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A 5000-Year Pollen Record From Chitsai Lake, Central Taiwan

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ABSTRACT

A 3.5 m core taken from Chitsai Lake (altitude 2890 m) of central Taiwan shows the vegetational and environmental changes in a *Tsuga* forest since 5000 yr BP. During about 5300-4840 yr BP (Zone 4), the *Tsuga* forest experienced a clear fluctuation toward a *Tsuga-Cyclobalanopsis* mixed forest. The high percentages of *Cyclobalanopsis* in the lower half of this zone (Subzone 4b) indicate the last episode of the mid Holocene warm interval. *Tsuga* forest was well established in the later half of this zone. The extremely abundant spores as well as the finest sediments together indicate high lake level and moist climatic conditions. Between about 4840 and 3730 yr BP (Zone 3), a warmer episode occurred in which *Cyclobalanopsis* increased slightly compared with Subzone 4a. Following this, during about 3730-2030 yr BP (Zone 2), the relatively high percentages of *Abies*, Ericaceae and *Tsuga* as well as lower percentages of *Alnus* and *Pinus* indicate cooler but stable environmental conditions. Zone 1 represents vegetational changes during the last 2000 years. The increase in *Cyclobalanopsis* indicates warmer conditions than before. The remarkable decline of *Tsuga* and Ericaceae accompanying the increase in the secondary forest elements such as *Alnus* and *Pinus* may indicate a change in environment. The larger grain size of silt in Zone 1 than in Zone 4, a higher erosion which may be due to stronger precipitation seasonality in a warmer climate. The upper 15 cm shows rapid increase in secondary forest elements such as *Pinus* and *Alnus*. Whether it is related to the increasing atmosphere CO_2 is worthy of further investigation.

(Key words: Pollen analysis, Alpine lake, Central Taiwan)

1. INTRODUCTION

Over the last decade, there has been an increasing interest in understanding the global climatic changes. An alpine lake which is immune from anthropogenic influence would be an ideal site to provide proxy records for natural climatic changes. Located at an altitude of 2890 m above mean sea level in the Central Range of central Taiwan (Lat. 23° 45' 10"

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N and Long. 121° 14' 10" E) (Figure 1), Chitsai Lake is topographically open with an area of 2.2 ha. The peat-bearing, 3.5 m-thick sediment taken by hand auger is suitable for C^{14} dating and palynological study. There have been several pollen diagrams illustrating the pollen stratigraphic changes in lake sediments (Tsukada, 1967; Huang and Huang, 1977a; 1977b) and fluvial -lacustrine sediments (Chen and Liew, 1990) as useful indicators for the late Pleistocene paleoenvironment of Taiwan. Yet, high-resolution records for the past several thousand years are badly needed to differentiate between natural variations and those attributed to human impact. Here we report a high-resolution, detailed pollen record of the past 5000 years obtained from Chitsai Lake. The modern vegetation around this lake now belongs to the *Tsuga-Picea* Zone of the mountain vegetation (2500-3100 m in altitude), but down core variation in pollen should reflect past changes resulting from possible vertical displacements of vegetation during the last 5000 years. Samples were taken at 3 cm interval to achieve a temporal resolution of approximately 30-50 years.

An influential framework of Holocene subdivision in Europe is the Blyt-Sernander model which is originally based on peat stratigraphy and fitted by the following pollen works (Roberts, 1989). It shows the periods of Pre-Boreal (10000-9500 yr BP); Boreal (9500-7000 yr BP); Atlantic (7000-5000 yr BP); Sub-Boreal (5000-2500 yr BP) and Sub-Atlantic (2500 yr BP to present). But it has become clear that Holocene vegetational changes were time-transgressional (Wendland and Bryson, 1974). Thus, the observed data from each part of the world should be established. In Taiwan, an available pollen diagram from Taipei Basin (Chen and Liew, 1990) shows warmer conditions of middle Holocene at approximately 9000-6000 yr BP and cooler conditions there after. But further interpretation is impossible due to inadequate age control in that study, especially the recent half of the Holocene. This study may provide the possible climatic changes of this stage.

