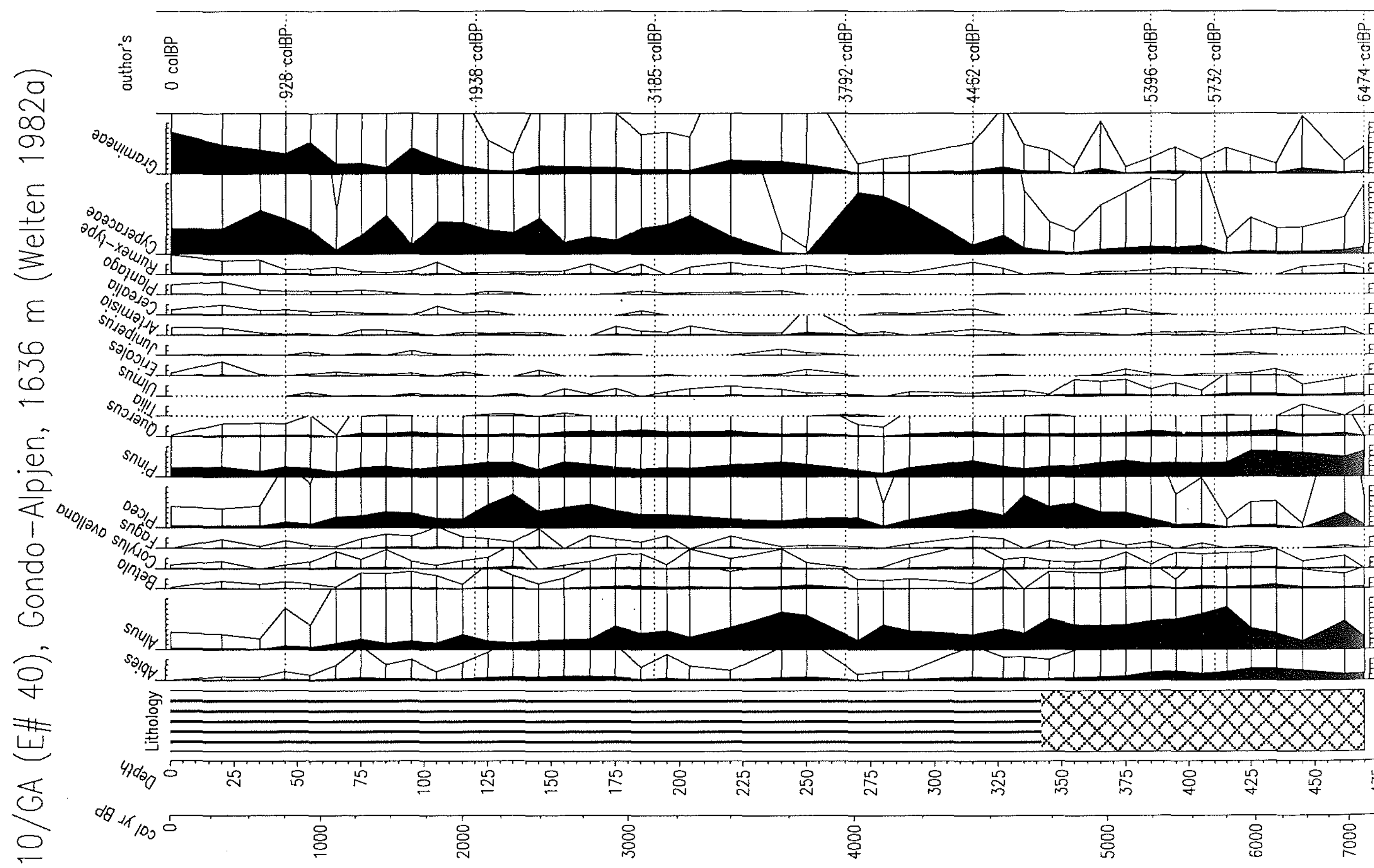

Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)

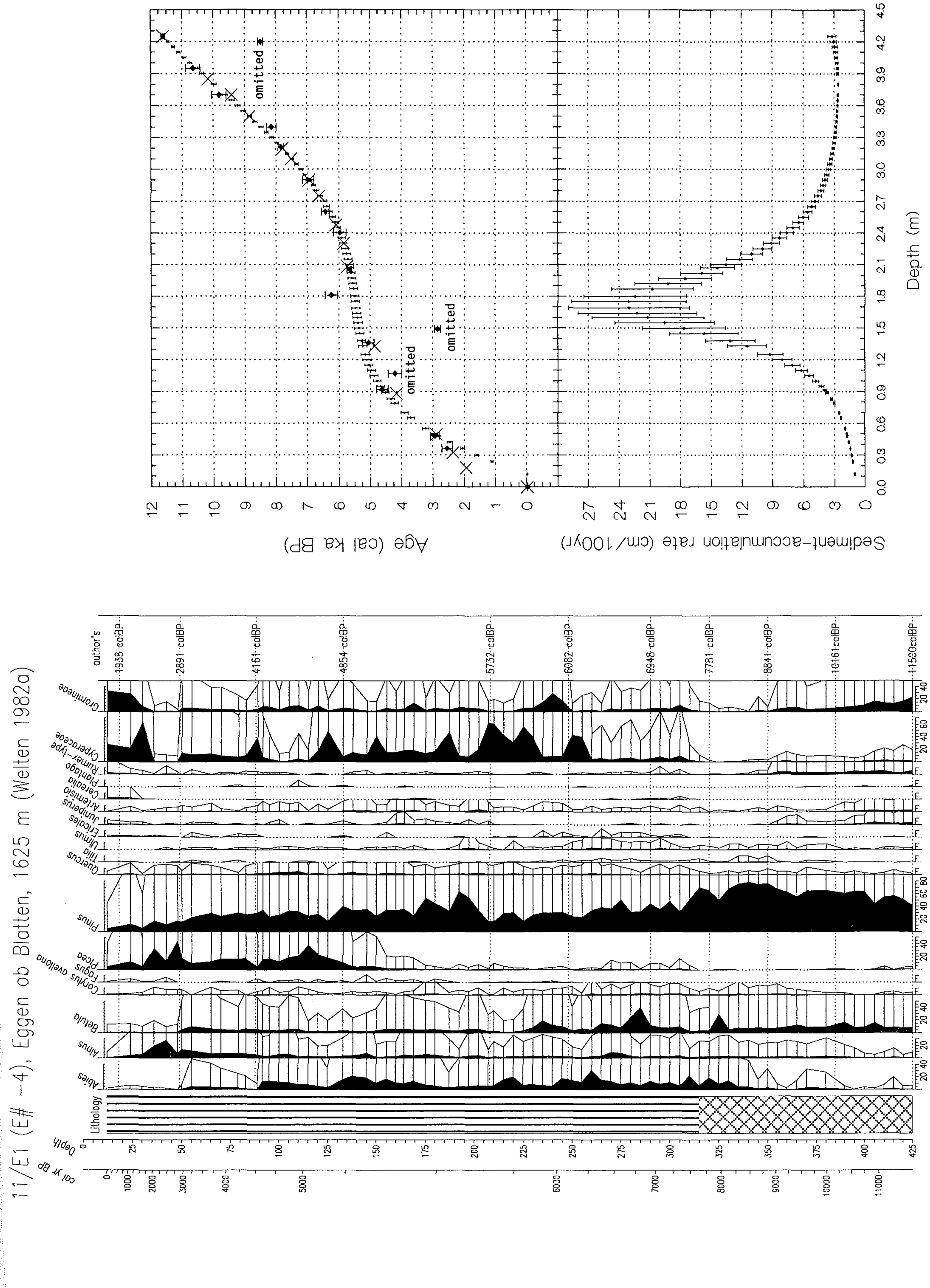

8/C (E# 21), Etang d'y Cor, 1500 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8262 calBP
8841 calBP
9975 calBP
11508calBP
12917calBP
13993calBP

9/Z (E# 23), Zeneggen–Hellelen A, 1510 m (Welten 1982a)




Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)


10/GA (E# 40), Gondo-Alpjen, 1636 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
0 calBP
928 calBP
1938 calBP
3185 calBP
3792 calBP
4462 calBP
5396 calBP
5732 calBP
6474 calBP


11/E1 (E# –4), Eggen ob Blatten, 1625 m (Welten 1982a)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
omitted
omitted
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
1938 calBP
2891 calBP
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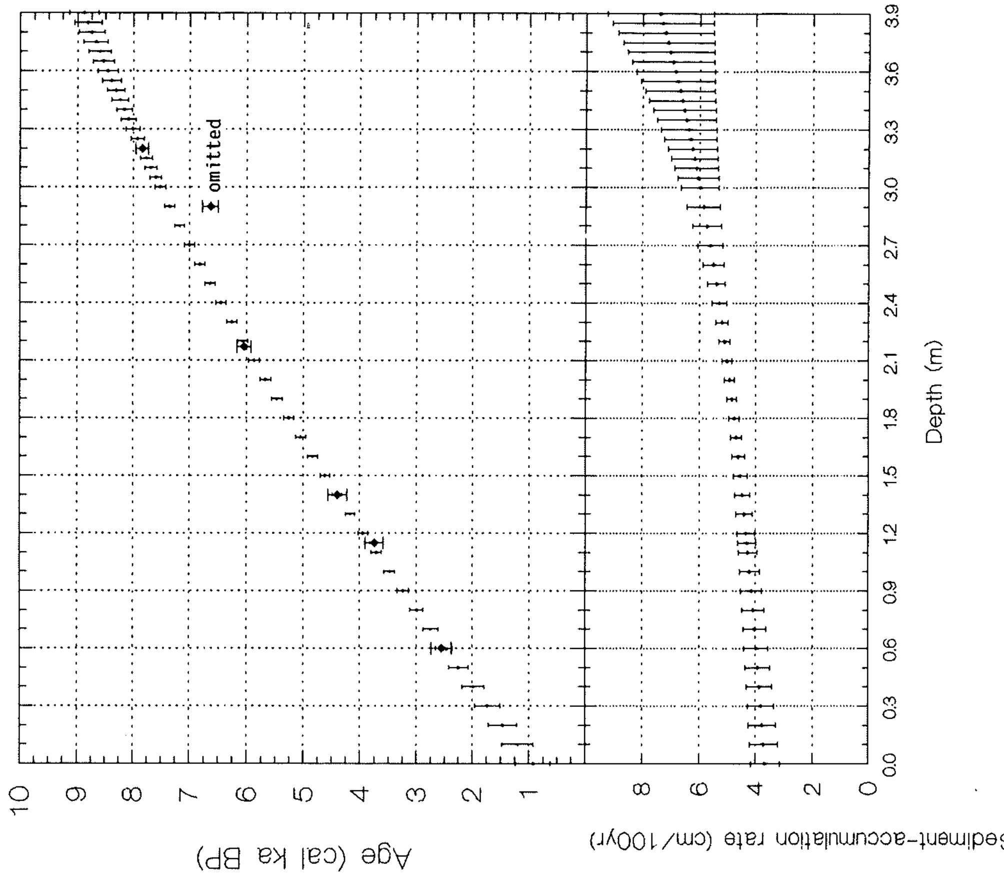
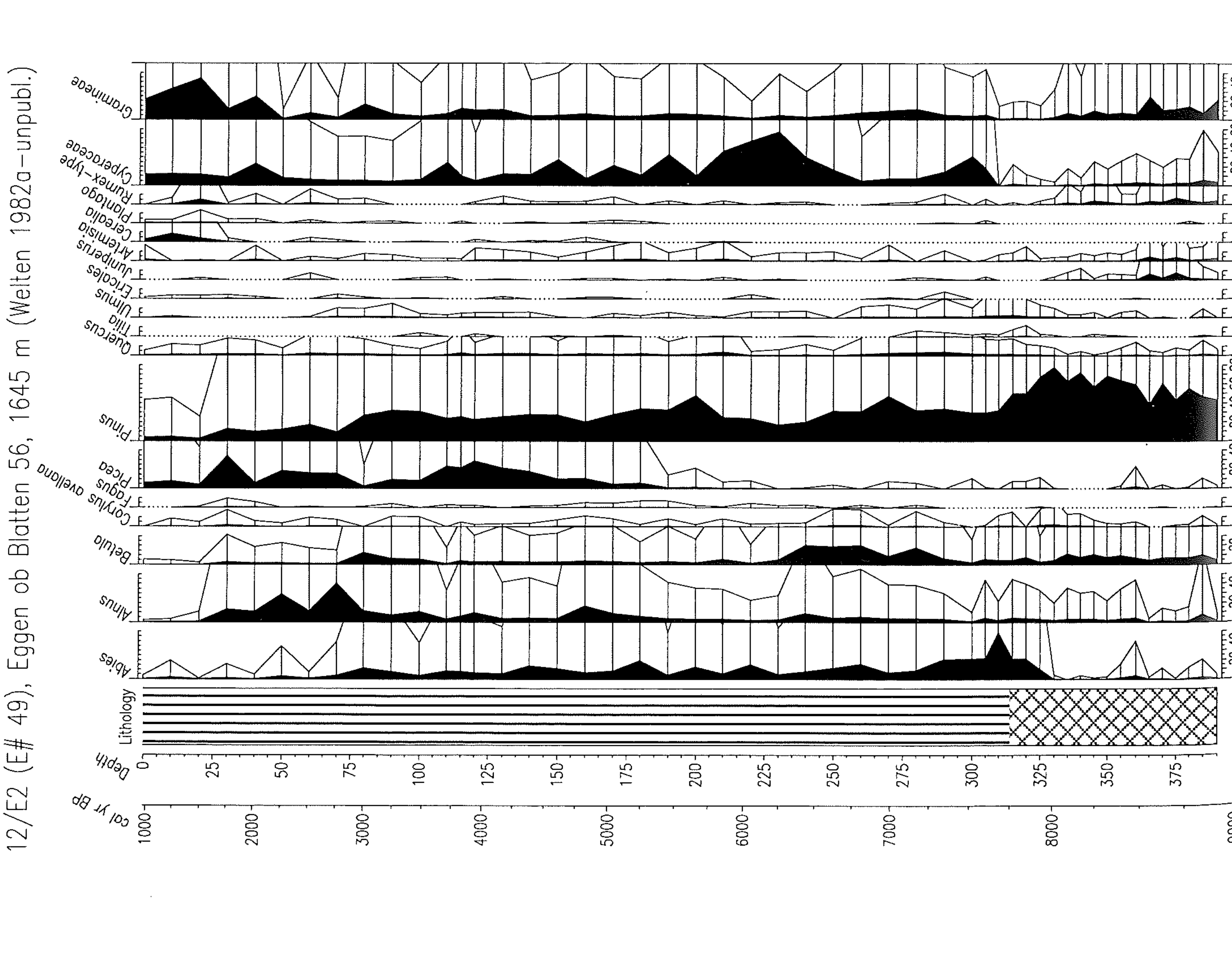
4854 calBP
5732 calBP
6082 calBP
6948 calBP
7781 calBP
8841 calBP
10161calBP
11580calBP


Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
3.0
3.3
3.6
3.9


12/E2 (E# 49), Eggen ob Blatten 56, 1645 m (Welten 1982a–unpubl.)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
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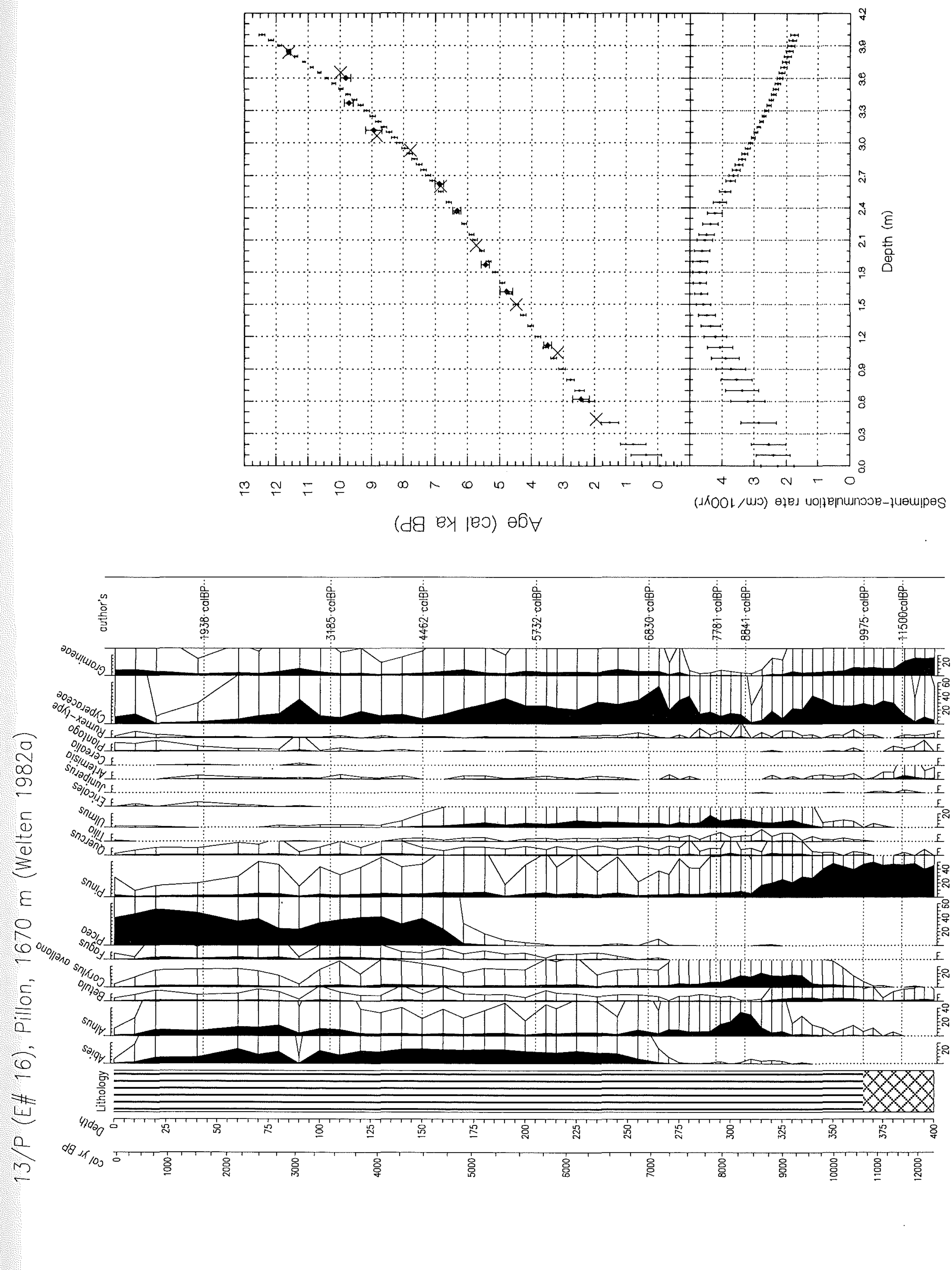
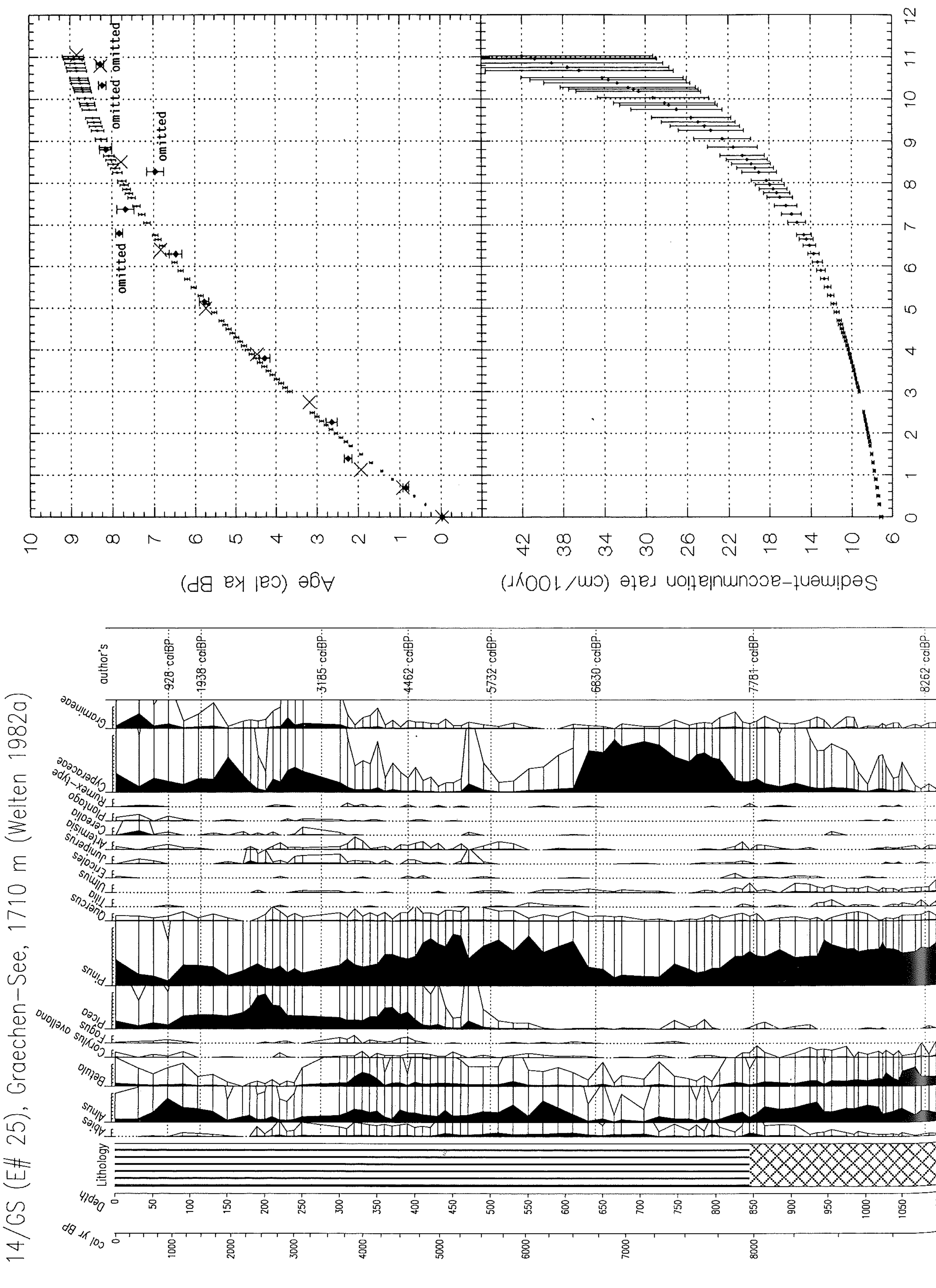
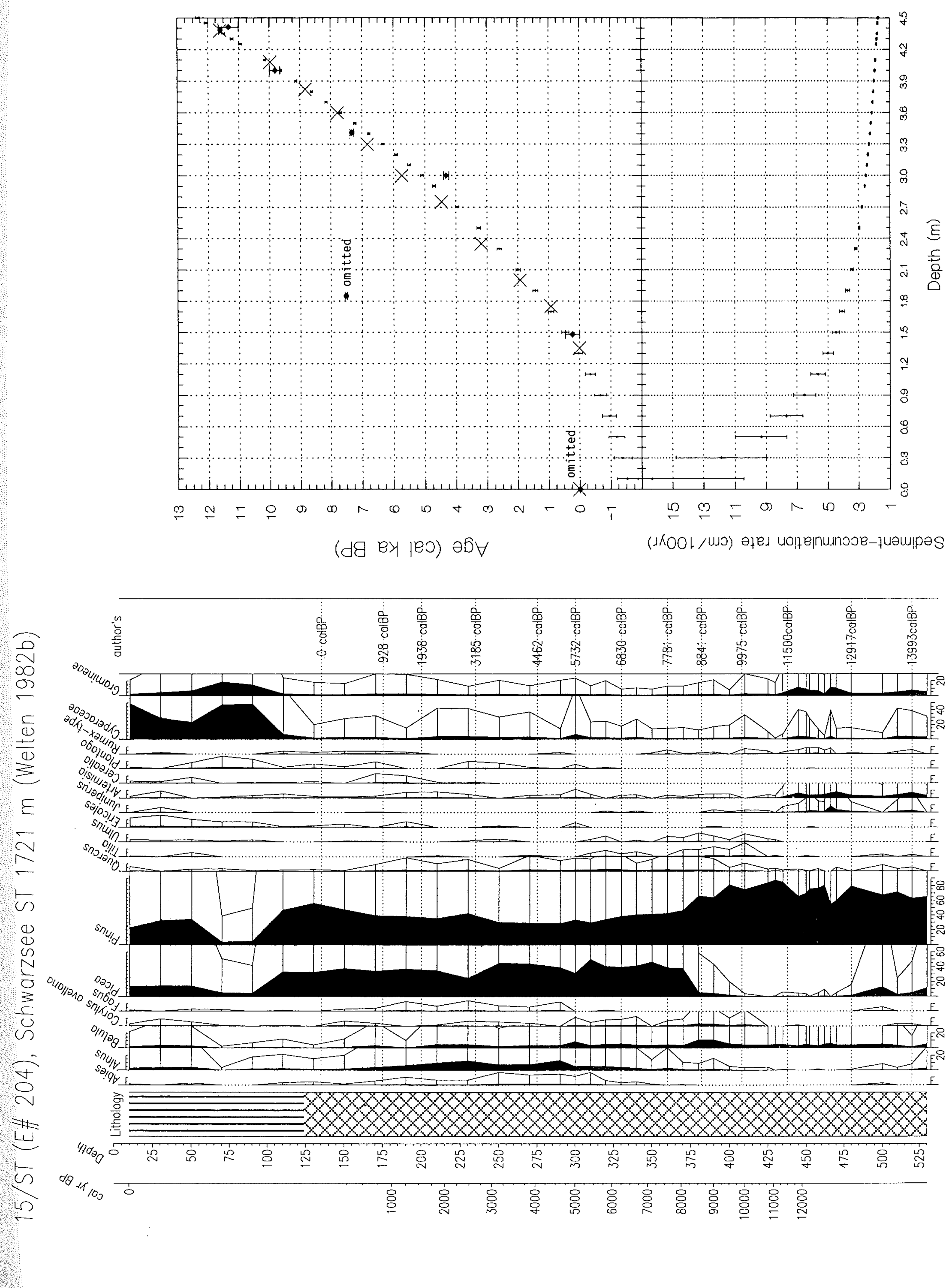
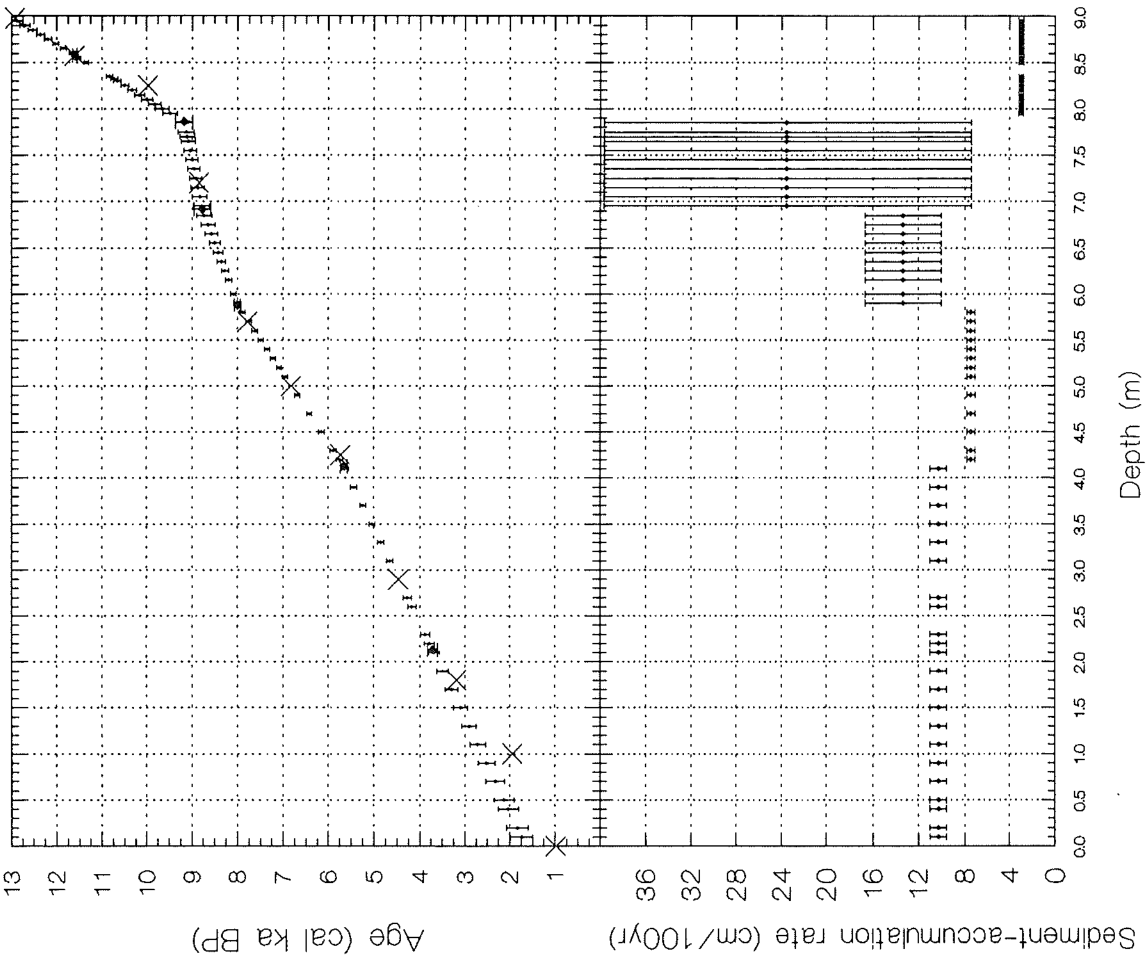
Cyperaceae
Gramineae

