Skeletal growth history of modern corals in Sekisei Lagoon as a bio-indicator

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We collected 82 samples of *Porites* coral cores from Sekisei Lagoon, South Ryukyus in October and November, 2000, two years after the 1998 bleaching event worldwide. For measuring the growth rate of core samples, we present growth characteristics before and after the bleaching event. Results show that the growth rates in the north area are markedly lower than those in the south area. This implies that the stress in the north areas as evidenced by growth history of *Porites* was always stronger than that in the south areas.

Keywords : Coral band, Sekisei Lagoon, X-ray image, growth history

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1. Introduction

In the summer of 1998, corals throughout Okinawa were bleached, and those in Sekisei Lagoon, which has the largest coral reef in Japan, were no exception. Other bleaching events were also reported in the summer of 2001. Experts reported that coral reefs are in crisis[1].

Living corals are usually brown or dark in color. Their color is due to the presence of zooxanthellae that live symbiotically with reef-building coral polyps. Nutrients supplied by zooxanthellae enable the corals to grow and reproduce quickly enough to form reefs. Zooxanthellae provide the corals with food in the form of photosynthetic products. In turn, the corals provide protection and access to light for the zooxanthellae. However, in coral bleaching, coral colonies turn white due to the loss of zooxanthellae from polyps and exposure of their skeleton. The exact mechanism underlying coral bleaching is unknown[2]. However, some environmental factors, such as an increase in seawater temperature, diseases, a decrease in the amount of sunshine, exposure to UV, pollution and changes in salinity, are implied.

Fig. 1 X-ray photograph of collected *Porites lobata*.

Most corals form distinct annual growth bands similar to tree rings (Fig. 1) and environmental changes are reflected in their skeletons as they grow. The age and annual growth rate can easily be determined by counting the bands and measuring the annual growth increments, respectively. It should be possible to determine if there have, indeed, been significant changes in the growth rate during the past 50 or more years.

After the massive coral bleaching event in the summer of 1998, we started coral ecosystem monitoring that included three aspects, namely, coral cover survey, and measuring water current and water temperature at Sekisei Lagoon[3) 4)]. This monitoring shows that the bleaching damage was different at each point in the Lagoon. In particular, corals in the north areas such as 19E and St. 19 were extensively damaged. Based on this finding, coral core samples of *Porites* species were collected from 12 areas representing various environments within Sekisei Lagoon to analyze the changes in the coral growth. Then, the core samples were X-rayed for visible coral growth bands, and growth increments were measured to determine the growth rate of corals from each area. In this paper, we report the results of the basic study of coral growth rate in each study area.

The coral core sampling was carried out as a JAMSTEC's Project Research on "Elucidation of Mechanisms of Ocean Ecosystem Changes".

2. Sampling location and procedure

The 12 study areas, which we have been monitoring in Sekisei Lagoon since 1998, were selected as sample sources (Table 1, Fig. 2). Sekisei Lagoon is the biggest lagoon in Japan (25×20km) and is located between Ishigaki Island and Iriomote Island. Eighty-two core samples of *Porites* species were collected from Sekisei Lagoon, Okinawa on 7–12 October and 7–9 November 2000. Water depths in all areas varied from 1.8 to 15.9 m. By SCUBA diving, all the samples were obtained along the growth axis using a Micro Boring Machine[5] fitted with a drill bit of 2.4 and 3.0cm in diameter.

The geophysical locations of sampling areas were as follows:

- St. 19, St. 21, St. 26, 19E, KA and TE are located in the reef front.
- St. 6, St. 8, St. 12, AS, PA and TW are patch reefs[6].

The cored samples were cut along their growth axis

into three slabs (Fig. 3) to determine the number of polyps and coral bands, and for chemical analysis in the laboratory. One of the slabs for determing the number of coral bands was X-rayed using a SOFTEX CMB-2 and Fujifilm IX FR film. X-ray images revealed high- and low- density coral bands and one band pair represents one year's growth7). Annual growth increments were measured between the bottom of the high-density bands along the growth axis using Image J 1.19z (http://rsb.info.nih.gov/ij/). The annual growth increments were measured and the growth rate was graphed for each sample (Fig. 4); those for four samples (St. 8–9, St. 12–5, AS–3, AS–8) were not graphed because x-ray images are not clear. Further research such as elemental analysis should be carried out for the samples.

3. Results and discussion

For the mean growth history in each sampling area, the growth rate decreased in 1998 when coral bleaching occured and recovered the next year in St. 12, St. 8 and 19E. It decreased in 1999 and recovered the next year in St. 26, PA and TE. It did not decrease in 1998 and the next year in St. 21, KA and St. 6. It also decreased in 1998, and 1999 and 2000 in TW, AS, and St. 19. When the linear growth rates in all sampling areas were compared, corals from St. 26, St. 8, St. 21, KA, TW and AS always grew faster than those from 19E and St. 19, which showed a significantly low growth rate. In 19E and St. 19 (Okamoto, personal communication), high coral coverages in these areas were markedly decreased throughout the 1998 bleaching event. These

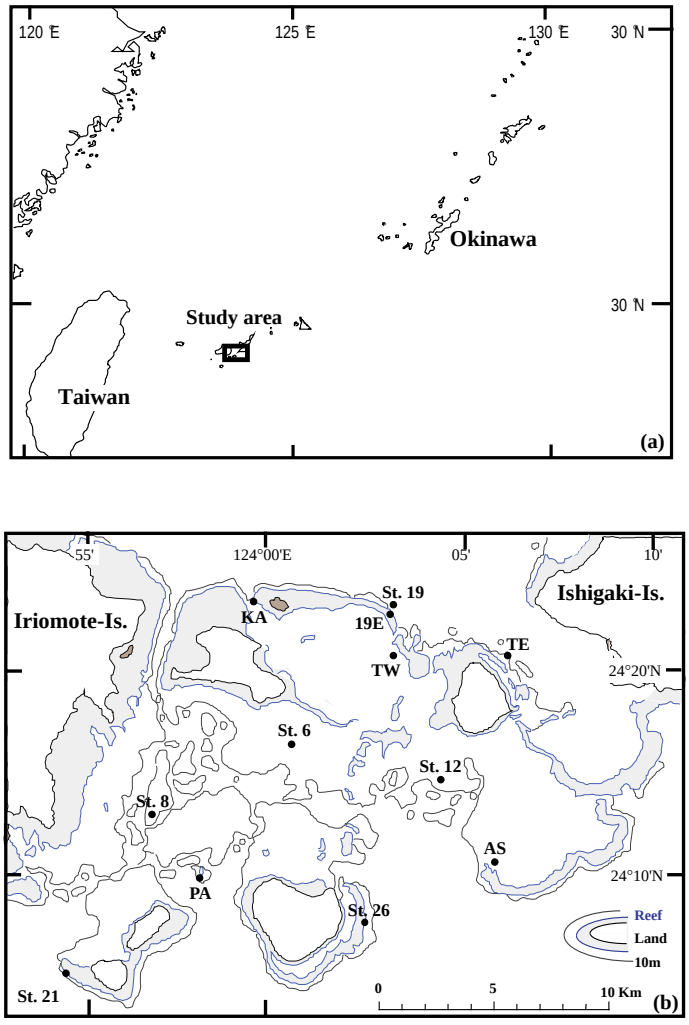

Fig. 2 Location map of the Sekisei Lagoon study area (a) and an enlarged view of the study areas in Sekisei Lagoon (b).

