finds of pinewood fragments in sediment of the subsequent Older Dryas chronozone (GTO 301/89, Demske 1995). The appearance of *Typha latifolia* and *Cladium mariscus* in species-rich telmatophyte communities in Bølling suggests mean July temperatures of no less than 16ºC, and mean January temperatures no colder than -4ºC.

– The occurrence of pine and birch tree stands during the Older Dryas is confirmed by macrofossils. Presence of Characeae, of all three *Myriophyllum* species, and *Typha latifolia* seem to indicate thermic conditions close to or only slightly more severe than those during the Bølling, defined by mean July temperatures of at least 14–15ºC.

5. The climate of the descending part of the Younger Dryas

The two-step change of vegetation during the younger part of Younger Dryas starting from ca. 12,100 cal BP is most distinctly recorded in the diagram from G1/87 profile, but it is also evident in all other profiles discussed. Its first step between 12,100 and ca. 11,820 cal BP involving a change of proportions between *Juniperus* and *Betula* contributions to the plant cover is explained mostly in terms of changing humidity, with the temperatures being still low; the second step (ca. 11,820–11,540 cal BP) showing all evidence of the progressing reduction of heliophyte herb communities is assumed to indicate also the amelioration of thermic conditions. The explanation of such pattern of changes by a change of climate gets some support from the stable-isotope studies (Kuc et al., Chapter 7.6). The $\delta^{18}O$ curve, measured with a very fine time resolution in the central cores (G1/87, G2/87) reveals minimum values documenting the coldest phase between ca. 11,950 and 11,880 cal BP, preceded around 12,000 cal BP by a short oscillation towards warmer conditions. In the G1/90 core from the western deep the whole profile between ca. 12,040 and 11,880 cal BP evidences the Younger Dryas thermic minimum. The increase of $\delta^{18}O$ indicating some warming begins around 11,850–11,870 cal BP in the central and in western cores. In Tobyłka Bay its beginning is recorded some decades later, around 11,790 cal BP. Generally, both stable-isotope and vegetational change speak for the more humid though rather cold climate at the time between ca. 12,100–11,880(11,850) cal BP, followed by a distinct warming during at least the last ca. 300 yr of the Younger Dryas.

Similar trends in vegetational succession recorded in some Polish sites with the sufficiently developed YD sediments (e.g. Lake Łukcze – Bałaga 1990, Lake Mały Suszek – Miotk-Szpiganowicz 1992) seem to confirm generally the proposed scheme. The rise of temperature in the younger part of YD has been widely recognized in the different part of Europe (Pennington 1977, Lowe & Walker 1980, De Groot et al. 1989). The onset of climatic warming around 10,250 ^{14}C BP (= ca. 11,870–11,880 cal BP), suggested long ago by Scandinavian scientists for SE Sweden (see Berglund 1966), has been more recently recognized by change in beetle fauna as a warming around 10,500 ^{14}C BP (ca. 12,300 cal BP) with a response of terrestrial vegetation delayed by ca. 300 yr (Berglund et al. 1984). A similar time of ca. 10,500 ^{14}C BP (ca. 12,300 cal BP) for the Younger Dryas rise of temperature was concluded for The Netherlands from pollenanalytical data (Bohncke 1992), where it seems to have been also connected with the precipitation decline. Both dates are rather close to the first step of vegetational change at Lake Gościąż, with still low temperatures indicated by ^{18}O. A more detailed discussion would be possible with the support of isotope data from Sweden and Holland.

6. The rates of climatic and vegetational change at the Late-Glacial/Holocene transition

The rapidity of climatic change terminating the last glacial stage as measured by the change of $\delta^{18}O$ content in the Lake Gościąż sediments (Kuc et al., Chapter 7.6) shows a good consistency with the very fast rates of a few decades stated for the Greenland ice-cores (Dansgaard et al. 1989). The response of vegetation was clearly differentiated into several steps: the earliest reaction of aquatics and telmatophytes seems coincident with the very first beginning of the temperature rise or starting even a little earlier, suggesting a water-level lowering preceding slightly the thermic change. The open rather xeric herb/shrub vegetation retreated very quickly, and tall herbs and *Populus* spread correspondingly within less than 50 yr after the isotope boundary. However, the actual expansion of trees (mostly *Betula*) proceeded with the distinct time lag of 200–300 yr. The repetition of pollen analysis at this critical transitional profile section with a very fine time resolution is now in progress.