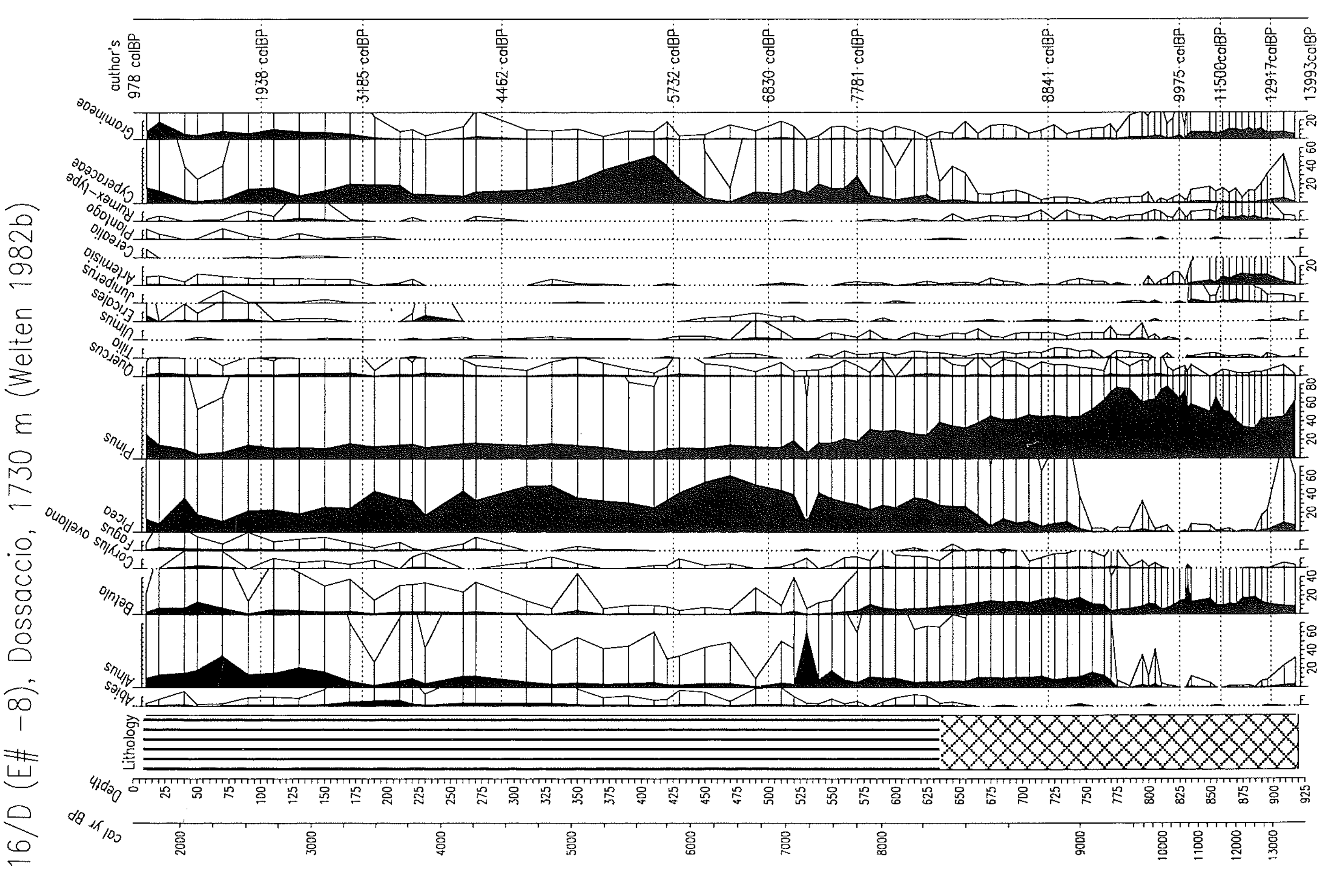


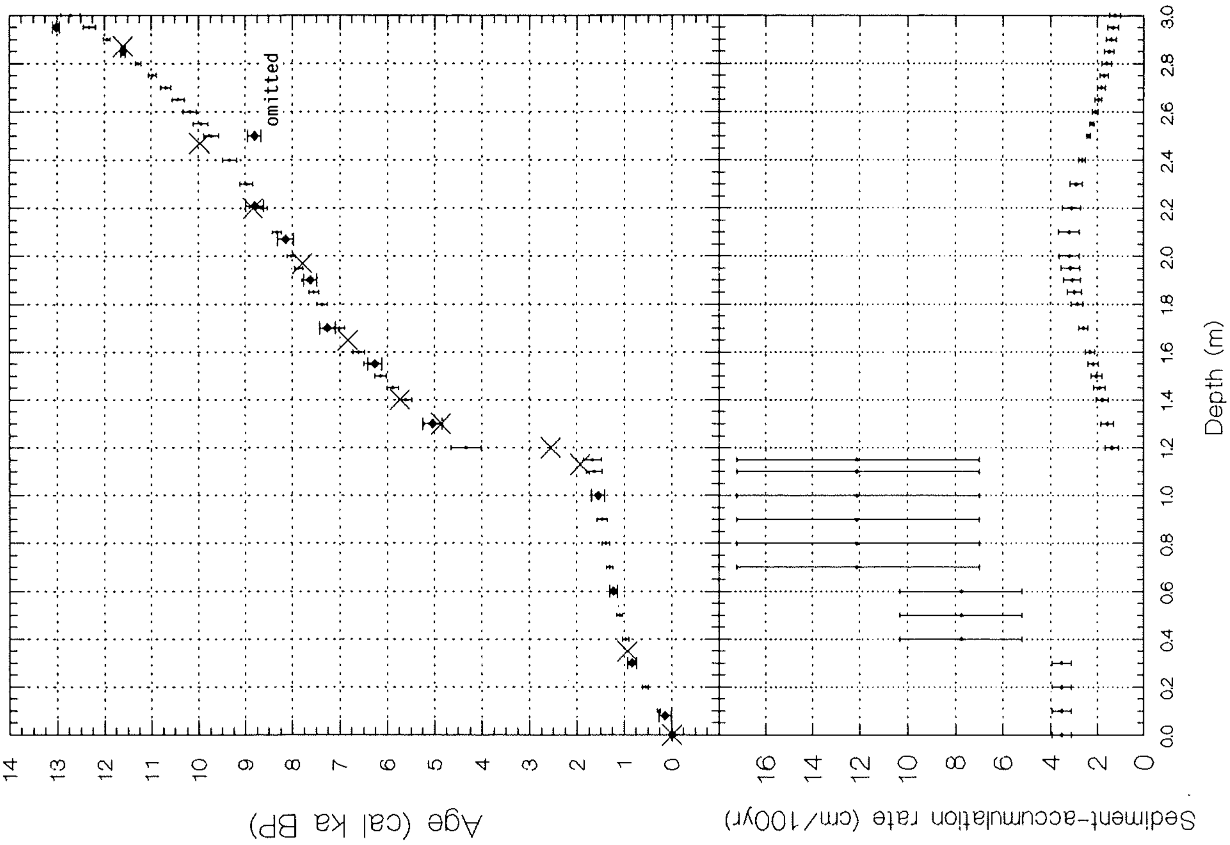
13/P (E# 16), Pillon, 1670 m (Welten 1982a)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11500calBP


14/GS (E# 25), Graechen-See, 1710 m (Welten 1982a)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
omitted
omitted
omitted
omitted
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8262 calBP

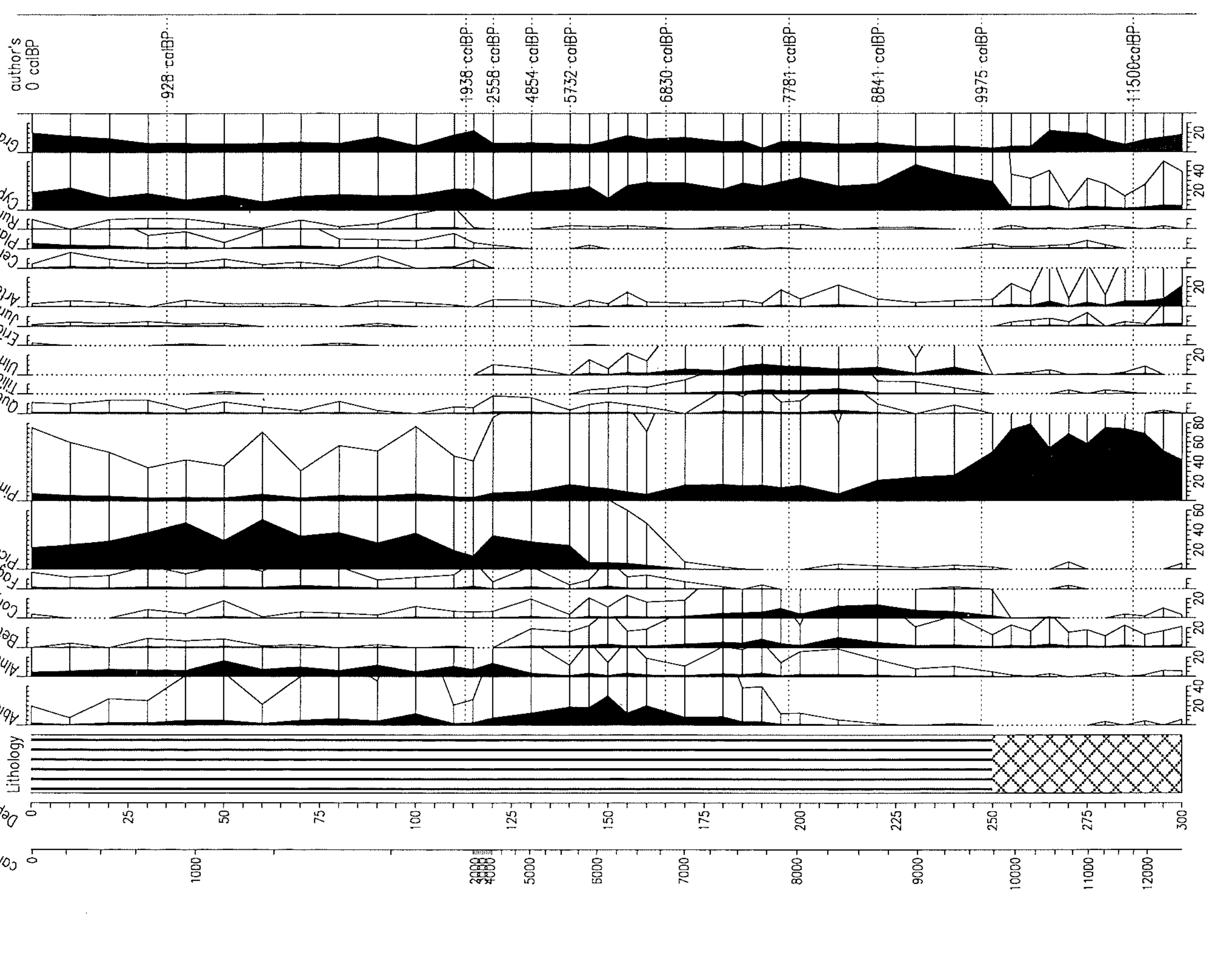

15/ST (E# 204), Schwarzsee ST 1721 m (Welten 1982b)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
omitted
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
0 calBP
928 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11500calBP
12917calBP
13993calBP

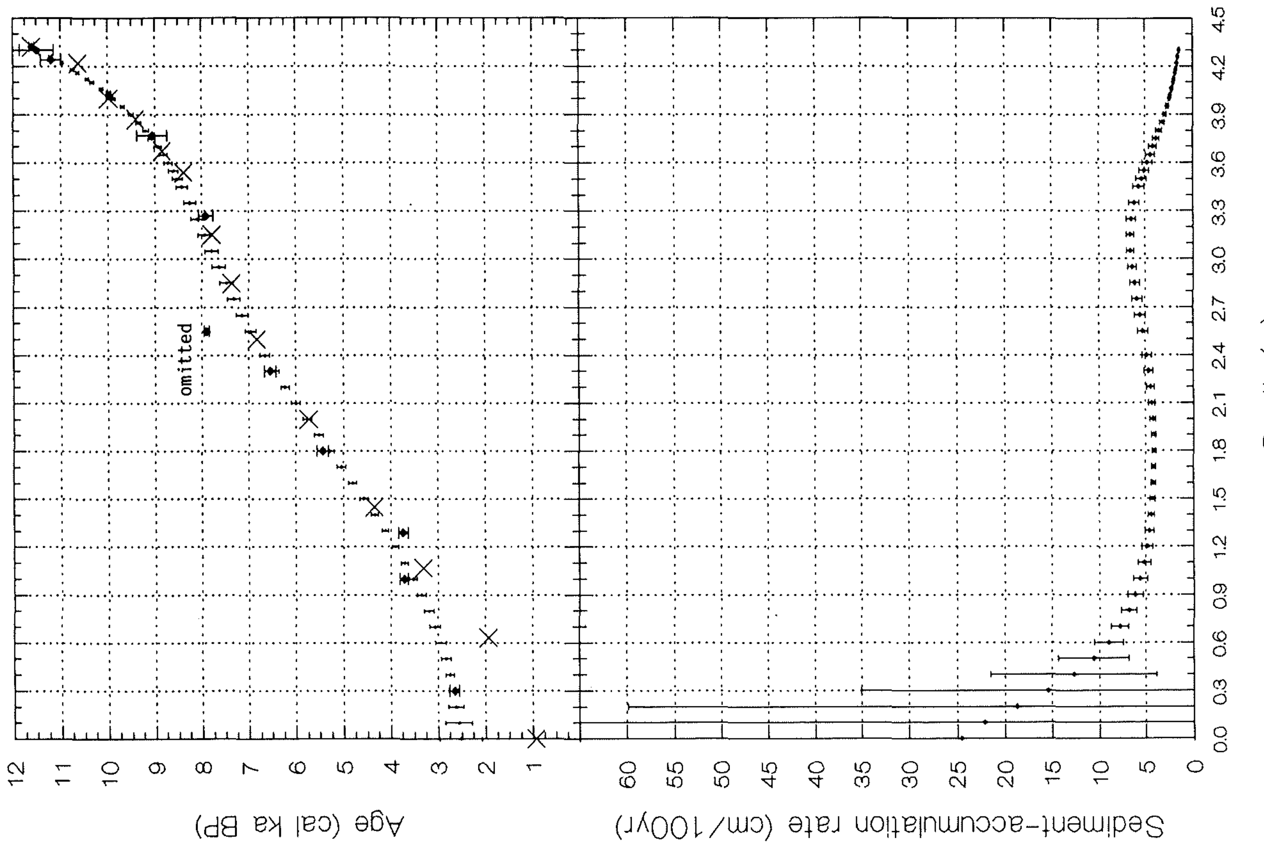

Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)

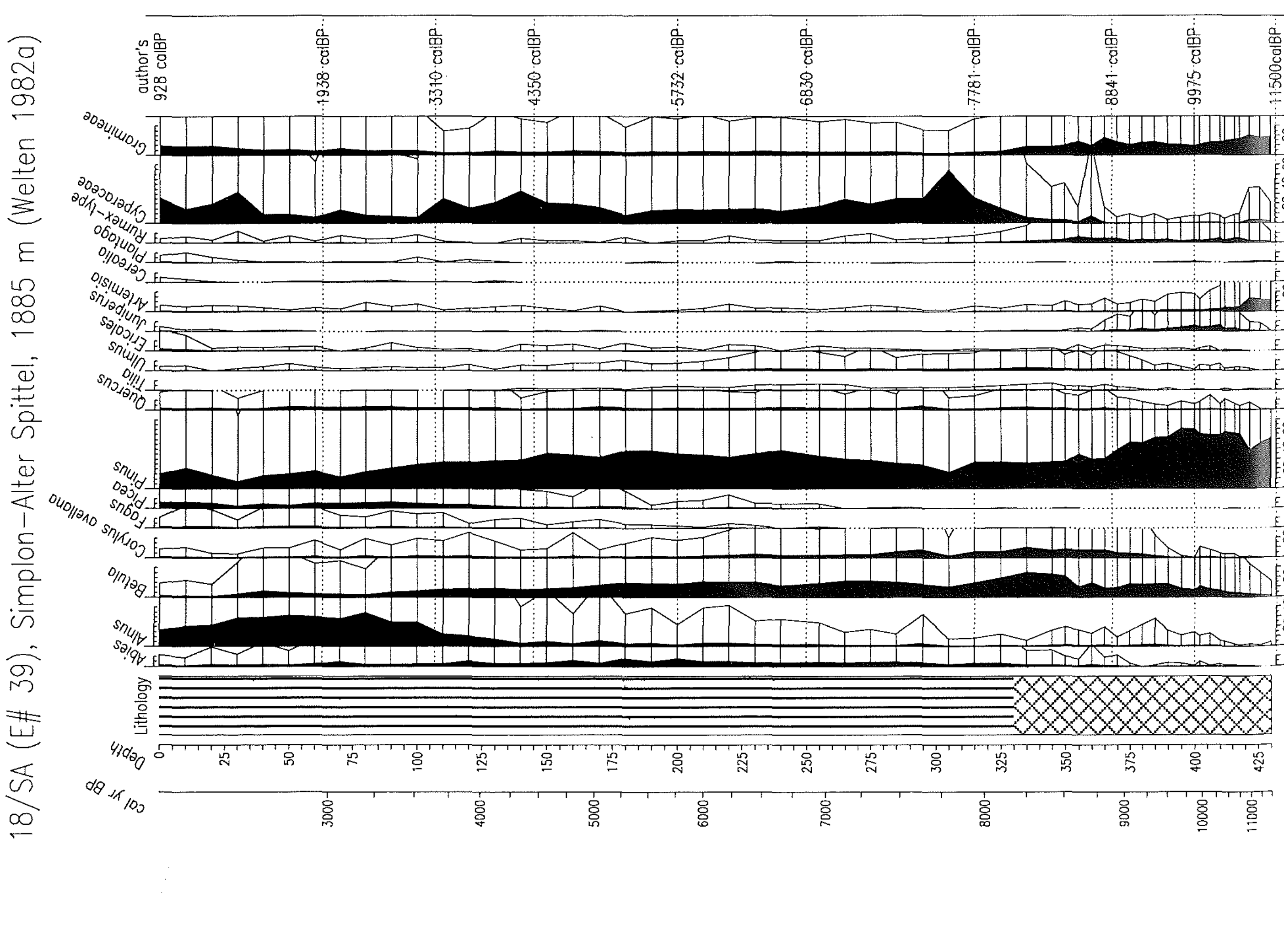

16/D (E# -8), Dossaccio, 1730 m (Welten 1982b)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
978 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11500calBP
12917calBP
13993calBP