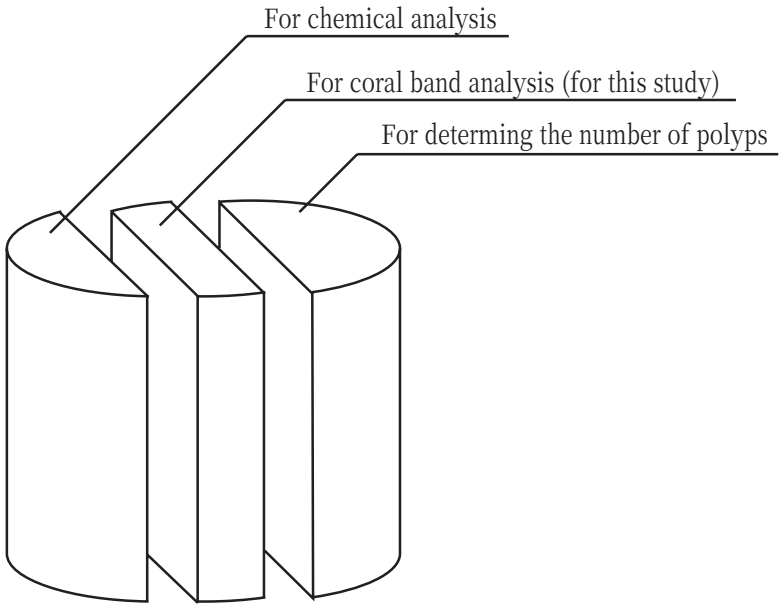

Fig. 3 Division of collected core samples.

results imply the direct relationship between coral growth rate and environmental conditions. It was also reported that the seawater temperature increased in the summer of 1998 and it occured coral bleaching[8]. The regional reconstruction of seawater temperature will be useful, and the coral skeleton is a good experimental tool because elemental contents in the coral skeleton indicate changes in seawater temperature.

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Table 1 Summary data from coral core samples

Sampling Site	Latitude	Longitude	Sample Number	Date	Coral Species	Modified Water Depth (m)	Colony Size (Length-Width-Height) (cm)
St.6	24° 18.246'N	124° 00.495'E	1	9.Oct.00	*Porites sp.*	3.9	19-18-24
			2	9.Oct.00	*P. lutea*	3.9	140-130-70
			3	9.Oct.00	*Porites sp.*	3.8	22-20-13
			4	9.Oct.00	*P. lutea*	3.8	25-24-18
			5	9.Oct.00	*Porites sp.*	3.8	95-80-55
			6	9.Oct.00	*Porites sp.*	3.8	22-20-16
			7	9.Oct.00	*P. lutea*	3.8	200-200-120
			8	9.Oct.00	*P. lutea*	3.7	19-18-16
			9	9.Oct.00	*Porites sp.*	3.7	23-22-17
St.8	24° 17.699'N	123° 56.956'E	1	8.Oct.00	*P. lobata*	13.0	95-75-55
			2	8.Oct.00	*P. lutea*	13.0	150-125-110
			3	8.Oct.00	*P. lutea*	13.0	80-70-45
			4	8.Oct.00	*P. lobata*	13.0	110-90-45
			5	8.Oct.00	*P. lobata*	13.2	60-55-30
			6	8.Oct.00	*P. lobata*	3.0	150-140-90
			7	8.Oct.00	*P. lobata*	3.0	130-130-90
			8	8.Oct.00	*Porites sp.*	3.0	38-30-20
			9	8.Oct.00	*Porites sp.*	3.0	24-24-20
St.12	24° 17.599'N	124° 04.679'E	1	7.Oct.00	*P. lutea*	10.2	45-55-38
			2	7.Oct.00	*P. lutea*	10.2	32-30-30
			3	7.Oct.00	*P. lobata*	11.6	29-24-27
			4	7.Oct.00	*P. lutea*	11.6	80-74-37
			5	8.Nov.00	*P. lobata*	15.9	100-85-45
			6	8.Nov.00	*P. lobata*	14.9	46-40-38
			7	8.Nov.00	*P. lobata*	14.4	55-70-35
			8	8.Nov.00	*P. lutea*	12.2	190-150-50
			9	8.Nov.00	*P. lutea*	4.6	120-50-50
St.19	24° 21.453'N	124° 02.947'E	1	7.Nov.00	*P. lutea*	14.6	155-110-55
			2	7.Nov.00	*P. lutea*	14.9	15-13-11
			3	7.Nov.00	*P. lobata*	14.6	26-21-14
			4	7.Nov.00	*P. lobata*	14.2	28-17-12
			5	7.Nov.00	*P. lobata*	14.2	50-35-10
St.21	24° 12.662'N	123° 54.708'E	1	8.Oct.00	*P. lutea*	3.9	42-38-25
			2	8.Oct.00	*P. lutea*	3.9	45-42-35
			3	8.Oct.00	*P. lutea*	3.6	28-22-20
			4	8.Oct.00	*P. lutea*	3.6	210-140-70
			5	8.Oct.00	*Porites sp.*	3.5	50-33-22
			6	8.Oct.00	*P. lutea*	3.2	85-60-45
			7	8.Oct.00	*P. lutea*	3.2	35-33-24
St.26	24° 14.034'N	124° 02.548'E	1	7.Oct.00	*P. lobata*	8.9	95-75-35
			2	7.Oct.00	*P. lobata*	8.9	120-95-35
			3	7.Oct.00	*P. lobata*	9.4	190-75-30
			4	7.Oct.00	*P. lobata*	10.1	200-170-50
			5	7.Oct.00	*P. lobata*	10.2	72-30-40
			6	7.Oct.00	*P. lobata*	10.0	116-95-40
19E	24° 21.165'N	124° 03.152'E	1	11.Oct.00	*P. lobata*	15.0	150-140-80
			2	11.Oct.00	*P. lutea*	14.8	24-17-9
			3	11.Oct.00	*Porites sp.*	15.1	30-25-7
			4	11.Oct.00	*P. lutea*	14.3	24-20-17
			5	11.Oct.00	*P. lutea*	14.4	22-16-12

(Continued)