7.5. DEVELOPMENT OF THE LAKE GOŚCIĄŻ BIOTA DURING THE LATE-GLACIAL

7.5.1. YOUNGER DRYAS DIATOM ASSEMBLAGES OF LAKE GOŚCIĄŻ

Barbara Marciniak

Forty four samples coming from the lower part of the profile G1/87 from the central deep of Lake Gościąż (Fig. 7.26) have been analysed for diatom content (age 11,558–12,644 cal BP). As a result of qualitative analysis 183 diatom taxa belonging to 33 genera have been distinguished.

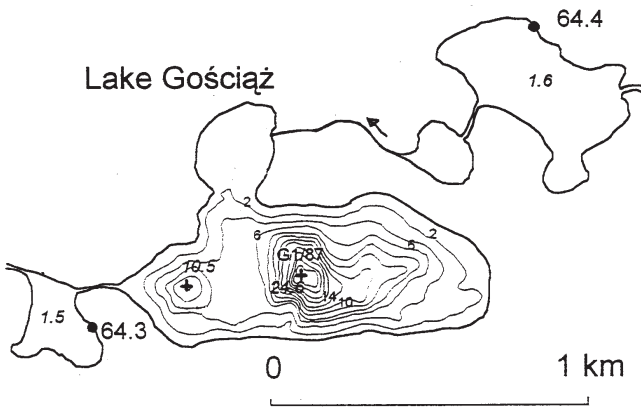Four local diatom-development phases have been dis-

Fig. 7.26. Location of the investigated profile G1/87 against the bathymetry of Lake Gościąż.

tinguished on the basis of changes of diatom assemblages and percentage frequency of the particular taxa (diatom phases GD-1 up to GD-4). Subphases within them point to lower-rank oscillations in the composition of microflora (Figs 7.27 and 7.28). The diatom phases distinguished can be mostly correlated with the three main pollen assemblage zones (PAZ) representing vegetational changes in the Younger Dryas and with phase II of the Cladocera development embracing three subphases a, b, c (Ralska-Jasiewiczowa et al. 1992, and Chapter 7.4, Ralska-Jasiewiczowa & van Geel 1993, Szeroczyńska 1993, and Chapter 7.5.2).

Diatom phase GD-1 (*Cyclotella – Stephanodiscus*)

This phase is characterized by rather low frequency of *Cyclotella* and *Stephanodiscus* genera which, however, are highly differentiated. These forms allow the distinction of two subphases (GD-1a and GD-1b). At the beginning *Cyclotella* prevails in the GD-1a subphase. Most of the *Cyclotella* specimens found here are difficult to identify with optical microscope because of the small dimensions of valves (diameter less than 10 μm). Maximal percent values, except for *Cyclotella* sp., are attained by *C. comensis* and *C*. cf. *cyclopuncta*. Less frequent taxa include *C. bodanica, C. krammeri,* and *C. rossii.* Frequent here are *Cyclotella ocellata* and *C. radiosa/C. comta* as well as genera *Fragilaria, Synedra, Amphora,* and *Stephanodiscus.* In the subphase GD-1b specimens of *Stephanodiscus* spp. with valves less than 10 μm in diameter prevail. Most are probably *S. parvus* and *S.* cf. *minutulus.* There were also frequent specimens of *Stephanodiscus sp.* which are most similar to *S. binatus* (Håkansson & Kling 1990). Similar valves described as *Stephanodiscus sp.* "A" were noted in the Holocene sediments of a small eutrophic lake Bussjösjön in southern Sweden (Håkansson & Regnéll 1993). Numerous are also *Synedra ulna* and *Fragilaria crotonensis.* Other *Fragilaria* species are less common.