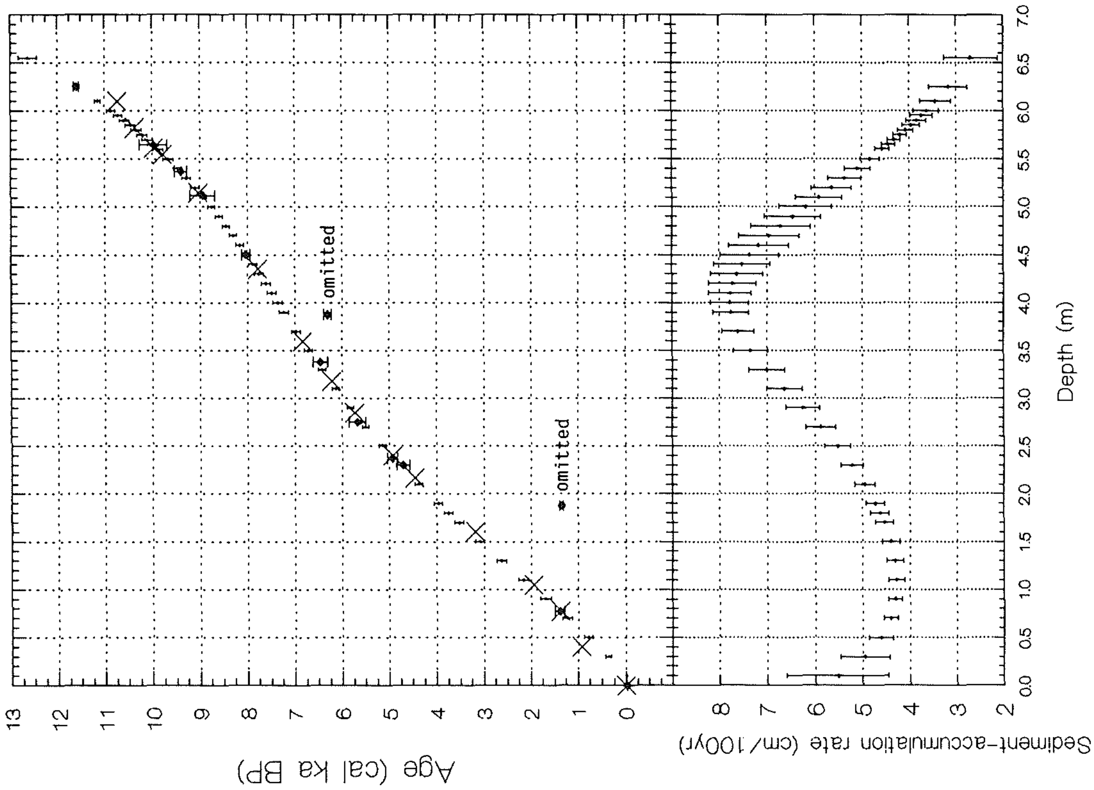


17/Wb (E# 15), Wallbach I, 1885 m (Welten 1982a)

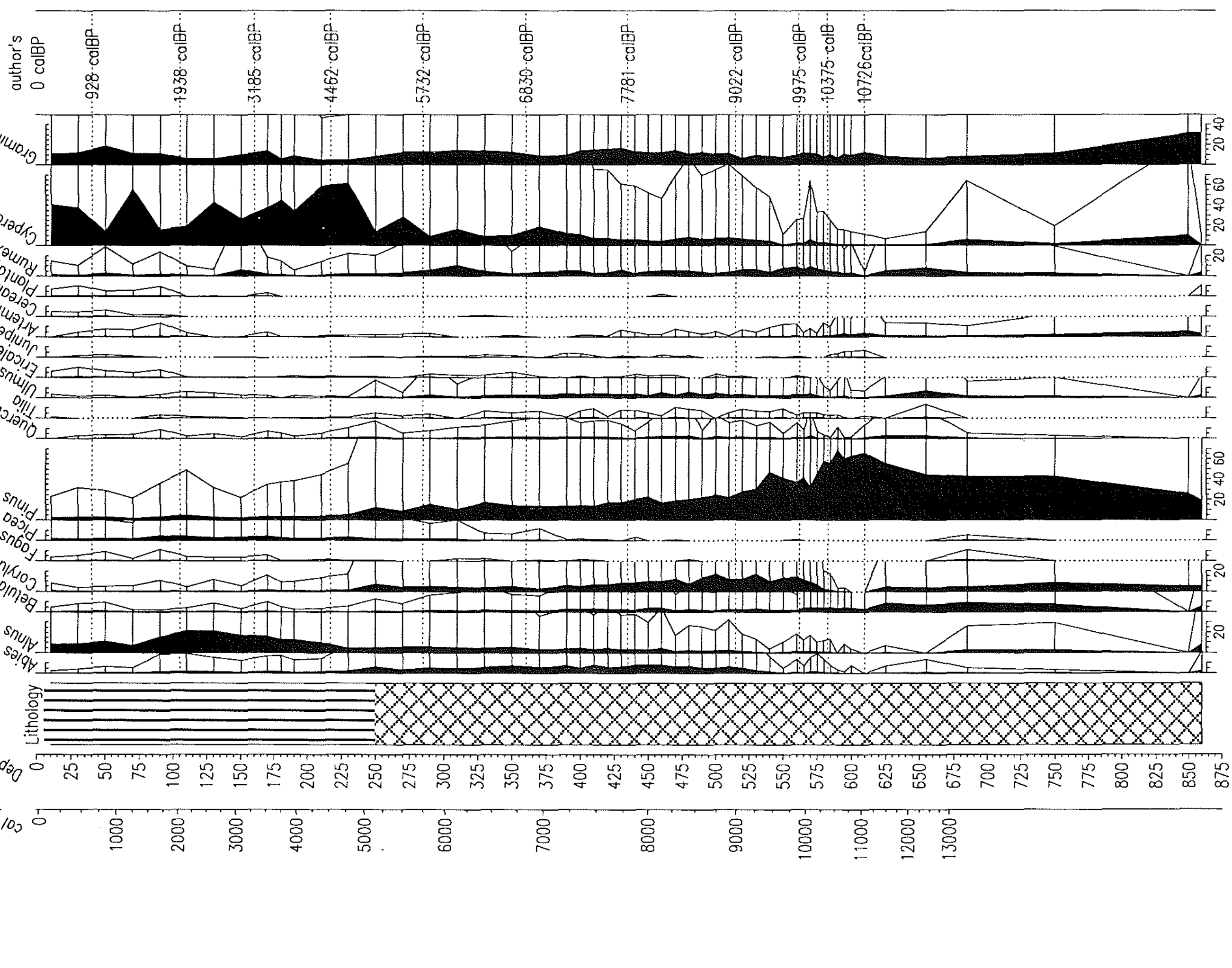


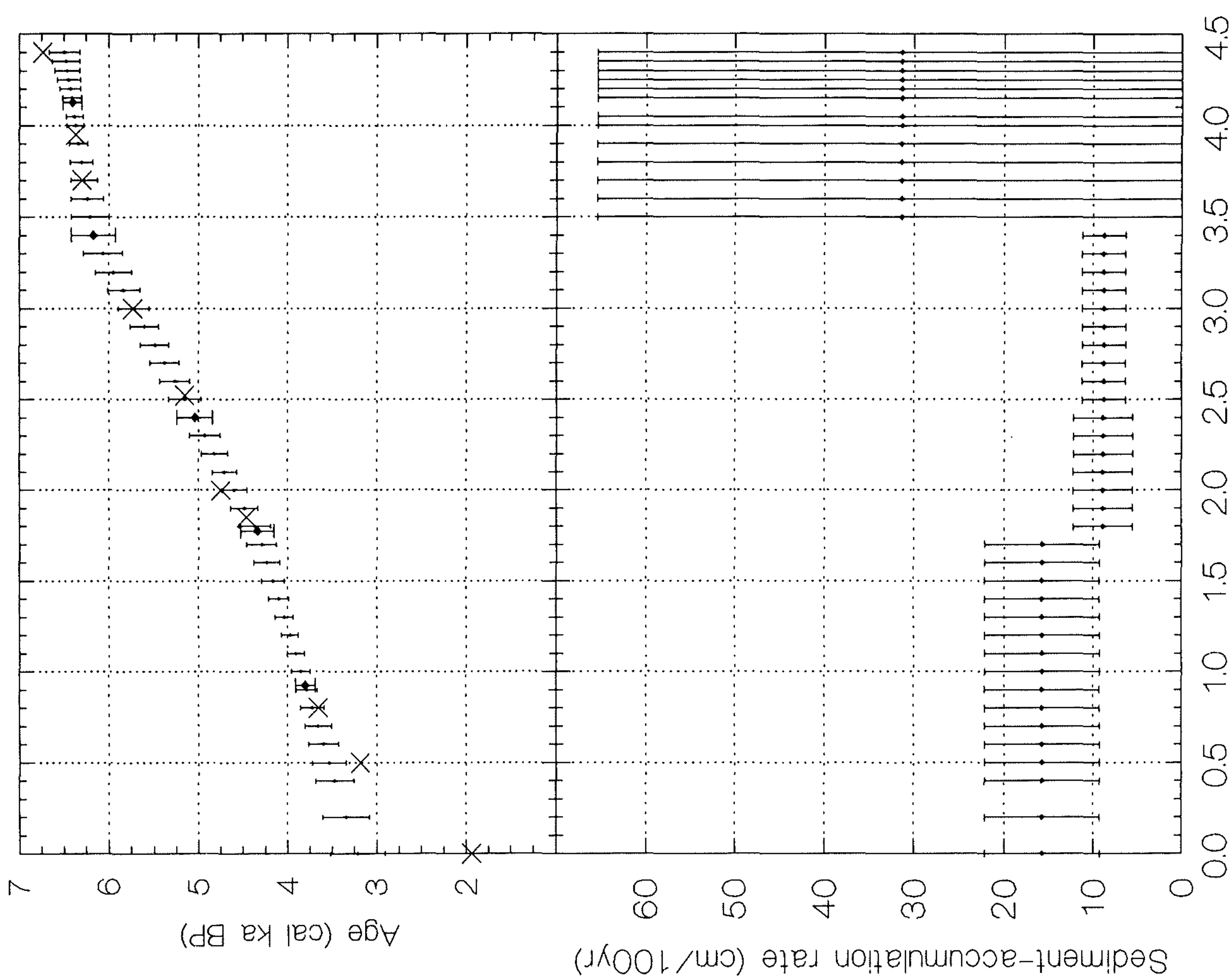

Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted

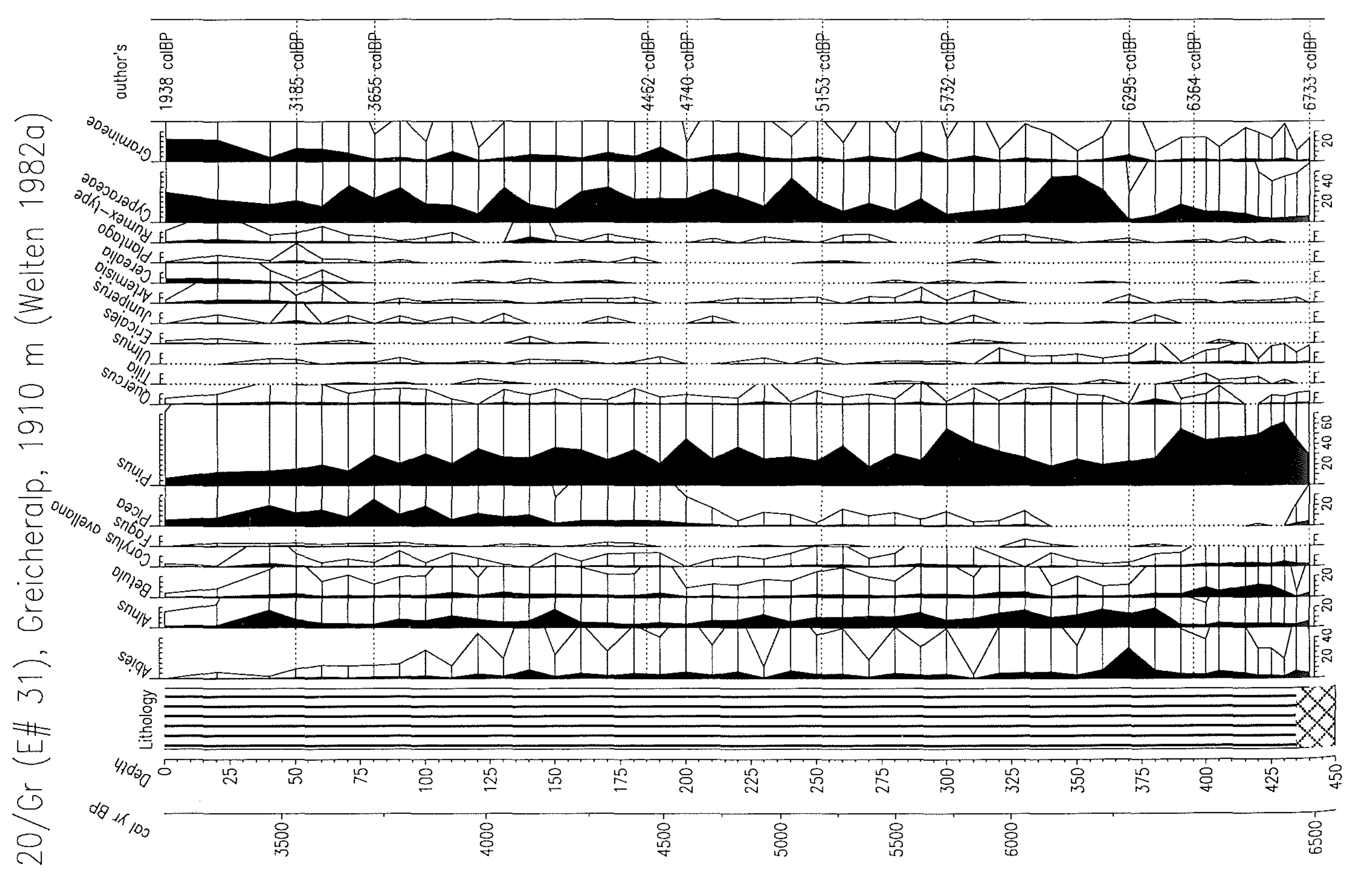

18/SA (E# 39), Simplon-Alter Spittel, 1885 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
1938 calBP
3310 calBP
4350 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11500calBP