Sampling Site	Latitude	Longitude	Sample Number	Date	Coral Species	Modified Water Depth (m)	Colony Size (Length-Width-Height) (cm)
AS	24° 15.744'N	124° 05.854'E	1	10.Oct.00	*P. lobata*	4.7	50-45-40
			2	10.Oct.00	*Porites sp.*	2.3	19-18-13
			3	10.Oct.00	*P. lutea*	4.4	30-25-20
			4	10.Oct.00	*P. lobata*	1.8	55-45-50
			5	10.Oct.00	*P. lutea*	2.8	45-45-57
			6	10.Oct.00	*P. lobata*	2.8	110-75-90
			7	10.Oct.00	*P. lutea*	3.3	35-28-29
			8	10.Oct.00	*P. lutea*	3.3	20-20-25
			9	12.Oct.00	*P. lutea*	12.1	160-120-145
			10	12.Oct.00	*P. lutea*	10.7	250-150-110
			11	12.Oct.00	*P. lutea*	10.4	25-22-19
KA	24° 21.498'N	123° 59.438'E	1	9.Oct.00	*P. lobata*	9.8	65-68-21
			2	9.Oct.00	*P. lobata*	10.7	120-90-45
			3	9.Oct.00	*P. lobata*	11.1	66-43-36
			4	9.Oct.00	*P. lobata*	9.9	200-170-150
			5	9.Oct.00	*P. lobata*	7.6	140-130-80
			6	9.Oct.00	*P. lobata*	7.9	100-80-80
PA	24° 15.026'N	123° 58.175'E	1	11.Oct.00	*P. lutea*	5.8	115-110-85
			2	11.Oct.00	*P. lutea*	8.5	29-20-12
			3	11.Oct.00	*Porites sp.*	6.3	19-18-20
			4	11.Oct.00	*P. lutea*	7.2	25-25-6
			5	11.Oct.00	*P. lutar*	7.8	20-15-15
			6	11.Oct.00	*P. lutea*	9.0	20-12-15
			7	11.Oct.00	*P. lutea*	9.0	22-21-11
TE	24° 20.343'N	124° 06.057'E	1	12.Oct.00	*P. lutea*	12.4	105-85-50
			2	12.Oct.00	*P. lutea*	12.5	110-100-40
			3	12.Oct.00	*P. lutea*	12.7	150-130-80
			4	12.Oct.00	*P. lutea*	13.1	120-60-75
			5	12.Oct.00	*P. lutea*	13.1	40-35-28
TW	24° 20.279'N	124° 03.042'E	1	10.Oct.00	*P. lobata*	6.2	300-250-150
			2	10.Oct.00	*P. lobata*	4.9	25-25-20
			3	10.Oct.00	*P. lobata*	5.9	25-23-25

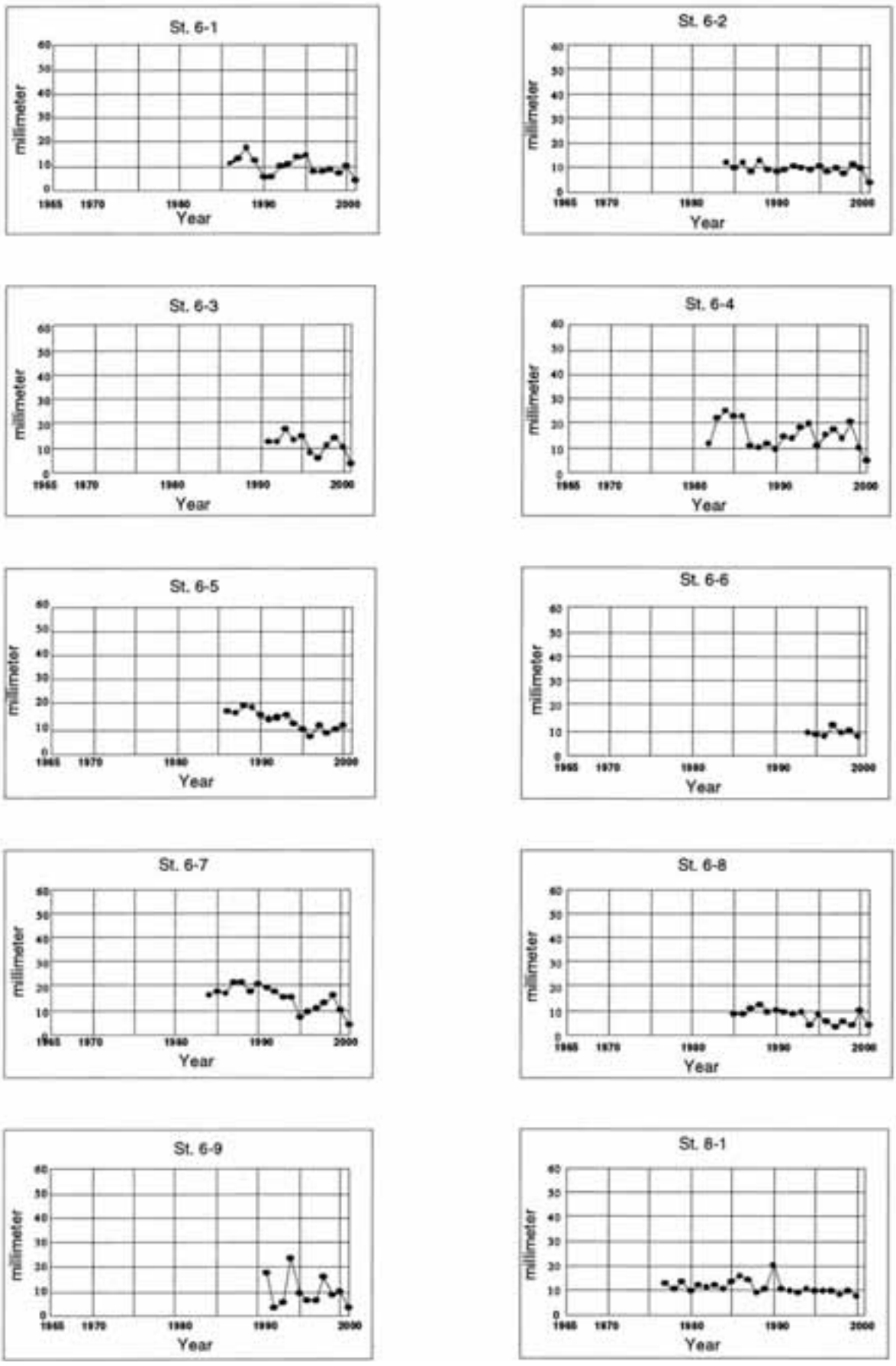
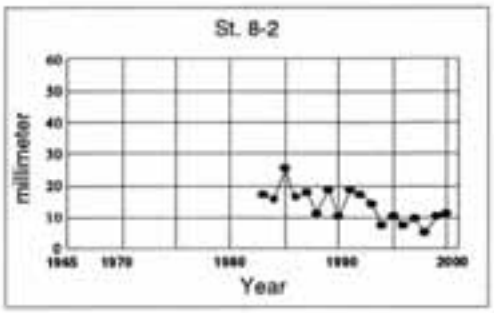