Diatom phase GD-2
(*Cyclotella-Stephanodiscus-Fragilaria-Synedra*)

The second diatom phase is also characterized by the small quantity of diatoms, particularly in the sand layer. Two subphases GD-2a and GD-2b were distinguished. Oscillations in diatom frequencies were much smaller than in the first phase. *Cyclotella* (mainly *C. ocellata)* and *Stephanodiscus* dominate in the GD-2a subphase. In the sandy sediments of the middle part of this subphase *Fragilaria* and *Synedra* definitely increase. At the beginning of GD-2b subphase frequencies of *Synedra acus* and then of *S. ulna, Stephanodiscus,* and *Fragilaria* increase, as *Cyclotella ocellata* decreases. Another development of *Cyclotella ocellata* at the end of this subphase is associated with a considerable increase of *Fragilaria construens.*

Diatom phase GD-3 (*Stephanodiscus-Synedra*)

Aside from the dominant *Stephanodiscus* the contribution of *Synedra acus* distinctly increases in this phase, whereas *Cyclotella ocellata* decreases, as does *Fragilaria.*

In the GD-3b subphase *Stephanodiscus* continues as dominant genus. The subdominant diatoms slightly increase (*Fragilaria crotonensis, Synedra ulna, Asterionella formosa*), and *Synedra acus* decreases.

Diatom phase GD-4 (*Stephanodiscus-Fragilaria crotonensis*)

This phase is characterized by mass development of *Stephanodiscus* spp. Its two subphases (GD-4a and GD-4b) differ in the content of subdominant diatoms.

Synedra ulna is frequent at the beginning of the GD-4a subphase. Then *Fragilaria crotonensis* is most frequent. At the beginning of the GD-4b subphase *Asterionella formosa* increases, and at the end of this subphase the frequency of *Fragilaria* spp., *Cyclotella comta,* and *C. ocellata* as well as *Amphora, Epithemia,* and *Navicula* increase.

Diatom succession and development of Lake Gościąż during the Younger Dryas

On the basis of the diatom phases described above (GD-1 up to GD-4) four stages in the development of the lake (I – IV) have been established. They can be correlated with vegetation changes around the lake and with the Younger Dryas subdivision on the basis of pollen analysis (Ralska-Jasiewiczowa et al. 1992, and Chapter 7.4, Ralska-Jasiewiczowa & van Geel 1993).

Stage I

During stage I, represented by diatom phase GD-1 (*Cyclotella-Stephanodiscus)* frequent transitory changes