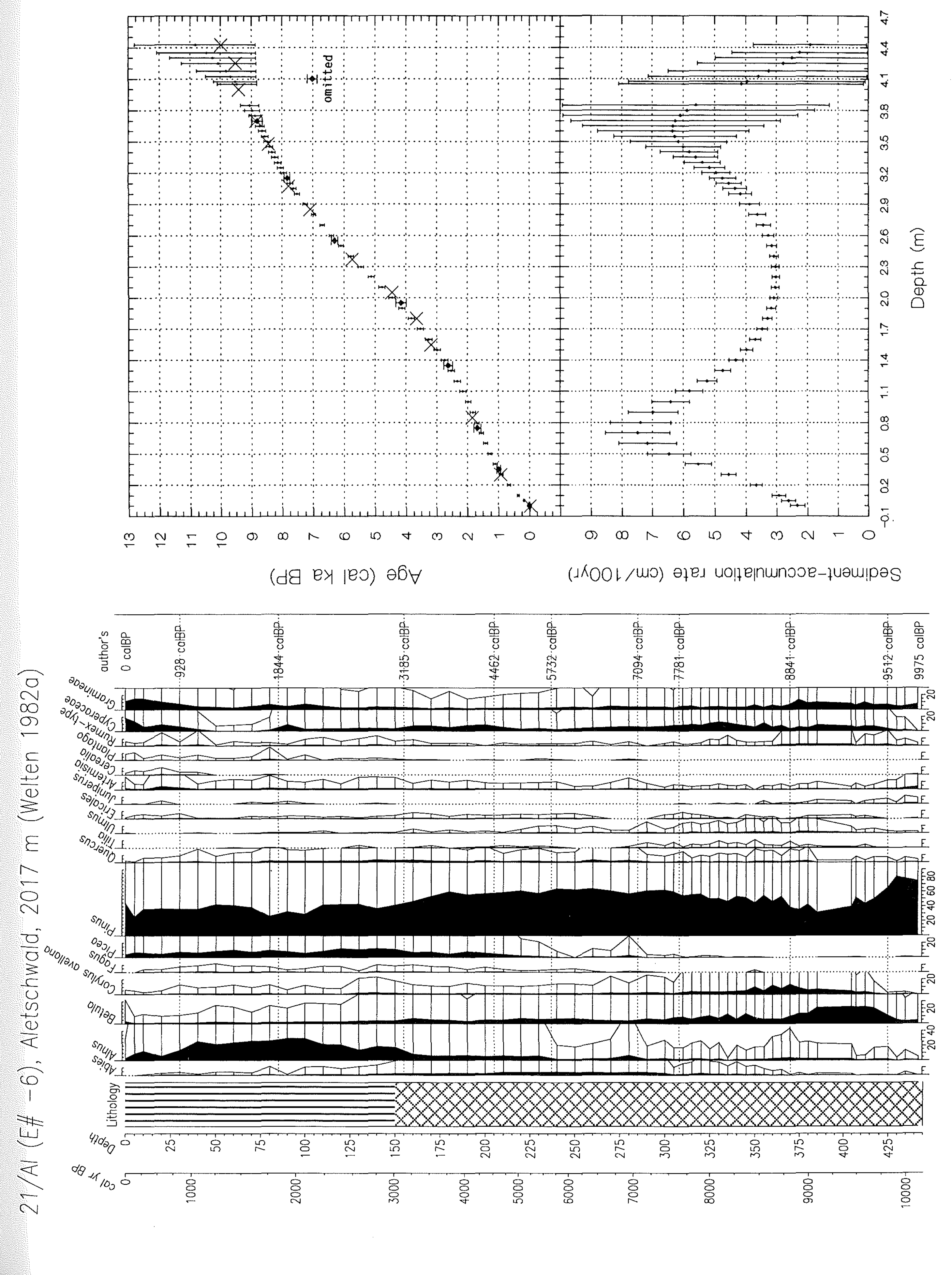


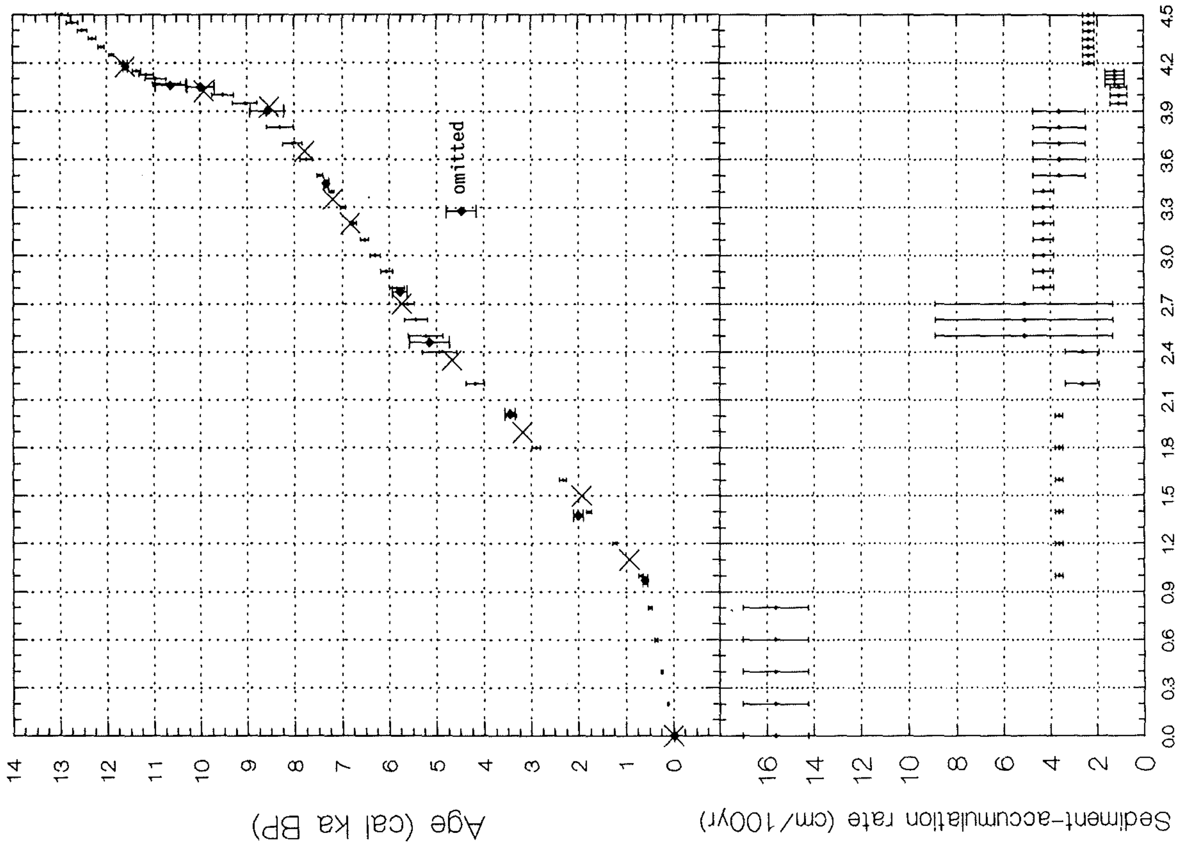
19/R (E# −12), Robiei II, 1892 m (Welten 1982a)

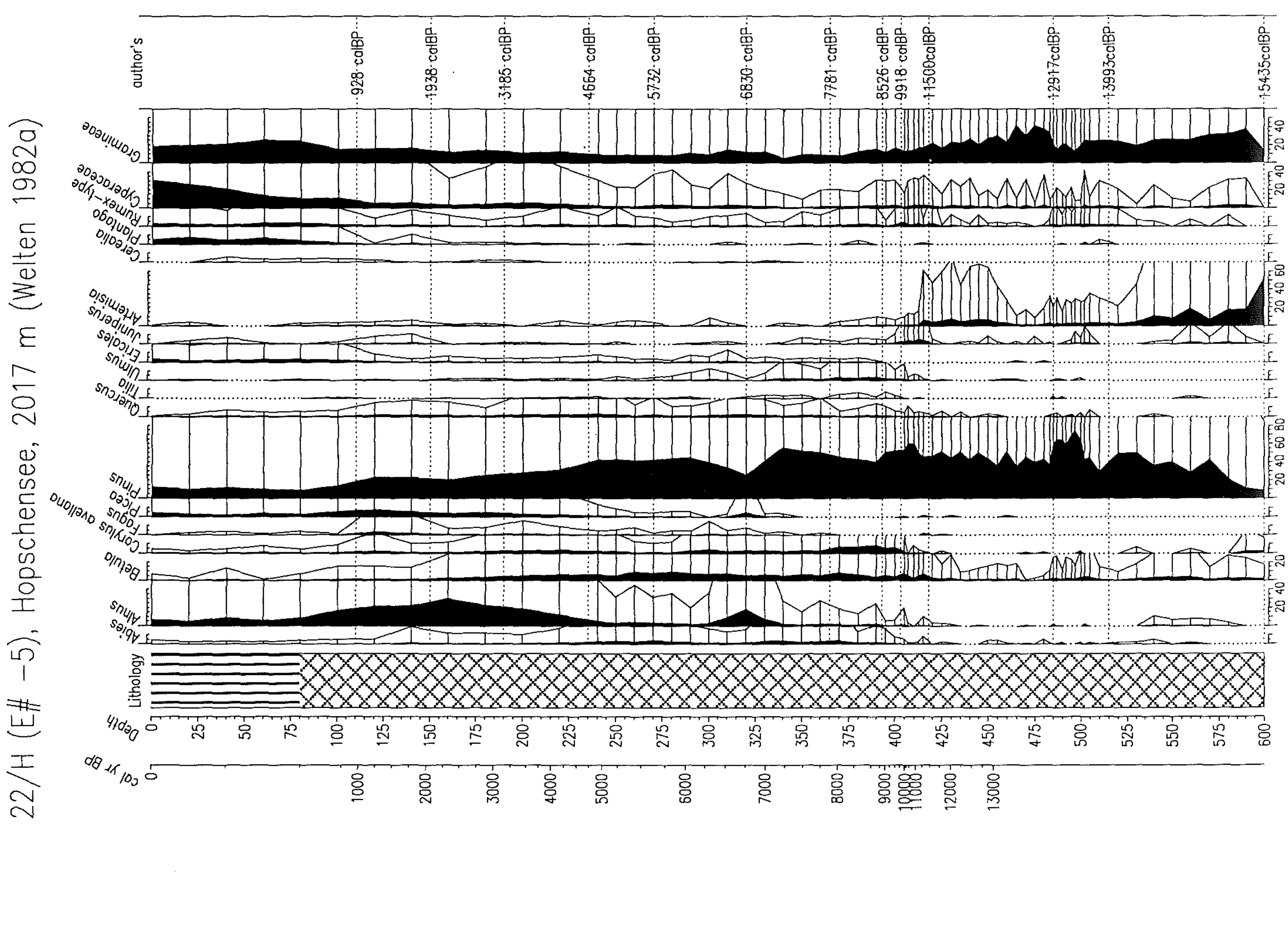


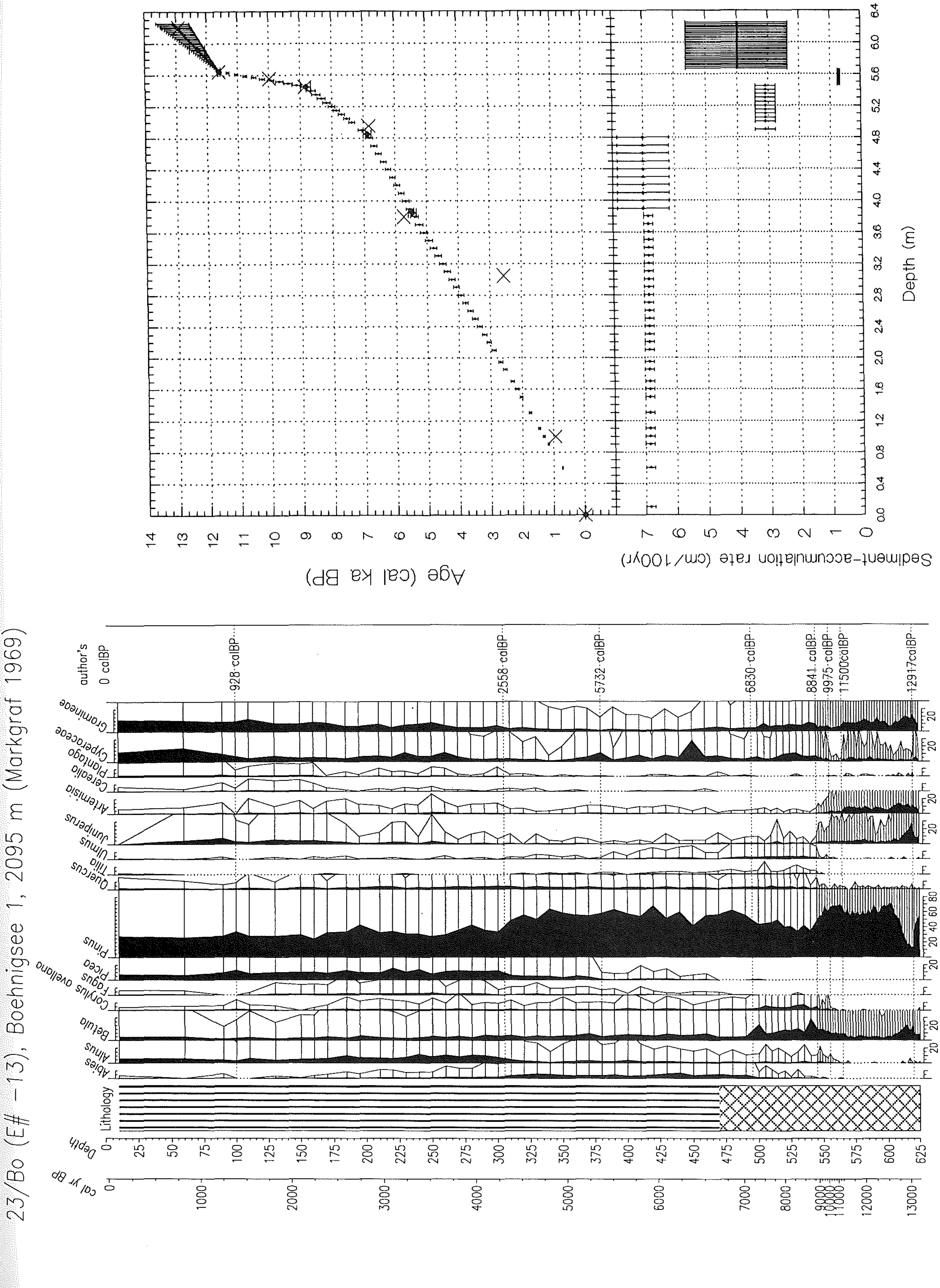

Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)