Fig. 4　Growth history of *Porites* species for each samples.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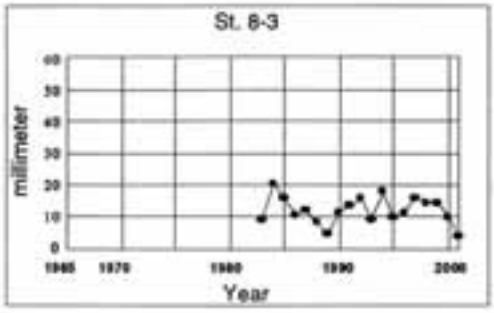
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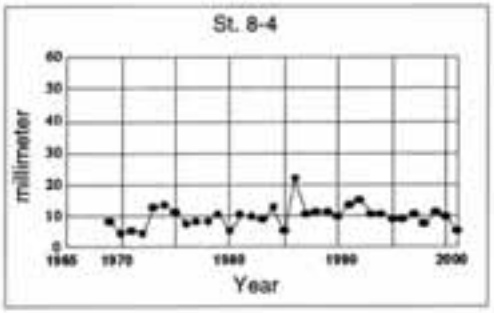
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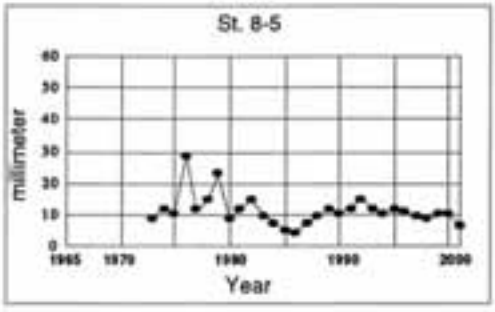
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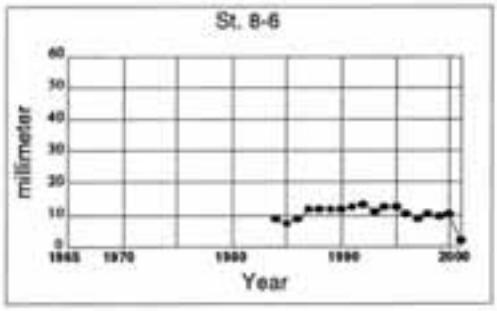
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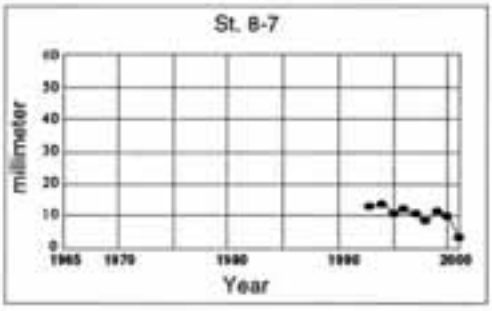
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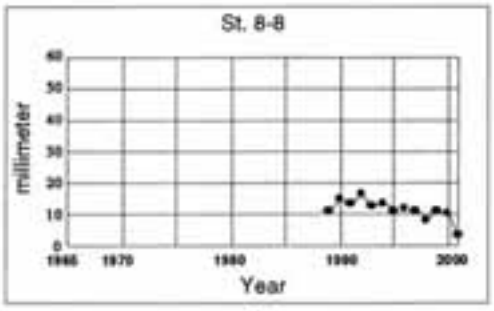
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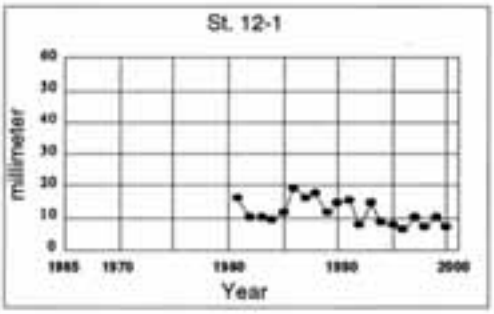
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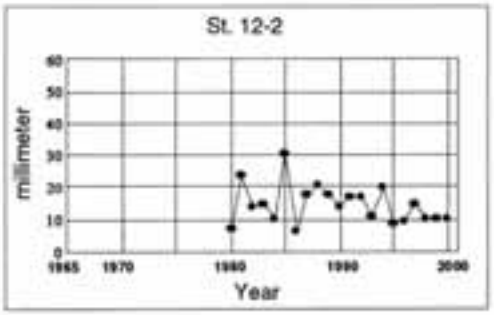
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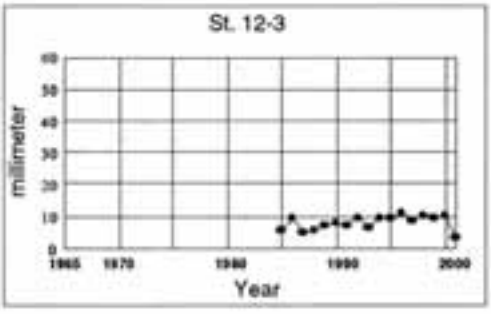
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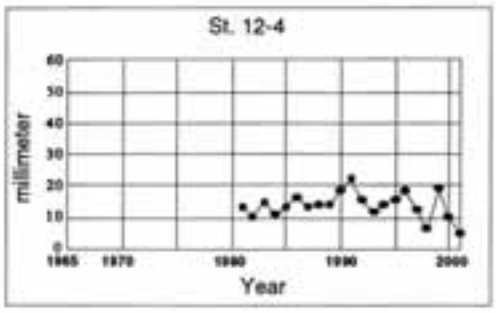
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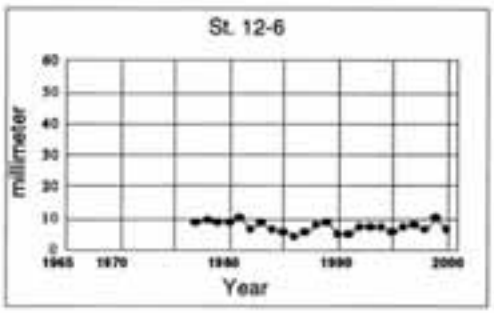
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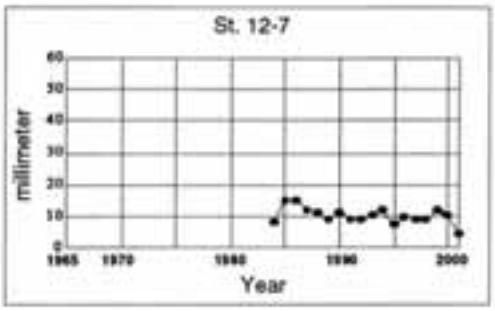
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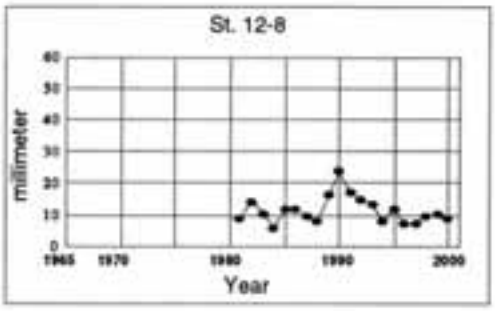
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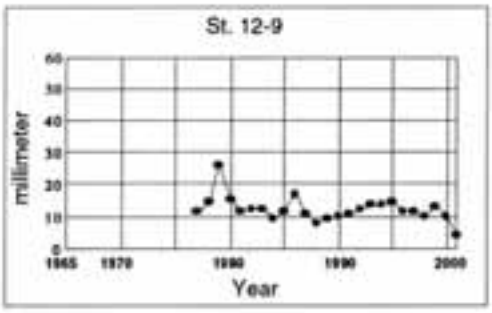
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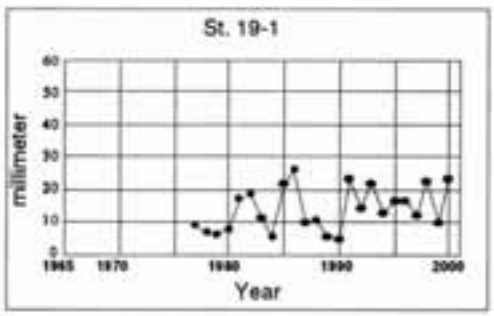
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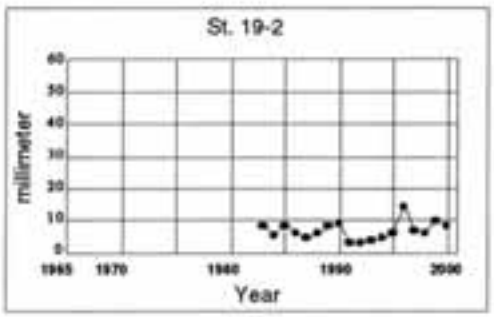
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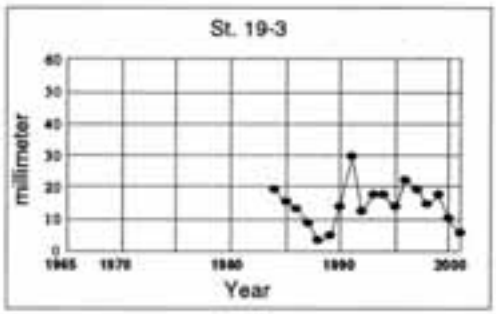
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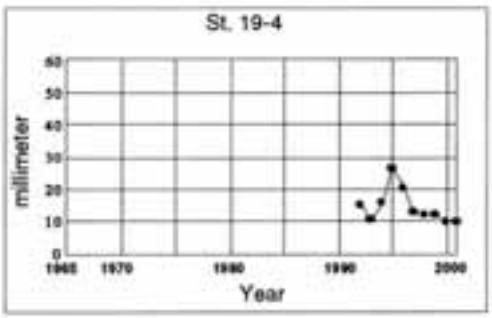
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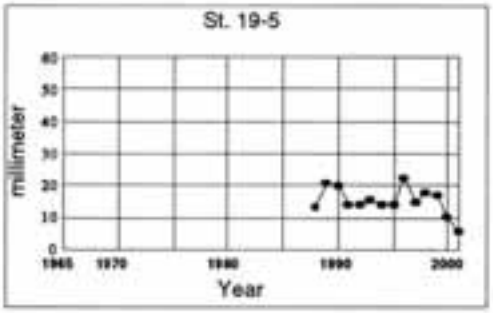
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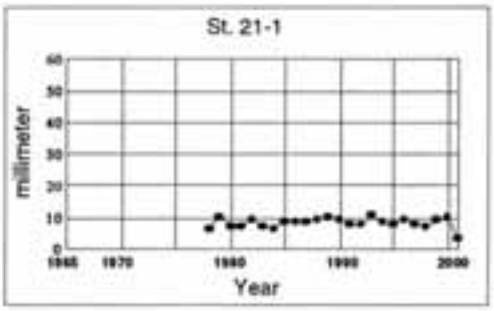
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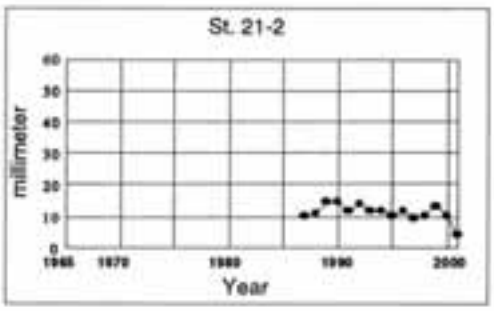
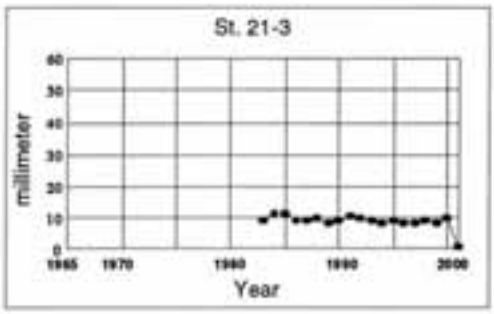
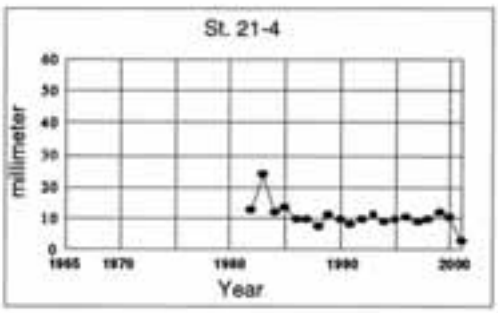
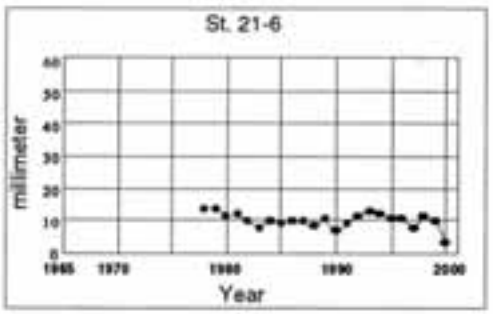
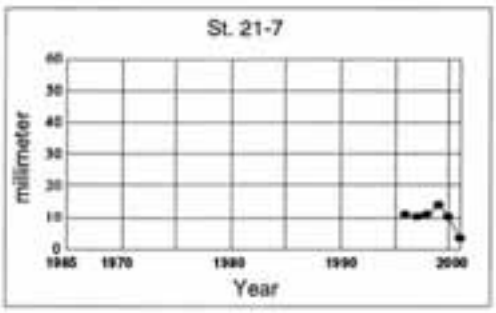