Stage of lake development

14-C BP

Local diatom phases

GD-4b GD-4a GD-3b GD-3a GD-2b GD-2a GD-1b GD-1a

Synedra spp.
Synedra ulna
Synedra acus
Stephanodiscus spp.
Stephanodiscus cf. *alpinus*
Rhopalodia gibba
Pinnularia spp.
Opephora martyi
Nitzschia spp.
Neidium spp.
Navicula spp.
Gomphonema spp.
Fragilaria spp.
Fragilaria pinnata
Fragilaria crotonensis
Fragilaria con.-v. venter
Fragilaria con.-v. binodis
Fragilaria construens
Fragilaria brevistriata
Epithemia spp.
Diploneis spp.
Cymbella spp.
Cymatopleura elliptica
Cyclotella spp.
Cyclotella ocellata
Cyclotella krammeri
Cyclotella cf. *cyclopuncta*
Cyclotella distinguenda
Cyclotella comta
Cyclotella comensis
Cyclotella bodanica et v.
Cyclotella antiqua
Asterionella formosa
Anomoeoneis sphaerophora
Amphora spp.
Amphora pediculus
Amphora ovalis
Amphora libyca
Amphipleura pellucida
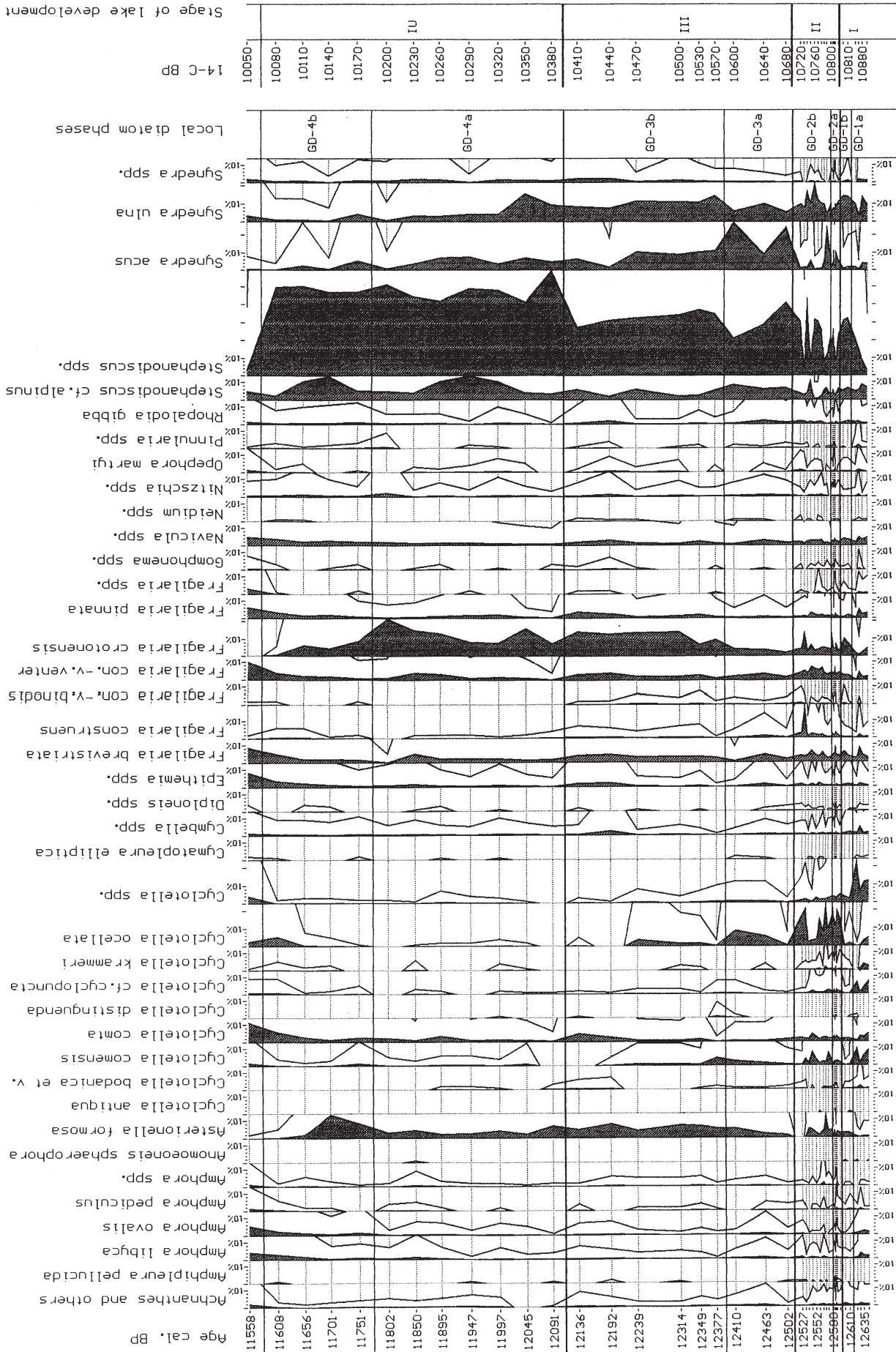*Achnanthes* and others

Age cal. BP

Fig. 7.27. Diagram of selected diatom taxa occurring in Younger Dryas sediments of Lake Gościąż profile G1/87.

of the dominant diatom composition lasted probably a few seasons.