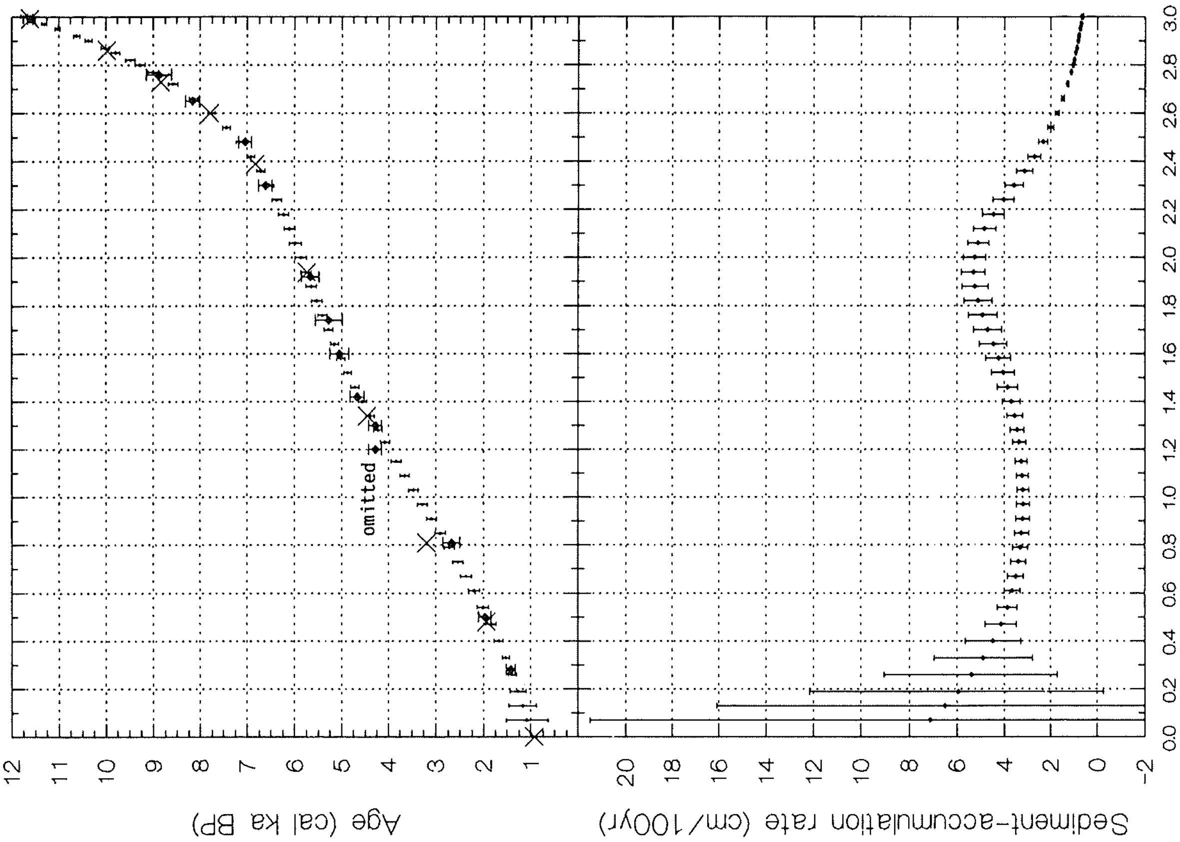

20/Gr (E# 31), Greicheralp, 1910 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
1938 calBP
3185 calBP
3655 calBP
4462 calBP
4740 calBP
5153 calBP
5732 calBP
6295 calBP
6364 calBP
6733 calBP

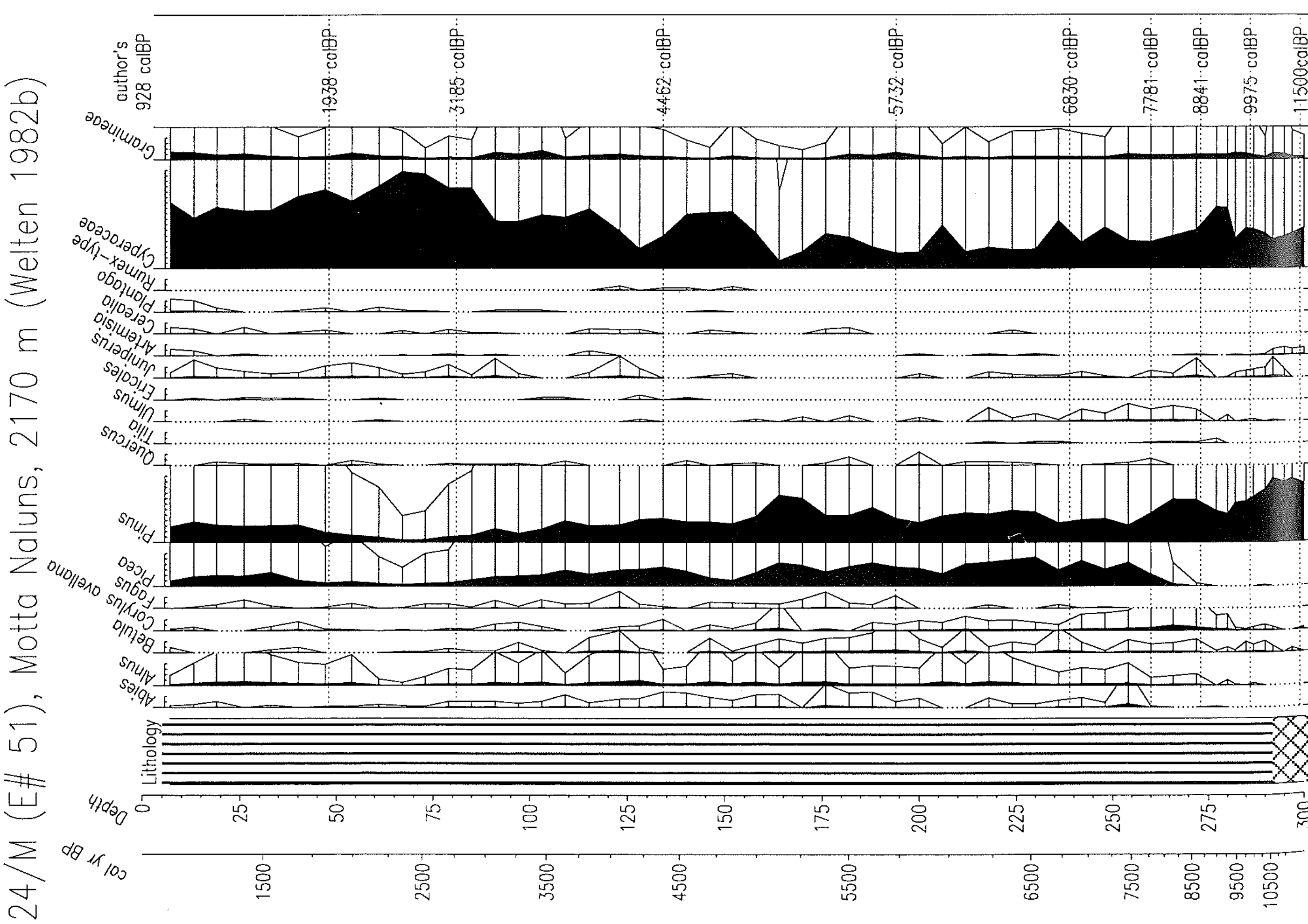

21/AI (E# -6), Aletschwald, 2017 m (Welten 1982a)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
0 calBP
928 calBP
1844 calBP
3185 calBP
4462 calBP
5732 calBP
7094 calBP
7781 calBP
8841 calBP
9512 calBP
9975 calBP

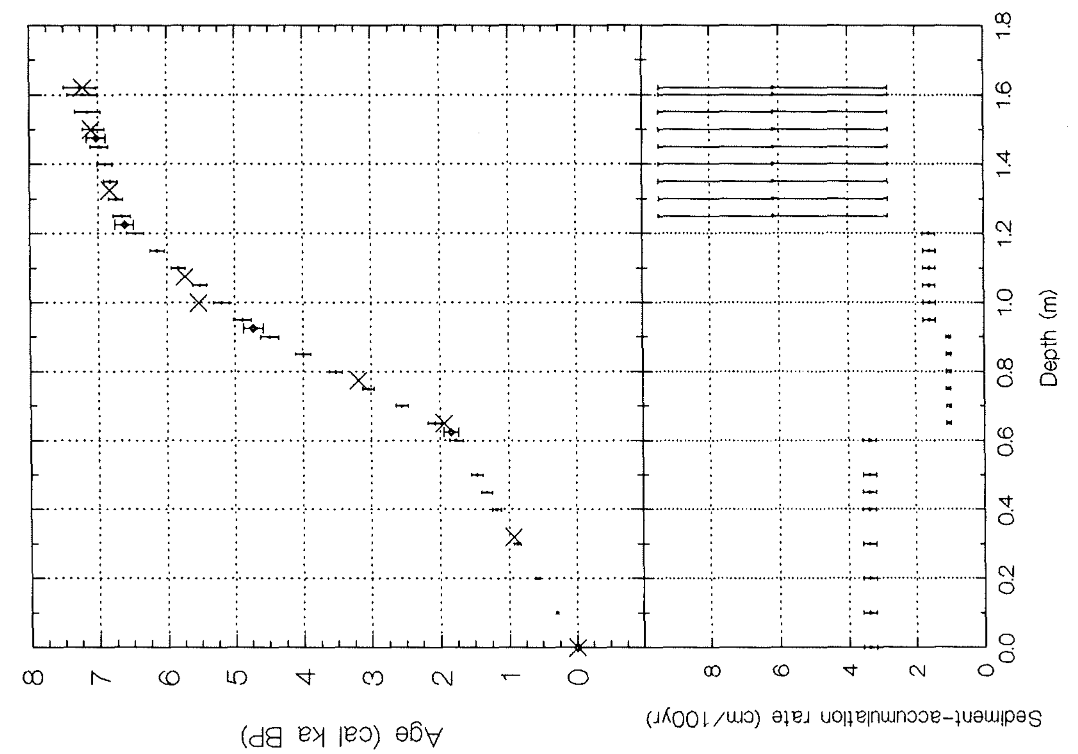

omitted
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)

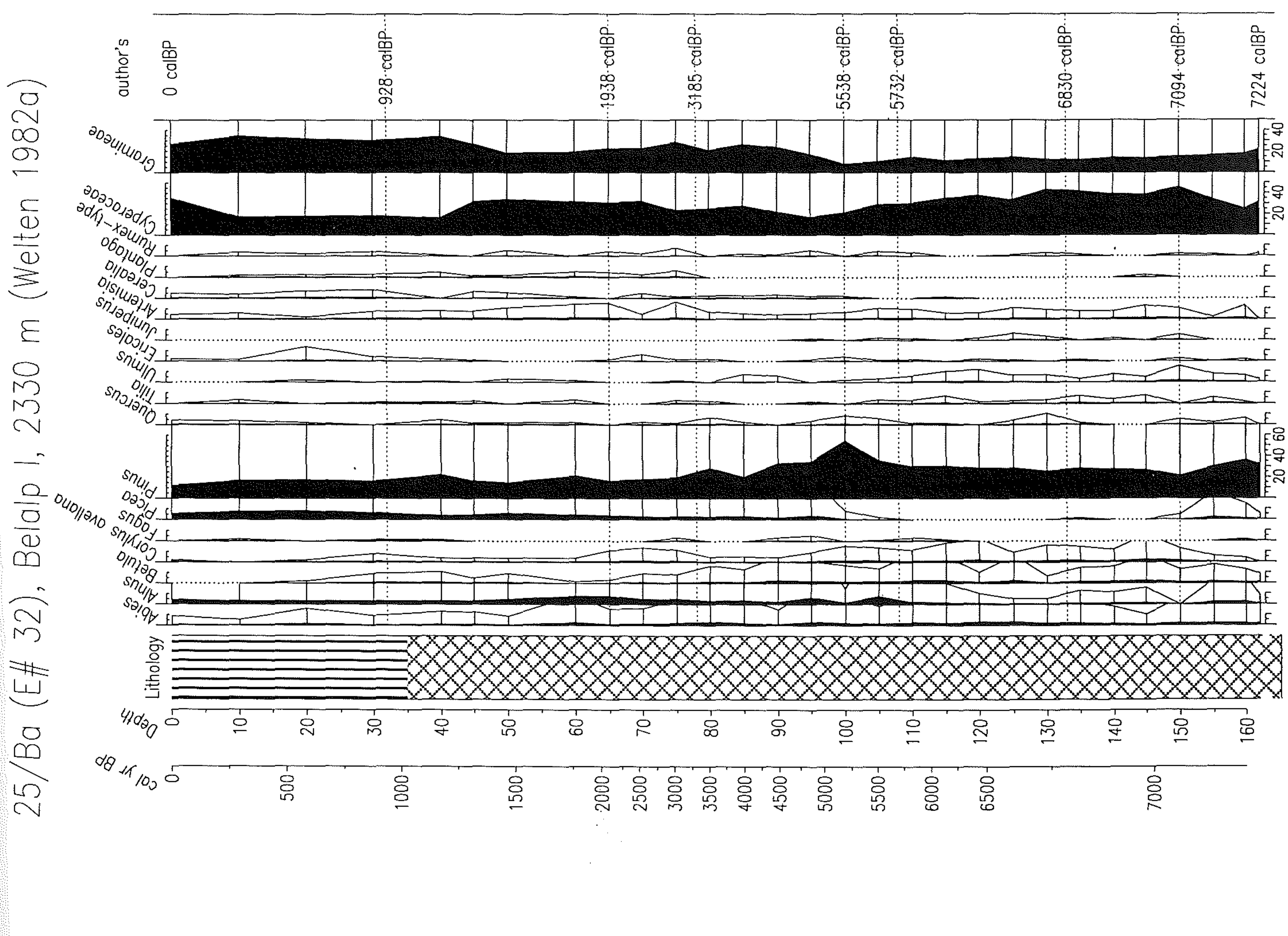

22/H (E# -5), Hopschensee, 2017 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
1938 calBP
3185 calBP
4664 calBP
5732 calBP
6830 calBP
7781 calBP
8526 calBP
9918 calBP
11500calBP
12917calBP
13993calBP
15435calBP


23/Bo (E# −13), Boehnigsee 1, 2095 m (Markgraf 1969)
Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Juniperus
Artemisia
Cerealia
Plantago
Cyperaceae
Gramineae
author's
0 calBP
928 calBP
2558 calBP
5732 calBP
6830 calBP
8841 calBP
9975 calBP
11500calBP
12917calBP


Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)
omitted


24/M (E# 51), Motta Naluns, 2170 m (Welten 1982b)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
928 calBP
1938 calBP
3185 calBP
4462 calBP
5732 calBP
6830 calBP
7781 calBP
8841 calBP
9975 calBP
11500calBP


Age (cal ka BP)
Sediment-accumulation rate (cm/100yr)
Depth (m)


25/Ba (E# 32), Belalp I, 2330 m (Welten 1982a)
cal yr BP
Depth
Lithology
Abies
Alnus
Betula
Corylus avellana
Fagus
Picea
Pinus
Quercus
Tilia
Ulmus
Ericales
Juniperus
Artemisia
Cerealia
Plantago
Rumex-type
Cyperaceae
Gramineae
author's
0 calBP
928 calBP
1938 calBP
3185 calBP
5538 calBP
5732 calBP
6830 calBP
7094 calBP
7224 calBP

Pollen diagram 2/O (Lac du Mont d'Orge), 640 m (Fig. 3-2)
The acceptance of a very low sediment-accumulation rate during the Preboreal and an abrupt change in sediment-accumulation rates around 8.5 cal ka BP inferred by the original author (WELTEN, 1982a) lead to the choice of linear interpolation of sample ages between dates rather than a polynomial function for the new chronology.
The three dates omitted from the depth-age model were also rejected by WELTEN (1982a). One date rejected by WELTEN (1304 cm) is included in our depth-age model.
The minor irregularity in the depth-age relationship around 3 cal ka BP is related to the fact that the pollen diagram is composite, resulting from two corings in the same site put together at this level.
Although the new chronology seems acceptable, linear interpolation has inevitably resulted in constant sediment-accumulation rates between dates changing abruptly at dated levels, which seems unrealistic except for the transition at 8.5 cal ka BP. Sediment-accumulation rates should therefore be treated with caution and interpreted in a general way only. Increasing rates around 2.5 cal ka BP might be the result of increased erosional imput due to human activity since Roman times, whereas successive increases after 1.5 cal ka BP might be related to the transition from lake sediment to peat.

Pollen diagram 3/Gä (Gänsemoos), 795 m (Fig. 3-3)
The new chronology suggests maximum sediment-accumulation rates around 6-7 cal ka BP. We observe no effect of the transition from lake sediments to peat around 9 cal ka BP on the sediment-accumulation rates. The upper 3 ka are absent from the sequence as a result of disturbance of the mire.