St. 21-2
millimeter
Year

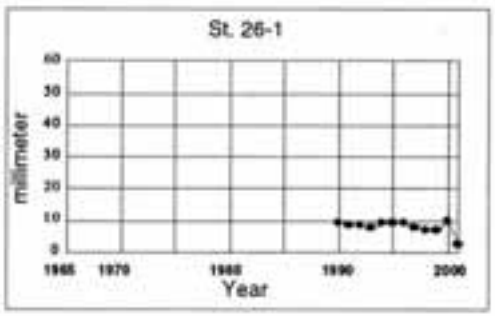

St. 21-3
millimeter
Year

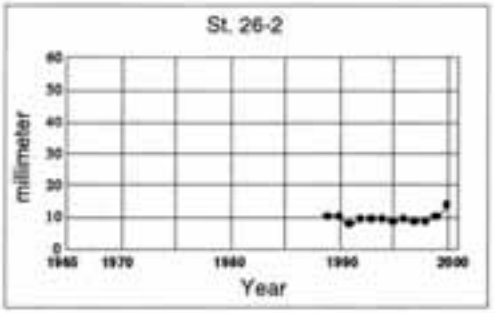

St. 21-4
millimeter
Year


St. 21-5
millimeter
Year


St. 21-6
millimeter
Year


St. 21-7
millimeter
Year


St. 26-1
millimeter
Year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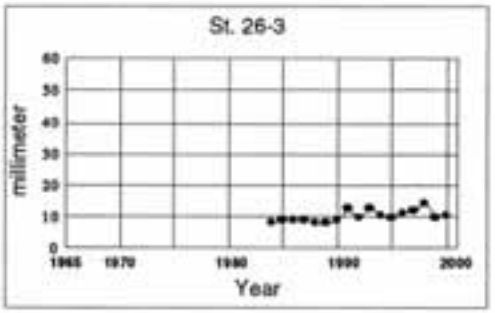
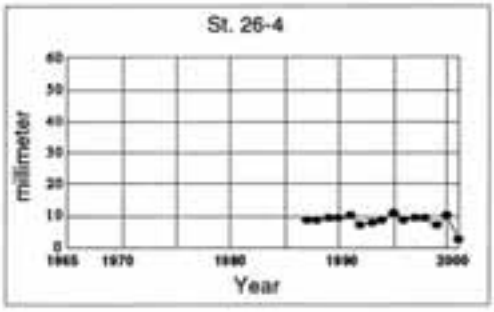