At the beginning of that stage (GD-1a subphase) oligohalobous, nannoplanktonic diatoms (*Cyclotella*) typical in oligo-mesotrophic waters flourished. It was interrupted by an increase of littoral forms, mainly periphytic ones. This interruption may have been caused by water-level fluctuations or by a considerable drop of water temperature in the lake, which may have limited development of planktonic diatoms at that time.

In the second part of that stage, represented by a short-lasting subphase (GD-1b), *Stephanodiscus* spp. prevail and periphytic diatoms are less frequent. Such a rapid change of the planktonic diatom composition may have been a result of very unstable thermal and hydrologic conditions and an influence of continental climate as well. It is not clear whether this subphase should be associated with stage I, or with the initial part of the next stage.

Stage II

This stage (embracing the GD-2 diatom phase) is characterized at first by a small diatom content, particularly in sand layer, in which *Cyclotella, Fragilaria,* and *Synedra* have large contribution, whereas that of *Stephanodiscus* is smaller. In the later part of this stage except for prevailing species of *Cyclotella* (mainly *C. ocellata*) and *Stephanodiscus* a considerable increase of *Synedra acus* and then *Synedra ulna* was noted. In the final part of that stage (Gd-2b subphase) *Cyclotella ocellata, Fragilaria construens*, and *F. crotonensis* increase together with the decrease of *Stephanodiscus*.

Frequent changes of dominant and subdominant diatoms reflect most probably the unstable ecologic and hydrologic conditions associated with large seasonal variations, probably as a result of considerable cooling and increasing continentality of climate. This is suggested by irregular domination cycles of several diatom species, as
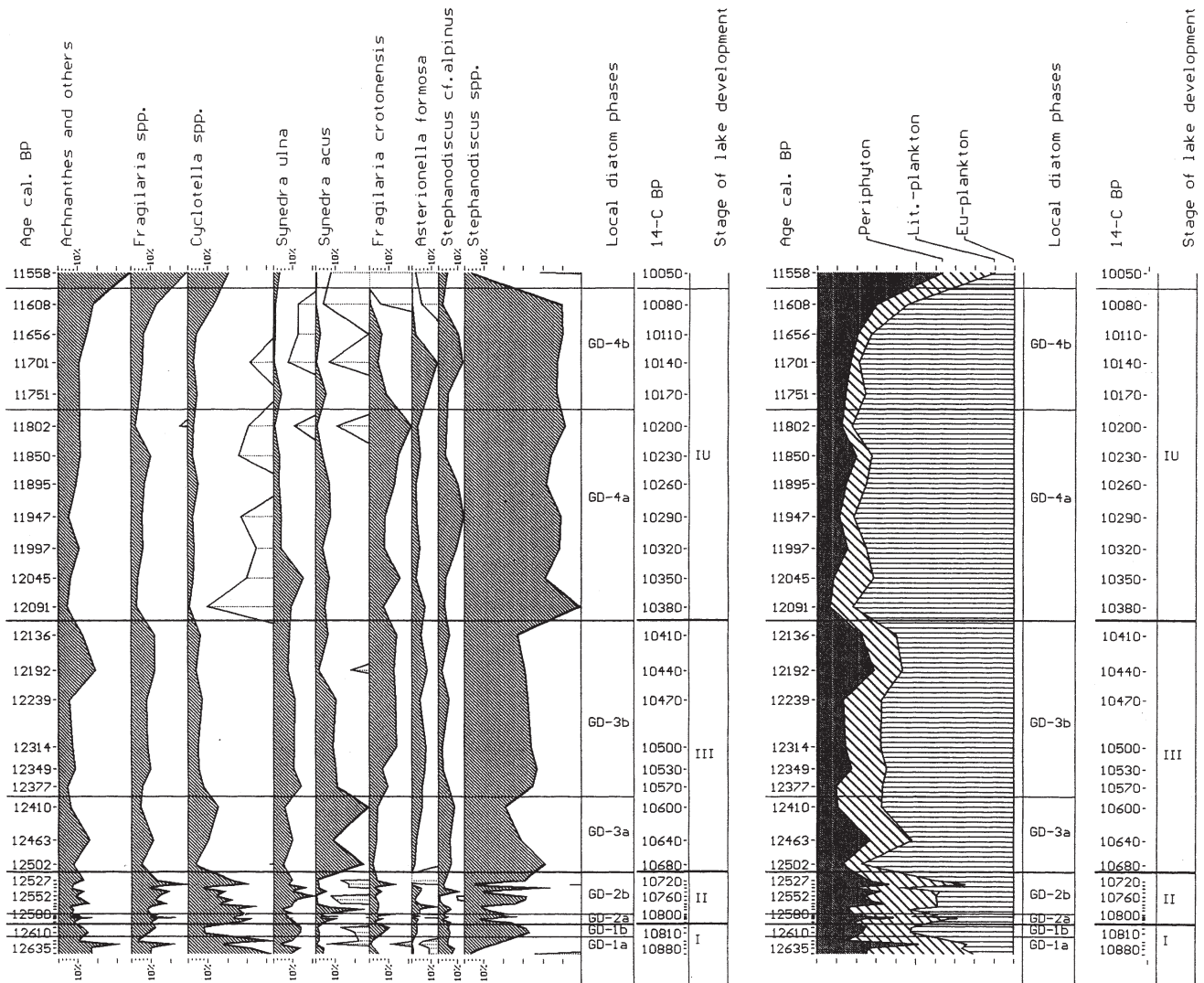