Pollen diagram 4/Li (Linden), 900 m (Fig. 3-4)
The new and the original chronologies differ mainly around 10-11 cal ka BP, which is the period of immigration of *Alnus*, *Corylus avellana*, *Quercus*, *Tilia*, and *Ulmus*. No acceptable dated levels are available for this period. Linear interpolation of sample ages between dated levels, on which the new chronology is based, therefore results in a constant sediment-accumulation rate from the base of the Holocene (11.6 cal ka BP) to 7.5 cal ka BP, whereas the original chronology proposed large fluctuations. We consider the new chronology for this period to be of limited usefulness.
HEEB & WELTEN (1972) state that surficial peat layers have been removed and that no peat acculumation takes place today. They guess the age of sub-surface peat layers at a millennium BP, but with a question mark. The age estimate of the top used here is based on this estimate.
The four dates omitted from the model are concentrated down in the section. Five dates between 775 and 1085 cm fall in the narrow range of 10370 to 10600 BP and a deeper date (1180 cm) gives 9490 BP; only two of them conform to palynological expectations. We suspect irregularities in the sediment, either in the field or in the laboratory.
The new chronology suggests changes in sediment-accumulation rates at the dated levels only, which is the inevitable result of the use of linear interpolation between dates as a depth-age model; see the remarks on this under pollen diagram 2/O above. Sediment-accumulation rates should therefore be interpreted in a general way only. The heterogeneous lithology consisting of alternating layers of peat, clay, gyttja, and lake marl indicates that sediment-accumulation rates may have changed repeatedly in the early Holocene at more levels than could be reconstructed with the dates available.

Pollen diagram 5/WU (Wachseldorn Untermoos), 980 m (Fig. 3-5)
The discrepancies up to 1 ka between the new and the original chronologies in the top 7 ka are related to the fact that this part was originally undated. There are no reasons to doubt the new chronology. The curves in the depth-age relationship seem to be gentle, but this results in marked changes in sediment-accumulation rates that show two maxima around 9 and 3-3.5 cal ka BP separated by a broad minimum around 5-7 cal ka BP.

Pollen diagram 6/Ae (Aegelsee AE-3), 989 m (Fig. 3-6)
The dates at 70 and 310 cm were transferred from the pollen diagram Aegelsee/Diemtigen of WELTEN (1982a) that was made earlier from a different coring in the same lake. They are inserted according to WEGMÜLLER & LOTTER (1990) based on the pollen stratigraphy. The date at 445 cm, although rejected by WEGMÜLLER & LOTTER as falling out of sequence as it seemed too old, is included in the model for the new chronology, as its apparent error seems small.
The new chronology suggests maximum sediment-accumulation rates around 6-7 cal ka BP. No dates at or near the transition from lake sediments to peat (modelled to 9.25 cal ka BP) are available, so any effect of this transition on sediment-accumulation rates remains untraced.

Pollen diagram 7/BN (Bitsch-Naters), 1030 m (Fig. 3-7)
The depth-age relationship in the two parts of the pollen diagram above and below 365 cm depth have been modelled separately. The abrupt and strong increase in sediment-accumulation rate at 365 cm coincides approximately with the change in lithology from gyttja to peat at 335 cm.

Pollen diagram 8/C (Etang d'y Cor), 1500 m (Fig. 3-8)
WELTEN (1982a) based the inferred chronology entirely on biostratigraphy because he did not have radiocarbon dates (WELTEN, 1982a). He stated that radiocarbon dating was impossible because too little was preserved of the sediment that was cored in 1938. AMS dating has now been carried out on the small samples taken by WELTEN for pollen analysis but not used. A strongly compressed Preboreal in the original chronology might be correct, although it is not reflected in the new chronology. The new chronology suggests a maximum in sediment-accumulation rates around 5 cal ka BP.

Pollen diagram 9/Z (Zeneggen-Hellelen A), 1510 m (Fig. 3-9)
The base of the Holocene (650 cm) is 1 ka too young in the new chronology.
The new chronology suggests high and fluctuating sediment-accumulation rates after *ca.* 3-4 cal ka BP, which coincides roughly with the transition from lake sediment to peat.

Pollen diagram 10/GA (Gondo-Alpjen 2), 1635 m (Fig. 3-10)
The original chronology seems to be based on linear interpolation between dates. The new and original chronologies diverge in the undated part below 6 ka cal BP; the pollen assemblage, however, gives no indication which chronology is more realistic.
The new chronology suggests maximum sediment-accumulation rates around 3.5-4.75 cal ka BP, just following the transition from lake sediments to peat.

Pollen diagram 11/E1 (Eggen ob Blatten), 1625 m (Fig. 3-11)
The new chronology suggests a very pronounced maximum in sediment-accumulation rates around 5-6 cal ka BP, more so than is suggested by (but not in contradiction to) the original chronology (WELTEN, 1982a).

Pollen diagram 12/E2 (Eggen ob Blatten 56), 1645 m (Fig. 3-12)
This unpublished pollen diagram is from a different coring at the same site as pollen diagram 11/E1 made by the same analyst. It was used by WELTEN (1982a) as back-ground information. No original chronology is therefore available. The chronology of the main palynological events differs up to 0.5 ka from that of pollen diagram 11/E1 in either direction. We feel that the 5 dates included in our model are not enough for a reliable depth-age relationship.

Pollen diagram 13/P (Pillon), 1670 m (Fig. 3-13)
The new chronology suggests less variable sediment-accumulation rates than in many other pollen diagrams, showing a broad maximum around 5 cal ka BP. The original chronology, however, infers strongly changing rates and wiggles in the depth-age relationship in the period 11.5-8 cal ka BP that are not reflected in the new chronology. It can be seen in the graph that a model using linear interpolation between dates would produce a chronology closer to the original model than the polynomial function used in the new model. The original chronology might be correct at this point, but it would need more radiocarbon dates to verify this.

Pollen diagram 14/GS (Grächen-See), 1710 m (Fig. 3-14)
The new chronology suggests continuously decreasing sediment-accumulation rates. The radiocarbon dates below 650 cm show a pattern that makes their reliability doubtful. The new chronology for this part is therefore only accepted with caution. Note that the curve formed by the samples and their confidence intervals have a shape that resembles an Alpen-horn!

Pollen diagram 15/ST (Schwarzsee ST), 1721 m (Fig. 3-15)
WELTEN (1982b) considered the "very watery peat" between 0-140 cm to be reworked and he supposed it to be transported horizontally, possibly by a landslide, although he himself found this completely inexplicable in view of the surrounding landscape. The date at 148 cm supports WELTEN's idea of reworked material above 140 cm. He did therefore not discuss the pollen stratigraphy of the presumed reworked section. There is no sharp transition in pollen assemblage at 140 cm, but a phase of strong deforestation (low tree-pollen values) and strong grazing (grazing indicators) is suggested at 90-60 cm followed by partial forest regeneration (more tree pollen) and reduced grazing (less grazing indicators). The model used for the new chronology (which omits the biostratigraphical date at the top of core) supports the idea of reworked material above 140 cm, because it results in negative ages for samples 0-140 cm. However, a different explanation is possible, accepting the peat as being locally grown rather than transported horizontally. The very watery peat might have grown very fast and the pollen stratigraphy might reflect vegetation changes on and adjacent to the mire. Further research is needed to test these hypotheses.
The new chronology suggests fairly constant but slowly increasing sediment-accumulation rates for the section represented by lake sediments.

Pollen diagram 16/D (Dossaccio), 1730 m (Fig. 3-16)
The discrepancy between the new and the original chronologies in the top 3 ka is due to the lack of radiocarbon dates in this part, whereas WELTEN (1982b) gives three inferred dates based on biostratigraphy. This part of the new chronology is therefore not reliable.
Linear interpolation of sample ages between the dated levels was used for the new chronology, which inevitably results in abrupt changes in sediment-accumulation rates at the dated levels. The marked increase at *ca.* 9.2 cal ka BP seems to be realistic in view of the sequence of dates available, but increases or decreases at other levels should be interpreted in a general way only. The transition from lake sediments to peat (around 8.3 cal ka BP) falls in a period of strongly decreasing sediment-accumulation rates stabilizing around 8 cal ka BP.

Pollen diagram 17/Wb (Wallbach I), 1885 m (Fig. 3-17)
The new chronology consists of two parts modelled independently (0-115 cm and 120-300 cm). This has been done because of a hiatus inferred by WELTEN (1982a) based on pollen trends and supported by radiocarbon dating, although the lithology does not suggest any hiatus. WELTEN inferred the hiatus between the pollen samples at 120 and 130 cm, but a close look at the pollen diagram shows that the hiatus should be placed between samples at 115 and 120 cm (see, *e.g.*, the curves of *Pinus*, *Ulmus*, Gramineae, Ranunculaceae, Rosaceae, and *Plantago alpina*-type). Sediment-accumulation rates are high in the top part (2-0 cal ka BP), but they show little variation in the basal part (12-4.5 cal ka BP) in which there is a broad maximum around 8 cal ka BP. The transition from lake sediments to peat, dated 9.7 cal ka BP, is not reflected in the sediment-accumulation rates.

Pollen diagram 18/SA (Simplon Alter Spittel), 1885 m (Fig. 3-18)
A difference up to 1.6 ka between the new and the original chronologies from 3.5 cal ka BP upwards (top m of sediment) depends on one date only. The new chronology is considered uncertain for this part. According to the new chronology, sediment-accumulation rates before 3.5 cal ka show a maximum around 8 cal ka BP, approximately coinciding with the transition from lake sediments to peat dated at 8.2 cal ka BP.

Pollen diagram 19/R (Robiei II), 1892 m (Fig. 3-19)
The new chronology suggests maximum sediment-accumulation rates around 7-8 cal ka BP. The transition from lake sediments to peat around 5 cal ka BP falls in a period of little changing sediment-accumulation rates.

Pollen diagram 20/Gr (Greicheralp), 1910 m (Fig. 3-20)
The new chronology is based on linear interpolation

Table 3: Depth-age modelling methods and results.
No. = No. of pollen diagram; diagrams are sorted on elevation
Code = One- or two-character abbreviation of name of pollen diagram
E# = No. of pollen diagram in the Alpine Palynological Data Base. For name of site, see Table 1
Dates included in model:
radioc.tot = Number of radiocarbon dates available
rej = Number of radiocarbon dates rejected in model (marked O under "Use?" in Table 2)
biostr.tot = Number of biostratigraphic dates available
rej = Number of biostratigraphic dates rejected in model
oth. = Other date available:
LST = Laacher See tephra
δ018 = Oxygen-isotope transition at base of Holocene (9 samples measured in N° 8)
Modelling method :
Linear interpolation between dates
Polynomial function with n terms
Modelled range in cal ka BP (millennia before AD 1950)
Reliability of model : The subjectively assessed reliability of the depth-age model selected for the "new chronology". "ka" is shorthand for "cal ka BP".
Agreement with chronology of original author(s) : The agreement between our new chronology and the inferred chronology of the original author(s). "ka" is shorthand for "cal ka BP".

No.	Code	E#	Dates used in model: radioc. tot-rej	biostr. tot-rej	oth.	Modelling method	Modelled range in cal ka BP	Reliability of model (time span in cal ka BP) high	medium	low	Agreement with chronology of original author(s)
1	Lo	82	24-3	2-0	LST	polynomial 6 terms	0.8-12.0	1.5-12		<1.5	moderate 0-3 ka; good 3-12 ka
2	O	-3	9-1	2-0		linear interpolation	0.0-12.0	0-12			good
3	Gä	5	9-1	1-0	LST	polynomial 6 terms	3.0-12.0	4.5-12		3-4.5	good
4	Li	216	11-4	2-0		linear interpolation	0.5-12.0	0.5-8	8-12		mod.0-4.5 ka; good 5-7 ka; bad 8-10 ka
5	WU	-9	10-2	1-0		polynomial 6 terms	0.8-12.0	1-12			bad 3-7 ka; good 8-12 ka
6	Ae	73	12-1	2-0	LST	polynomial 4 terms	0.0-12.0	2-12			good
7	BN	27	8-2	2-0		pol. 2 t.; composite	0.0-11.6	0-11.6			good
8	C	21	6-0	1-0	δO18	polynomial 4 terms	0.0-12.0	0-12			moderate 0-2 and 7-11 ka; bad 2-7 ka
9	Z	23	10-0	2-0		polynomial 5 terms	0.0-12.0	0-10		10-12	rather good
10	GA	40	5-0	1-0		polynomial 5 terms	0.0- 7.4	0-6.2		>6.2	good 0-6 ka
11	E1	-4	14-1	2-0		polynomial 5 terms	0.0-11.6	2.4-11.6		0-2.4	moderate 0-5 ka; good 6-12 ka
12	E2	49	6-1			polynomial 3 terms	0.9- 8.9	2-8		<2; >8	-
13	P	16	9-0	1-0		polynomial 4 terms	0.0-12.0	0-8	8-12		good 2-8 ka; moderate 8-11 ka
14	GS	25	12-4	1-0		polynomial 3 terms	0.0- 8.9	0-8		8-9	good 0-8 ka
15	ST	204	6-1	2-1		polynomial 3 terms	0.0-12.0		0-12		good
16	D	-8	5-0	1-0		linear interpolation	1.7-12.0	3-12		1.7-3	moderate 1-3 ka; good 3-12 ka
17	Wb	15	11-2	2-0		pol. 4 t.; composite	0.0-12.0	≤1.6; ≥5.5		1.6-5.5	good
18	SA	39	11-1	1-0		polynomial 6 terms	2.5-11.5	3-11.5		2.5-3	good 4-12 ka
19	R	-12	11-2	2-0		polynomial 6 terms	0.0-12.0	0-12			good
20	Gr	31	5-0			linear interpolation	3.2- 6.5	3.7-6.4		<3.7; >6.4	good 6.5-3.5 ka
21	Al	-6	7-0	1-0		polynomial 6 terms	0.0-10.8	0-9		9-10.8	good 0-9 ka
22	H	-5	10-0	2-0		linear interpolation	0.0-12.0	0.5-12	0-0.5		good
23	Bö	-13	4-0	2-0		linear interpolation	0.0-12.0	5-12	0-5		bad 1-5 ka; good 5-12 ka
24	M	51	13-1	1-0		polynomial 6 terms	1.1-11.8	1.25-11.8		<1.25	good
25	Ba	32	4-0	1-0		linear interpolation	0.0- 7.3	0-7.3			good

between dates, which inevitably results in unrealistic, abrupt transitions in the sediment-accumulation rates at dated levels. The use of a polynomial function would remove this, but none could be accepted because it produces inversions in the depth-age relationship (*i.e.* older samples lying above younger samples) even though the dates do not show any inversions (*i.e.* older dates lying above younger dates).

Pollen diagram 21/Al (Aletschwald), 2017 m (Fig. 3-21)

The extremely large confidence intervals of sample ages in the new chronology below 380 cm depth (before 9 cal ka BP) makes this part of the sequence of doubtful reliability. The new chronology suggests two maxima in sediment-accumulation rates around 8.5 and 1.5 cal ka BP. The earlier maximum depends only on the lowest date included in the model and might therefore not be realistic. The transition from lake sediments to peat around 3 cal ka BP is not reflected in the sediment-accumulation rates.

Pollen diagram 22/H (Simplon Hopschensee), 2017 m (Fig. 3-22)

The new chronology is considered uncertain in the top metre (0.5 cal ka) due to the scarcity of dates. The depth-age model is based on linear interpolation of sample ages between dates, and thus the sediment-accumulation rates should be interpreted in general terms only. The abrupt increase in rates around 8.5 cal ka BP, however, seems to be realistic in view of the sequence of dates and is in accordance with the original chronology. The high sediment-accumulation rates suggested for this part (0.75-0 cal ka BP) coincide with the part of the core represented by peat.

Pollen diagram 23/Bö (Böhnigsee 1), 2095 m (Fig. 3-23)

The discrepancy between the new and the original chronology in the second half of the Holocene is partly caused by a lack of dates and partly by the lack of pollen trends on which a confident pollen zonation could be established. We are inclined to favour the new chronology, because it is simple. However, we consider the pollen diagram to be insufficiently dated.

The new chronology suggests increasing sediment-accumulation rates at 9 and 7 cal ka BP, which might be gradual rather than stepwise. The increase at 7 cal ka BP coincides approximately with the transition from lake sediments to peat. Rates are constant in the entire period represented by peat.

Pollen diagram 24/M (Motta Naluns), 2170 m (Fig. 3-24)

The date at 120 cm that is omitted from the model nearly overlaps the curve of sample ages.