St. 26-3
millimeter
Year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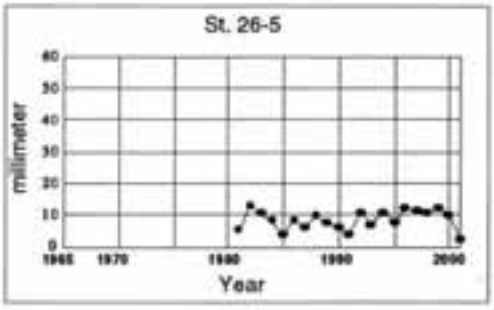
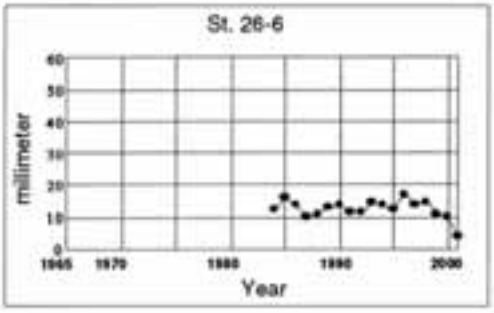
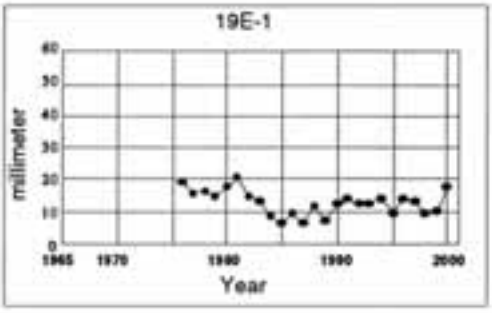
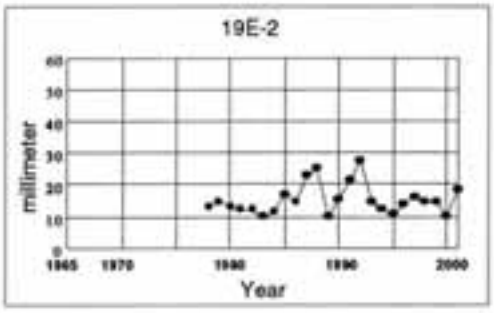
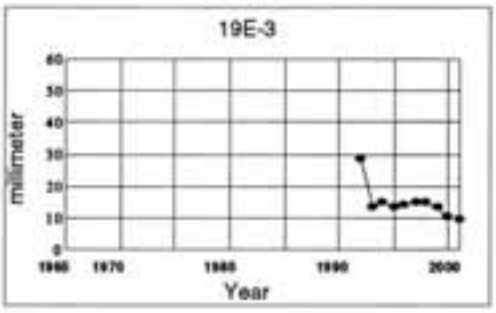
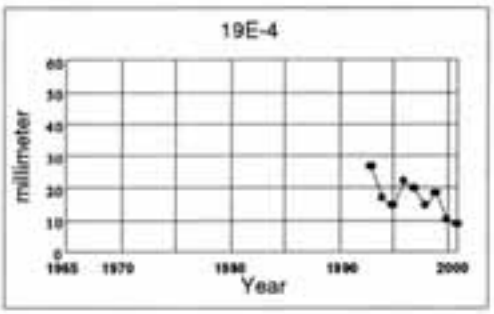