Fig. 7.28. Diagram of the dominant diatom genera (left) and groups of periphytic, littoral-planktonic, and euplanktonic diatoms (right) occurring in the Younger Dryas sediments of Lake Gościąż profile G1/87.

euplanktonic ones are interrupted by an increase in the frequency of diatoms typical for littoral zone. These changes were probably associated with a shallowing of the lake and longer periods of overfreezing. They are best marked at the beginning and at the end of the stage.

During the increase in the number of littoral (periphytic) diatoms there appears also *Cyclotella antiqua,* which is characteristic mainly in Late-Glacial lakes in Poland, particularly during Dryas periods (see Marciniak 1969, 1979). This is a rare, north-alpine species. It occurs as single specimens among mosses. It is known also from the Tatra Mts (Siemińska 1964). Besides that, single aerophilous and terrestrial diatoms (e.g. *Pinnularia borealis, Hantzschia amphioxys)* occur in stage II. They may have been blown (together with sand) onto the frozen lake surface from adjacent land areas or from the lake littoral zone.

A more complete image of the diatom succession during stage II of the Lake Gościąż evolution during Younger Dryas may possibly be obtained when a diatom analysis from the G1/90 profile (western deep) is completed. A continuity of lamination is preserved in the sediments in an analogous section of that profile (Goslar 1993a, b, Kuc et al. 1993).

As suggested by palynological studies, it is most probably the coldest part of Younger Dryas, represented by the lower part of *Juniperus-Artemisia*-Chenopodiaceae-*Salix* pollen assemblage zone, pointing to open subarctic flora (Ralska-Jasiewiczowa & van Geel 1993, Ralska-Jasiewiczowa et al., Chapter 7.4).

Stage III

The subphase GD-3a has been included in the stage III, but this is probably a transition between stages II and III of Lake Gościąż development. It is associated with the second cycle of *Synedra acus* occurrence. A similar short-lasting increase of that species is noted at the beginning of subphase GD-2b i.e. in the middle part of stage II.

Stage III, embracing diatom phase GD-3, is characterized by the increase of euplanktonic diatoms (mainly *Stephanodiscus* spp. and *Fragilaria crotonensis*). Subdominant forms here are *Synedra* and *Asterionella formosa.* Other *Fragilaria* species are less common. *Cyclotella* is rare as well.

In this stage an increase of euplanktonic forms was associated with a decrease of diatoms occurring in the plankton of the littoral zone and with considerable variations in the frequency of periphytic diatoms (Fig. 7.28).