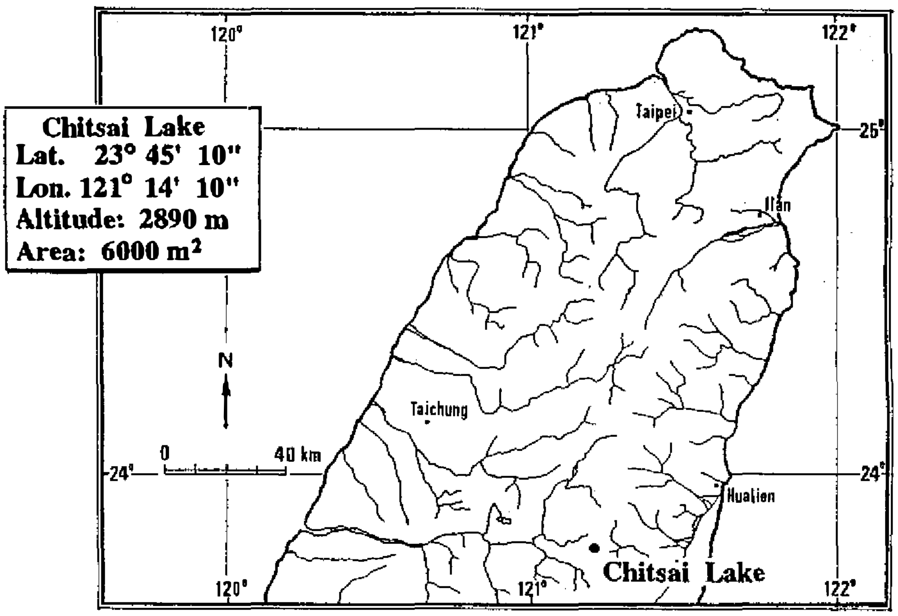

Fig. 1. The location of Chitsai Lake.

2. GENERAL DESCRIPTION OF THE STUDY SITE

This lake is surrounded by schists of the metamorphic belt of the Central Range. It is actually composed of two lakes: a big one (2 ha) and a small one (6000 m^2) about 60 m apart. A 3.5 m core was taken from the small one which has gradually desiccated recently. The vegetation in the Central Range of central Taiwan has been divided into the following zones along altitude by Su (1984),

Ficus-Machilus Zone (below altitude 500 m; 23-26 OC)
Machilus-Castanopsis Zone (500-1500 m;17-23 OC)
Lower Quercus Zone 1500-2000 m;14-17 OC)
Upper Quercus Zone (2000-2500 m; 14-11 OC)
Tsuga-Picea Zone (2500-3100 m; 8-11 OC)
Abies-Zone (3100-3700 m; 5-8 OC)

According to the lake's altitude, the study site is within the *Tsuga-Picea* vegetation zone. It has been documented (Su, 1984) that in the mountain area of central Taiwan, pure stands of *Abies* descend downward to about 3100 m and merge into the *Tsuga* forests. In the *Tsuga-Picea* zone, the upper montane coniferous forest is largely represented by the forest of *Tsuga chinensis.* Pure stands of *Tsuga* are very common while *Picea morrisonicola* are not frequent. They can grow at lower elevations but are mixed with other conifers and hardwoods. In the Central Range at about 1500-2500 m the broad leaved forest is dominated by the forest with an association with oaks. However, the evergreen oaks have been named under genus *Cyclobalanopsis.* The *Quercus* zone, is divided into the upper and lower belts based on tree composition and ground vegetation types. In the upper belt, the dominant trees are *Cyclobalanopsis morii*; *Cyclobalanopsis stenophylloides, Trochodendron aralioides* and *Castanopsis carlesii*; the ground vegetation is characterized by large colony of *Plagiogyria glauca philippinensis* and /or *Yushania niitakayamensis.* The lower belt is dominated by *Cyclobalanopsis longinux* and *Cyclobalanopsis gilva,* while the ground flora is rich in *Dryopteris, Arachniodes, Selaginella* and *Monachosorum.* At the submontane zone below 1500 m, the vegetation is Laurel-oak forests. Well drained upper slopes are dominated by *Castanopsis* whereas middle or lower slopes are characterized by *Machilus.*

The extant vegetation has been disturbed by fires during the past several decades. Thus, around the lake, a mixed forest of *Pinus* and other small trees indicates a secondary succession after fire. *Tsuga chinensis, Pinus, Juniperus formosana, Rhododendron* are common in moderate relief area. *Rubus hirsutopungens, Osmanthus heterophyllus,* and *Ranunculus matsudai* are the low plants (Hsu and Chen, 1992). *Yushania niitakayamensis* is widely distributed. Gramineae or Poaceae prevail including *Deschampsia caespitosa, Deschampsia flexuosa, Miscanthus flavidus; Yushania niitakayamensis* in which the *Yushania niitakayamensis* is most common. In addition, some aged *Tsuga* and *Pinus* are also present among the Poaceae.