St. 26-5
millimeter
Year

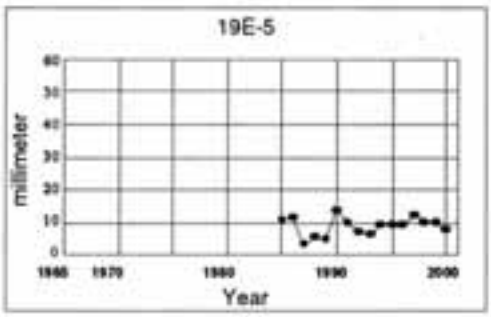

St. 26-6
millimeter
Year

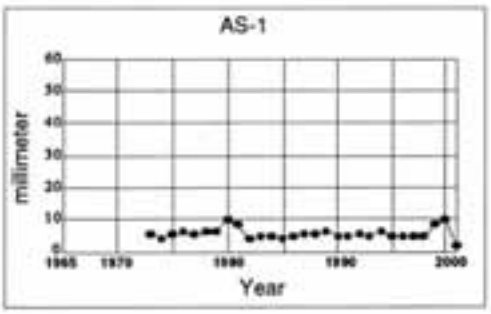

19E-1
millimeter
Year

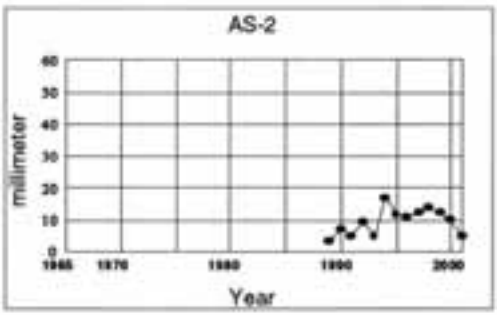

19E-2
millimeter
Year

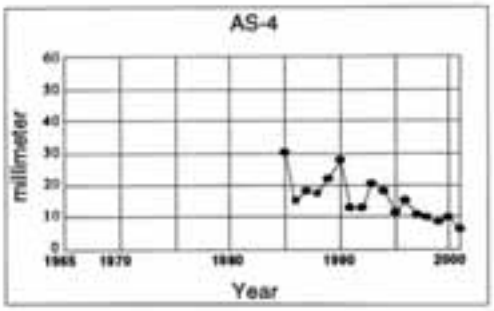

19E-3
millimeter
Year

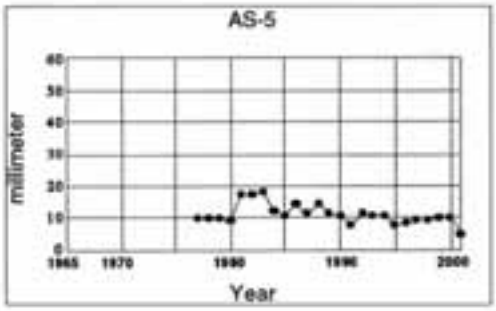

19E-4
millimeter
Year


19E-5
millimeter
Year


AS-1
millimeter
Year


AS-2
millimeter
Year


AS-4
millimeter
Year


AS-5
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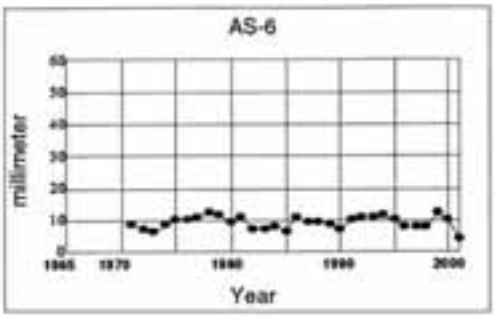
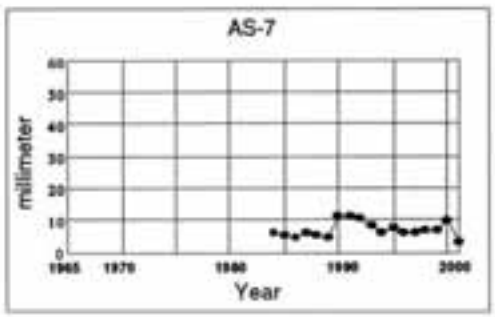
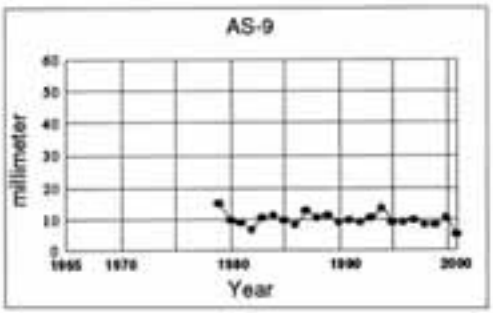
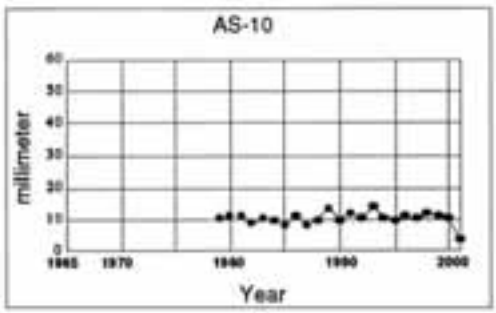
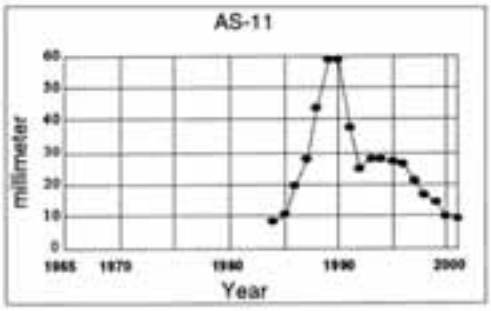
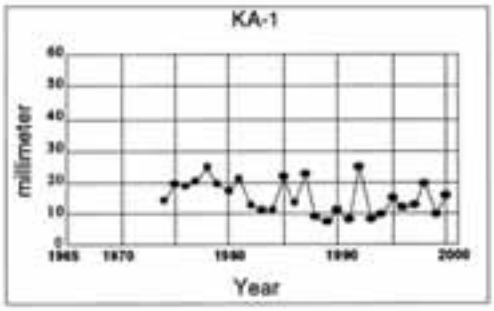