The new chronology suggests a maximum in sediment-accumulation rates around 5.5-6 cal ka BP. The increasing rates since 2 cal ka BP are very uncertain in view of the large confidence intervals.

Pollen diagram 25/Ba (Belalp I), 2330 m (Fig. 3-25)

The abrupt transitions in sediment-accumulation rates at the dated levels are an artefact of the method of depth-age modelling (linear interpolation of sample ages between dates). A smooth curve through the dates is probably more realistic, but we failed to produce this with a polynomial function, because functions with 4 to 6 terms produce inversions in the depth-age relationship (*i.e.* older samples lying above younger samples). The new chronology suggests decreasing sediment-accumulation rates around 6.5 cal ka BP. Rates increase again around 1.5 cal ka BP, approximately at the transition from lake sediments to peat.

DISCUSSION

Selection of depth-age models

Our aim is to create a depth-age model for every pollen diagram based on the available dates that reflects the "true" depth-age relationship and faithfully dates the pollen assemblages at every level. A basic assumption is that the majority of the dates used is correct, *i.e.* they give a reliable radiocarbon age for the fossil pollen assemblages. We restricted the methods of depth-age modelling to linear interpolation between dates and polynomial functions with up to 6 terms, because only for these methods confidence-intervals can be calculated with the available computer programs. We discuss now the implications of the different models and functions.

The simplest depth-age model possible is to use linear interpolation of sample ages between dates. This is applied to eight pollen sequences (2/O, 4/Li, 16/D, top part of 17/Wb, 20/Gr, 22/H, 23/Bö, 25/Ba; see Fig. 3). Four or them (2/O, 16/D, 22/H, 23/Bö) share a pattern of very low sediment-accumulation rates in the beginning of the Holocene, increasing rates around 9 cal ka BP, and sometimes increasing again *ca.* 2-1 cal ka BP. Linear interpolation inevitably results in abrupt changes in sediment-accumulation rates at dated levels. Such abrupt changes may be real occasionally, but it is highly improbable to infer this for every dated level. Sample ages are therefore approximate. Linear interpolation assumes that all dates are correct and that sediment-accumulation rates are constant between adjacent dates. Both assumptions are probably not entirely true, but they might be adequate approximations in some cases. However, it would in most cases seem more realistic to draw a smooth curve through the dates, occasionally allowing dates to lie a little off the fitted curve. This is what polynomial functions try to achieve.

The simplest polynomial function has 2 terms only (y = a+bx, in which y is the estimated sample age and x is sample depth) and is identical to simpler linear regression. This implies a constant rate of sediment accumulation throughout the pollen sequence. The difference with the model of linear interpolation is that the estimate of each sample age depends on all dates included (rather than on the two nearest dates only) and that it allows the dates not to fall exactly on the fitted line drawn through the sample ages. We found no simple example in our study sites, but we used it in two parts of pollen diagram 7/BN. The two parts were modelled independently and combined into a single graph (Fig. 3-7). The abrupt change of sediment-accumulation rates at the junction of these two parts coincides with the transition from lake sediments to peat and is therefore accepted. All the dates included in the model seem to overlap at least, in part, the fitted curve formed by the sample ages; we thus consider the model successful for this pollen sequence. If, on the other hand, sediment-accumulation rates in a pollen sequence are thought to change gradually, a polynomial function with more terms is required.

A polynomial function with 3 terms (y = a+bx+cx^2) implies a constantly increasing or decreasing rate of sediment accumulation. We used this model in pollen sequences 14/GS, which has a slightly increasing rate, and 15/ST, which has a decreasing rate. We observe in the two pollen diagrams that a few dates (with 1 SD range) do not overlap with the sample ages (with confidence intervals). We have the choice of interpreting this as dating and modelling inaccuracies, or trying instead a different model - either linear interpolation between dates or a polynomial function with more terms.

A polynomial function with 4 terms results in a depth-age curve that is symmetrically sigmoidal in shape. Sediment-accumulation rates gradually increase at first, become constant, and then decrease with the same rate as the increase (or *vice versa*), forming a symmetric curve. This model could be applied to three pollen sequences (6/Ae, 8/C, 13/P) and to part of a fourth (17/Wb). In the three pollen sequences, the transition from increasing to decreasing sediment-accumulation rates falls in the mid-Holocene (5-6.5 cal ka BP). The actual depth-age curve may consist of only part of the complete sigmoid curve, showing, for example, more of the increasing than of the decreasing sediment-accumulation rates (as in 8/C and 13/P), but it does not allow any deviations from this pattern (such as the rates of increase being larger than the rates of decrease, as in, *e.g.*, pollen diagram 3/Gä).

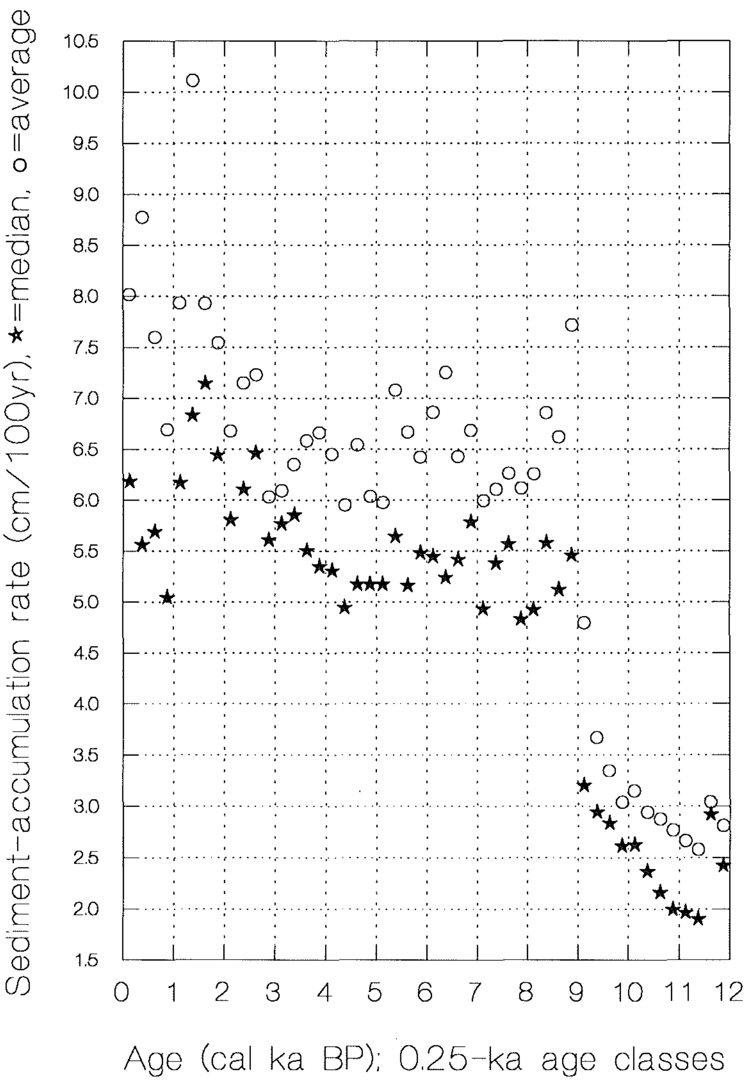
A polynomial function with 5 or more terms results in depth-age curves with various wiggles and more than one maximum and/or minimum in sediment-accumulation rates. The bends in a single depth-age curve may be different from each other in depth range and in sharpness; the more varied an actual depth-age relationship is in this respect the more terms are needed in the polynomial function to obtain a satisfactorily fitting curve. We modelled three sequences with a polynomial function with 5 terms (9/Z, 10/GA, 11/E1) and seven with 6 terms (1/Lo, 3/Gä, 5/WU, 18/SA, 19/R, 21/Al, 24/M).

However, the use of a high-order polynomial function carries some risks. It may result in bends in the depth-age curve that do not seem justified by the radiocarbon dates, but are a mathematical artifact. Alternatively it may result in unjustified inversions in the depth-age relationship: younger sample ages lower in the section than older ones. This occurs especially when the dates are distributed unevenly over the pollen sequence, many together in one part of the pollen sequence and only a few in another (*e.g.* 4/Li, 23/Bö). A solution to this problem may be to choose a simpler polynomial function. However, frequently this puts us in a dilemma. A lower polynomial function may not seem to fit the dates closely enough (as assessed by visual inspection), whereas a higher polynomial function shows an inversion or an undesirable bend in the depth-age curve. There are two ways around this. One is to model independently different parts of the pollen sequence; this usually permits the use of a lower polynomial function. We did this in pollen sequence 17/Wb. The other is to abandon polynomial functions and resort to linear interpolation between dates.

We have said above that linear interpolation of sample ages between dates is the simplest model possible, but this refers to the mathematical side only. The resulting sediment-accumulation rates in these sites do not follow a simple pattern (see 2/O, 4/Li, 16/D, top part of 17/Wb, 20/Gr, 22/H, 23/Bö, and 25/Ba). The simplest pattern achieved is one resembling a sigmoid curve reminiscent of a polynomial function with 4 terms (20/Gr; 25/Ba); however, polynomial functions were unsatisfactory for these pollen sequences mostly because they resulted in inversions in sample ages. The shape of depth-age curves for the other five sites is more complex, to such a degree that polynomial functions were of no use. Summarizing, although we do not favour the method of linear interpolation, we frequently had no better alternative.

The criteria for selecting a depth-age model from several possibilities are subjective and remain somewhat ambiguous. An underlying idea has been that we should make a depth-age model that is independent of the original author(s) and evaluate the differences between the two chronologies. In case of large differences between ages of the same samples (say, 1 ka or more), the ideas of the original author(s) can be seriously considered, which may or may not lead to a

Fig. 4 : Average and median sediment-accumulation rates in relation to time.
Sediment-accumulation rates of all pollen diagrams are summarized for 0.25-ka age classes. Average resp. median sediment-accumulation rates are calculated for each site for each age class; the average resp. median value of these values is shown.

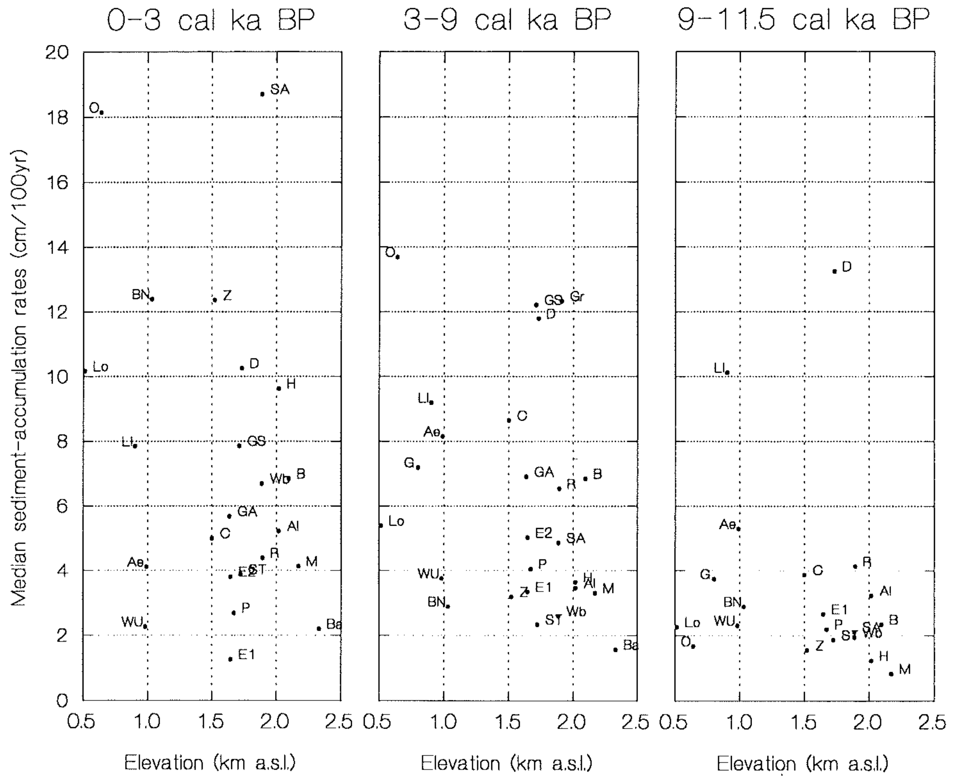


revision of the new chronology. It usually does not lead to a revision if the new chronology is based on better dating (more dates) than the original, as is frequently the case in this study. The strongest argument for adapting the new chronology is the inference of hiatuses in the sediment by the original author(s) based on pollen and/or lithology. In the remaining cases of serious conflicts between the two chronologies we tend to accept the new chronology based on radiocarbon dates rather than on biostratigraphical inferences.

Confidence intervals of sediment-accumulation rates

Sediment-accumulation rates with confidence intervals for all the pollen sequences are shown in Figure 3-1 to 3-25. Confidence intervals are often high if the depth-age model is based on linear interpolation of sample ages between dates, especially if the dates lie close together. The reason is that, using linear interpolation between dates, the age and confidence interval of each sample depends solely on the two dates bracketing the sample and not on any other date. This contrasts with a depth-age model based on a polynomial function, because that takes into account all dates at every sample level. Dates lying close together may have confidence intervals overlapping each other, which results in enormous confidence intervals of the sample ages between the dates; this is, for example, the case in two sections of pollen sequence 2/0 (Fig. 3-2). It is a characteristic, and may be considered as a disadvantage, of the use of linear interpolation between dates for a

Fig. 5 : Median sediment-accumulation rates in relation to elevation of sites.
Median sediment-accumulation rates are presented separately for the early, mid-, and late Holocene based on Fig. 3 (resp. 9-12, 3-7.5, and 0-2.5 cal ka BP (millennia before AD 1950)). Labels are site codes (cf. Table 1).



depth-age model that confidence intervals of sediment-accumulation rates increase with an increasing number of dates in the sequence.

Sediment type and accumulation rates

Sediment-accumulation rates increase at many sites around 8-9 cal ka BP and/or around 2-1 cal ka BP. Frequently the inferred increase is gradual, occasionally it is abrupt. The transition from lake sediment to peat coincides with a marked increase in four pollen sequences (7/BN, 9/Z, 22/H, 23/Bö), a weak or gradual increase in eight pollen sequences (2/O, 3/Gä, 10/GA, 13/P, 17/Wb, 18/SA, 21/Al, possibly 25/Ba that has no date at the sediment transition), approximately constant rates in five pollen sequences (4/Li, 8/C, 11/E1, 12/E2, 24/M), and a slight decrease in three pollen sequences (14/GS, 16/D, 19/R). The predominance of increasing sediment-accumulation rates during the transition from lake sediment to peat might indicate that peat usually accumulates faster than lake sediment.

Sediment-accumulation rates, sediment age, and elevation

We are using the term sediment here in a wide, unprecise sense to include both true sediments (deposited materials), sedentates (locally formed materials, such as peat), and mixed forms (*e.g.* gyttja). The net rate of sediment accumulation depends on site characteristics including geology, topography, climate, hydrology, and biology. These factors might correlate with simple factors known for all sites such as sediment age and site elevation. We explore here the relationships of sediment-accumulation rates with sediment age and elevation.

Figure 4 shows the relation between sediment age and average or median sediment-accumulation rates for all sites. Sediment-accumulation rates are low but increasing in the early Holocene (11.5-9 cal ka BP), intermediate during the long mid-Holocene period (9-3 cal ka BP), and somewhat higher in the last two to three millennia. The low early-Holocene rates of sediment accumulation suggest a low productivity of the lakes (which most sites were at that time, rather than mires).

The relationships between sediment-accumulation rates and site elevation are explored in Figure 5. The three periods discussed above (early Holocene 11.5-9 cal ka BP, mid-Holocene 9-3 cal ka BP, and late Holocene 3-0 cal ka BP) are presented separately. No clear trends can be observed for any of the time periods. The mechanisms behind sediment accumulation are complex, and their rates are clearly not predicted by elevation alone.

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