3. METHOD

The upper (0-100 cm) and the lower parts (317-350 cm) of the core consist of silt while the middle part (100-317 cm) is peat (Figure 2). In addition to pollen and algae, size analysis of peat-free sediments is carried out . Extraction of pollen fossil of most samples follows the standard method, except that HF is added for the lower clay. Calibrated C^{14} ages in depths 312-317 cm; 220-230 cm; 170 cm and 35 cm are 4840$\pm$50, 3467$\pm$40; 2763$\pm$60 and

946±90 yr BP (Figure 2). The core thus represents the last 5000 years record. This interval records the vegetational changes since the beginning of the cooling phase during the late-Holocene.

4. RESULTS OF POLLEN ANALYSIS

At least 500 grains of pollen fossil are counted for each sample. Pollen percentages were calculated on the basis of a pollen sum including all pollen grains, while percentages of spores were based on the sum of all pollen and spores. Ratios of pollen to spore are also tabulated. Based on the variation patterns of the main taxa, the following zones and subzones are delineated from the bottom upwards (Figure 2):

4.1 Zone 4 (about 5300-4840 yr BP)

This zone is defined by the relatively low percentages of *Pinus* (<5%) and the high frequences of spores (>25%, occasionally even >50%). *Cyclobalanopsis* and *Tsuga* fluctuate abruptly. *Ilex* is present. It is further divided into 2 subzones.

4.1.1 Subzone 4b: 348-337cm

This subzone marks a dramatic change in pollen assemblage: *Cyclobalanopsis* increases to higher than 10%, showing a clear contrast to the other part of the pollen sequence. *Tsuga* is between 40-80%. Other elements are *Alnus* (10-20%), *Polygonum*, and Gramineae.

4.1.2 Subzone 4a: 337-319 cm

This subzone differs from Subzone 4b in the abrupt increase of *Tsuga* (up to 60%). *Cyclobalanopsis* decreases to less than 10% and *Polygonum* to less than 5%. *Pinus* remains low.(<5%).

4.2 Zone 3 (316-251 cm; about 4840-3730 yr BP)

This zone is characterized by the association of *Pinus* (10-20%) and *Tsuga* (>30%). *Tsuga* is usually at 50% and *Cyclobalanopsis* is less than 10%. *Lithocarpus* exists. It differs from the previous zone (Zone 4) in the abrupt increase of *Pinus* and more stable values of *Cyclobalanopsis* and *Tsuga*. The decrease of spores is also clear. Based on changes in these genera, Zone 3 is divided into two subzones.

4.2.1 Subzone 3b: 316-289 cm

Pinus is higher than 10%. *Tsuga* is higher than 50% in most samples; *Alnus* is in the range of 6-12%. *Cyclobalanopsis* varies from 5-15%.

4.2.2 Subzone 3a: 284-251 cm

This subzone differs from Subzone 3b by the small increase in *Cyclobalanopsis* and small decrease in *Tsuga*.

Pinus is usually less than 10% and *Tsuga* is less than 40%. On the other hand, *Cyclobalanopsis* is more abundant than in the Subzone 3b. *Quercus* increases in this interval. Ericaceae begins to become an important element from here upward to Zone 2. *Artemisia* is higher than Subzone 3b. *Rubus* appears only in Zone 3 and 4.

4.3 Zone 2: (247-102 cm; about 3730-2030 yr BP)

Tsuga attains its peak again with a range of 42-70%. To the contrary, *Cyclobalanopsis* is usually at about 5% only. *Alnus* shows the same trend as *Cyclobalanopsis*. Although Ericaceae is less than 5%, but are visible frequently. *Pinus* is at about 15% and like *Tsuga*, occurs at stable frequencies. *Abies* is more abundant here than in any other zones. This zone differs from the previous zone in having relatively high and stable values of *Tsuga* and *Pinus* as well as relatively low values of *Cyclobalanopsis* and *Alnus*.