AS-6
millimeter
Year

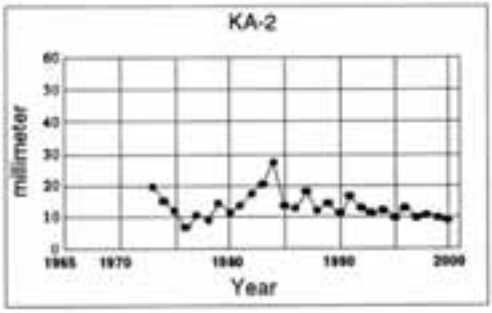

AS-7
millimeter
Year

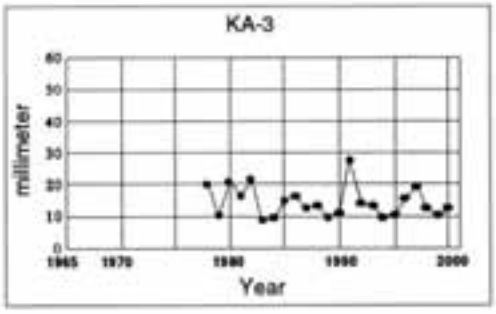

AS-9
millimeter
Year

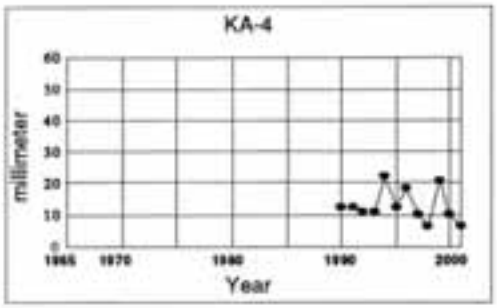

AS-10
millimeter
Year

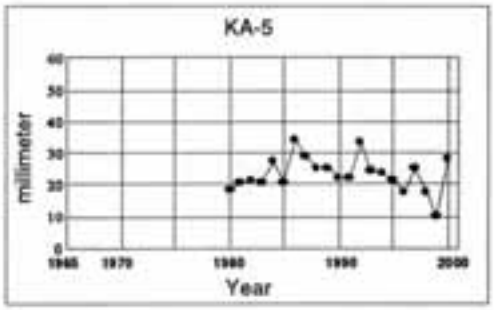

AS-11
millimeter
Year

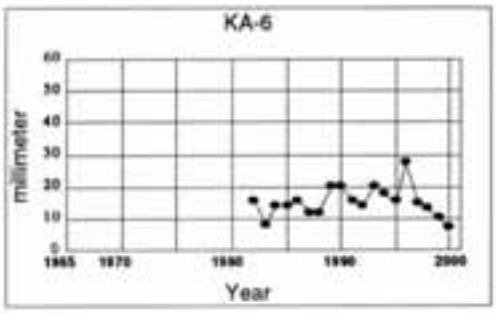

KA-1
millimeter
Year

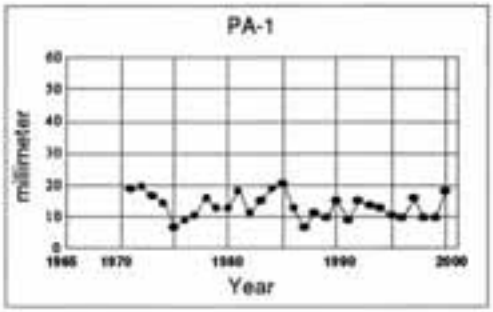

KA-2
millimeter
Year

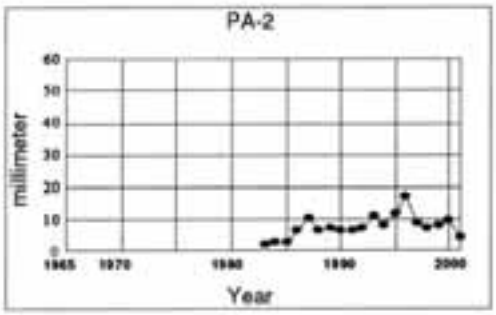

KA-3
millimeter
Year

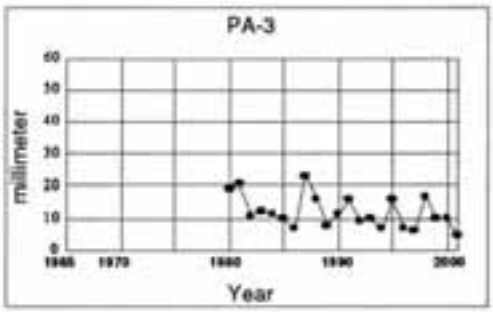

KA-4
millimeter
Year


KA-5
millimeter
Year


KA-6
millimeter
Year


PA-1
millimeter
Year


PA-2
millimeter
Year


PA-3
millimeter
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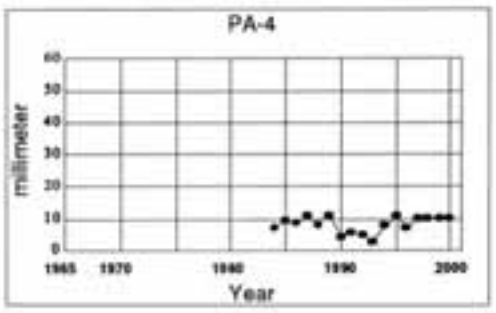
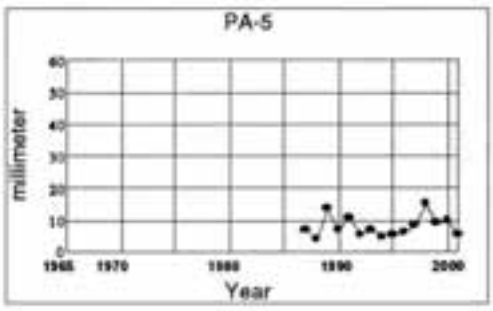

PA-4
millimeter
Year


PA-5
millimeter
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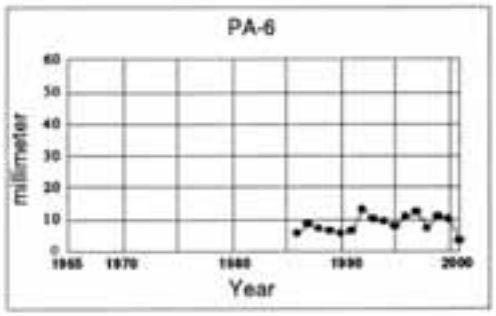
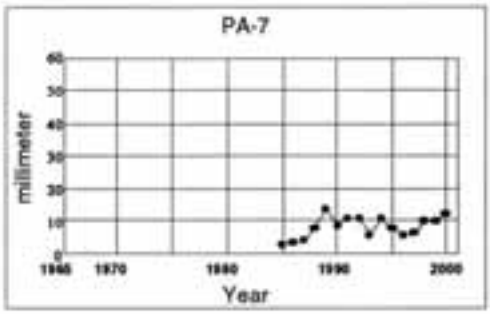
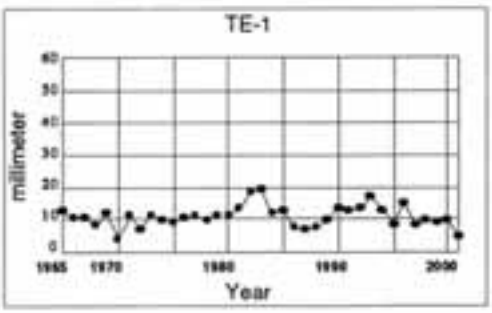
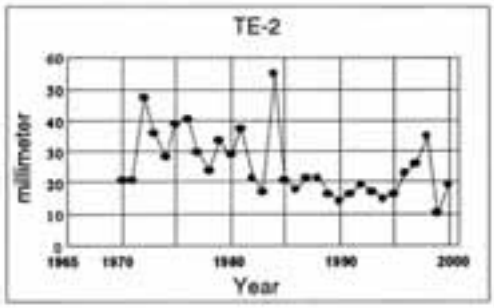
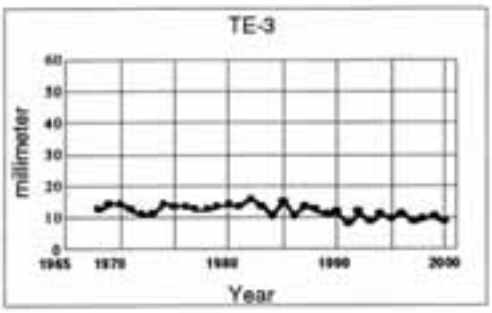
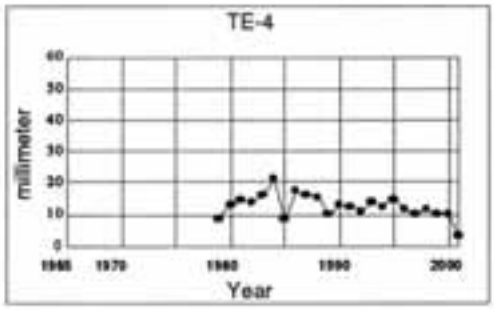

PA-6
millimeter
Year


PA-7
millimeter
Year


TE-1
millimeter
Year


TE-2
millimeter
Year


TE-3
millimeter
Year


TE-4
millimeter
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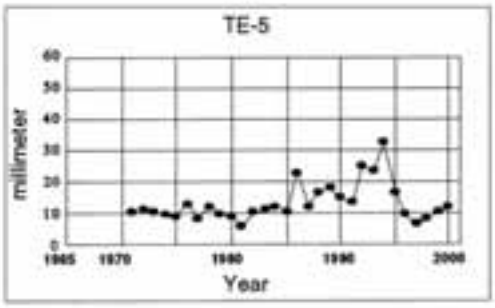
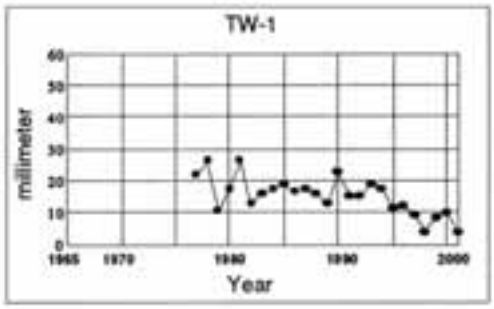
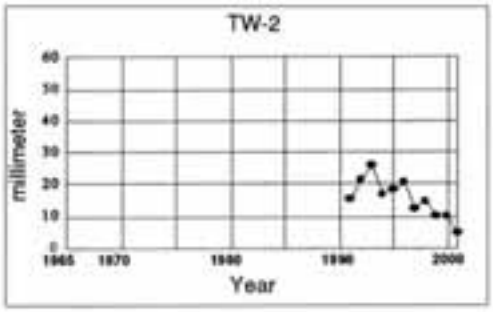
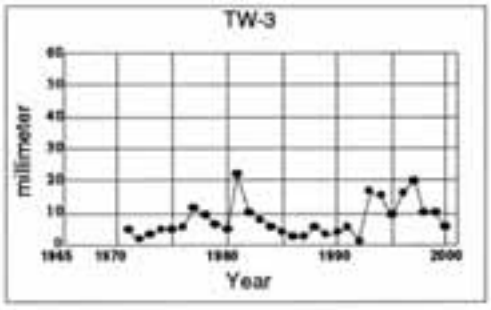

TE-5
millimeter
Year


TW-1
millimeter
Year


TW-2
millimeter
Year


TW-3
millimeter
Year