4.4 Zone 1: (102 -0 cm ; about 2030 yr BP to the present)

This zone is characterized by a decrease of *Tsuga* to the lowest percentages (5-10%) of the sequence. *Abies* is also decreased except in samples at 3 and 4 cm. This zone is also characterized by the increase of *Pinus*, especially in the upper 15 cm, to about 30%. *Cyclobalanopsis* increases to higher than 10%, and *Alnus* to 15-30%. *Castanopsis* achieves its maximum value in the interval. This zone indicates the progressive change of vegetation to the present condition in which *Pinus*, *Alnus* and *Cyclobalanopsis* increase whereas *Tsuga* and Ericaceae decrease. The increasing trend of *Pinus*, *Alnus* and the decreasing trend of *Tsuga* are remarkable in the recent several hundred years (about the top 15 cm).

5. INTERPRETATION OF POLLEN DIAGRAM

Based on the C^{14} dates, this sequence records the stage after the warm phase of the middle Holocene. The lowest part of the pollen sequence represented by Subzone 4b shows fluctuation between *Tsuga* forest and the *Cyclobalanopsis-Tsuga* mixed forest. The boundary between Subzones 4b and 4a indicates a vertical depression of forests belts which might respond to climatic cooling after the middle Holocene fluctuations occur abruptly. Gleicheniaceae, *Davallia*, and other monolete spores are the most common even exceeding the total number of pollen in this zone. The great abundance of spores indicates moist environmental conditions.

After the establishment of pure *Tsuga* forest in Subzone 4a, *Cyclobalanopsis* increased again in Zone 3 although still less frequent than Subzone 4b. *Quercus* and Ericaceae also increased. The abrupt increase of *Pinus* in the beginning of Zone 3 indicates vegetational change in the area surrounding the *Tsuga* forest. In Subzone 3a, *Cyclobalanopsis* increased slightly relative to Subzone 3b, while *Pinus* and *Tsuga*, decreased slightly. This indicates Subzone 3a may be slightly warmer than 3b, although not as warm as Subzone 4b. The existence of *Castanopsis* is consistent with this interpretation. The appearance of *Artemisia* in Subzone 3a probably indicates a less humid condition too.

Zone 2 represents a relatively stable interval of *Tsuga* forest in which *Tsuga* and *Pinus* reach their maximum values whereas *Cyclobalanopsis* is at minimum values. *Liquidambar* occurs consistently. This indicates a relatively dry and cool interval. The beginning of Zone 2 at about 3700 yr BP is consistent in time with climatic cooling documented from the Yangtze River delta (Liu *et al.*,1992). It is worth noting that *Chenopodium* and Compositae are only found in Zones 2 and 3.

Following the relatively cool stage of Zone 2, Zone 1 witnesses a remarkable change of the forest in the last 2000 years during which warmer conditions occurred again. This zone clearly shows a decrease in *Tsuga* and Ericaceae, and an increase in *Cyclobalanopsis*, *Castanopsis* and pioneer forest elements such as *Alnus* and *Pinus*. In the middle of this zone, *Castanopsis* reached its highest percentages which may correspond to the Medieval Warm Period of Europe. However, a cool phase might have resumed at the 3-4 cm levels as indicated by the relatively high abundance of *Abies* and lower amounts of *Castanopsis*.

6. RESULTS OF GRAIN SIZE ANALYSIS AND ALGAE STUDY

Grain size analysis of the clastic sediments are shown in Table 1. In the lower part, the values of grain size are small (6.16-18.19 μ) especially in the interval below 3.29 m (Zone 4) where grain size is smaller than 10 μ. The maximum grain size (48.34 μ) occurs at the level near 1.00 m where the lithology gradually changes from peat to silt upward.

Preliminary study of algae by Dr. J. C. Wu of the Academica Sinica has shows that algae are confined to levels above 0.69 m and all of them belong to the acidic type.

7. DISCUSSION

7.1 On the Paleoclimatic Conditions of Zone 4

Zone 4 is characterized by the extremely high abundance of spores which even exceeds the total abundance of pollen. This is a common phenomenon observed at certain Holocene horizons in northern and central Taiwan (Chen and Liew, 1990; Huang and Huang, 1977). The grain size of silt sediments in the lower part of the sequence (Zone 4) is finer than the silt in the upper part (Zone 1). This may indicate higher lake level and more active chemical weathering for Zone 4. The abundance of spores in this interval may indicate moist conditions. Thus, the climatic conditions might be moist and warm during the time of Subzone 4b. A few recent studies have indicated that during the Holocene there were several episodes of high precipitation (Wang, 1985; Hsieh *et al.*, 1994). One of them occurred at about 5000 yr BP Ka (An, 1993). A warm, wet mid-Holocene has also been documented extensively in the pollen records of eastern China (Liu, 1988). The humidity of Zone 4 is probably the tail-end of this event.

7.2 On the Regression of *Tsuga* Forest

One of the most remarkable changes in the pollen sequence is the progressive demise of the *Tsuga* forest from Zone 2 to Zone 1, especially in the uppermost 15 cm of Zone 1. Accompanying this is the increase of *Pinus, Alnus, Cyclobalanopsis, Castanopsis*, and spores. The increase of *Pinus, Alnus* and decrease of *Tsuga* indicate a more open forest than before. As aforementioned, Zone 1 is warmer than Zone 2 but whether it is also warmer than Zone 4 remains uncertain unless *Castanopsis* is determined to species level.

On ther other hand, Zone 1 has larger grain size than Zone 4, This is consistent with the more open forest in this stage. Two possibilities are considered for the change of grain size and pollen assemblages. The vegetational change could have been resulted from the changing soil conditions due to stronger erosion, which may be caused by a change in precipitation or seasonality. Alternatively, the forest change could have been caused by more frequent fires in this interval, in that case, there should be more charcoals in the corresponding levels. However, no remarkable charcoal peaks indicating fire events were found at the corresponding levels. Thus, climatic change perhaps involving increased precipitation seasonality seems to be a more likely explanation for the changing forests. The climatic condition of Zone 1

Table 1. Size analysis of peat-free sediments.

Depth (cm)	Arithm. mean diameter (u)	Geo. mean diameter (u)
001	19.16	12.66
005	14.37	10.22
008	16.09	11.36
011	15.35	10.42
014	16.42	11.64
017	19.27	12.30
024	19.16	13.23
039	21.90	15.41
042	19.23	14.53
045	18.05	12.80
048	18.59	12.82
052	18.52	13.05
054	19.69	13.81
057	21.53	14.24
060	23.27	14.28
063	25.84	17.43
066	24.49	17.20
069	20.01	12.86
072	23.16	15.68
075	20.80	13.56
078	25.54	17.03
081	24.48	16.24
084	24.33	15.43
087	22.15	15.43
090	24.54	16.43
093	19.62	12.74
096	30.08	16.54
099	38.90	24.14
100	48.34	26.98
107*	33.83	22.66
116*	36.39	25.01
126*	35.43	24.18
134*	29.90	20.63
140*	32.13	22.40
318	18.19	11.64
321	14.33	9.73
324	13.66	9.26
327	11.03	7.75
329	8.88	6.80
333	6.98	5.63
336	7.53	5.89
339	7.70	6.10
342	6.16	5.03
345	7.53	5.99
348	8.32	6.48

* : peaty mud

may be with stronger seasonality and/or uneven precipitation, resulting in the greater erosion. This in turn promotes the development of the pioneer plants such as *Alnus* and *Pinus*.

8. CONCLUSIONS

(1) The 5000 year pollen record from Chitsai Lake in central Taiwan shows the fluctuation and regression of a *Tsuga* forest. The *Tsuga* forest in Zone 4b experienced a dramatic fluctuation between pure *Tsuga* forest and mixed forest of *Tsuga* and *Cyclobalanopsis*. This perhaps is a characteristic of the onset of the cool phase after the mid Holocene warm stage. Following the *Tsuga* forest in Subzone 4a, Zone 3 is characterized by a small increase of *Cyclobalanopsis*, indicating conditions warmer than Subzone 4a. A relatively stable interval of the *Tsuga* forest is represented by Zone 2. This interval appears to be less warm and probably less humid than before. During the recent 2000 years (Zone 1), a warmer, more humid climate with increased seasonality is indicated by the pollen assemblages and the larger grain size of sediments. This probably led to the demise of *Tsuga* forest around the site.

(2) Based on the changing abundance of *Cyclobalanopsis* and *Castanopsis* (warm indicators) as well as *Abies* and *Tsuga* (cool indiactors), the inferred climatic cycles appears to parallel that documented in the historical records of China.

(3) Lake levels are inferred to be high in Zone 4, medium in Zone 1 and the low in Zone 2 and 3. Higher lake levels usually occurred during warmer stages.

(4) The uppermost 15 cm of Zone 1 shows the rapid increase of secondary forest elements such as *Pinus* and *Alnus* and the regression of *Tsuga* in recent centries. Whether this is related to the increased superposed effect of the increased CO_2 in atmosphere due to industrial activity needs to be further studied.

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