In the pollen diagram it is the upper part of *Juniperus-Artemisia*-Chenopodiaceae-*Salix* PAZ, which is characterised by *Juniperus* maximum, decrease of *Betula,* and disappearance of *Filipendula* pollen, indicating the driest, most continental climate in the whole Younger Dryas (Ralska-Jasiewiczowa & van Geel 1993, Ralska-Jasiewiczowa et al., Chapter 7.4).

Stage IV

In stage IV (diatom phase GD-4) a mass development of *Stephanodiscus* (including possibly *S. parvus, S. minutulus, S. binatus,* or *S.* sp., sensu Håkansson & Regnéll 1993) is remarkable. It is a particularly important genus from the ecological point of view. Its bloom may point to a high lake-water level and increased plankton productivity. This phenomenon was associated most probably with better thermal and edaphic conditions, especially in relation to former phases of diatom successions in Younger Dryas.

Other euplanktonic diatoms (mainly *Fragilaria crotonensis, Asterionella formosa*) that are common in the stage in question and broadly distributed now, belong to cosmopolitan eurythermal and rather eurytopic species. They occur in various types of lakes from oligo- to eutrophic ones. *Asterionella formosa* is common in eutrophic lakes (Siemińska 1964).

It is worthy of note that samples from the upper part of the Younger Dryas sediments from profile G1/87 embrace 10-year intervals (with 40-year gaps in between). They record first of all the main maxima of euplanktonic diatoms, which are typical usually in spring periods, and the summer or autumn maxima are less pronounced. Similar high maxima of diatom concentration (*Centricae)* and Chrysophyceae cysts were observed in spring laminae in late-Holocene sediments of Lake Gościąż (Goslar 1993c). However, *Stephanodiscus* is represented there mainly by *S. hantzschii* and this species is almost absent from sediments of Younger Dryas.

Stage IV corresponds to *Betula-Artemisia* PAZ, in which the contribution of *Betula* and *Pinus* pollen increases and *Juniperus, Salix,* Gramineae, and Chenopodiaceae pollen values diminish. More thermophilous aquatic plants appear in the lake. These changes suggest slow warming of climate (Ralska-Jasiewiczowa & van Geel 1993, Ralska-Jasiewiczowa et al., Chapter 7.4).

The stage IV could correlate as well with subphase IIc of Cladocera development. A maximum growth of deep-water species was noted in this subphase (primarily *Daphnia longispina* and then *Bosmina longispina*), which pointed to better edaphic and climatic conditions in subphase IIc (Szeroczyńska 1993 and Chapter 7.5.2).

Determination of the trophic state of Lake Gościąż during stage IV of Younger Dryas on the basis of preliminary diatom analysis is difficult. At the initial phase of taxonomic studies concerning the most frequent genus *Stephanodiscus* (done mainly on the basis of the light microscope) a complete identification of species of this genus is impossible. Unknown are their preferences or ecological demands as far as trophic conditions are concerned. It should be pointed out, however, that the importance of some small *Stephanodiscus* species is increasing. They are more and more used as bioindicators

for reconstruction of trophic changes in lakes (Battarbee 1978, Gaillard et al. 1991, Håkansson & Regnéll 1993, Marciniak 1990), particularly in determination of eutrophication stages of lakes during the Holocene.

7.5.2. CLADOCERA ANALYSIS IN THE LATE-GLACIAL SEDIMENTS OF LAKE GOŚCIĄŻ

Krystyna Szeroczyńska

Analysis of cladoceran remains has become a classical method of palaeolimnological research for reconstructing lake development. Results contribute to the modelling of the palaeoecological and palaeoclimatic situation.

Within the framework of the complex studies on the Late-Glacial history of Lake Gościąż, an analysis of cladoceran fossils in the sediments of the profiles G1/87, G1/90, and T1/90 (Fig. 7.29) were subjected to this analysis. Results allow reconstruction of conditions in different zones of sediment accumulation.

Widely applied methods (Frey 1986a) described in Chapter 4.7 were used. Each sample consisted of sediments deposited during a period of 6–10 years over an area of 1 cm^2 (profiles G1/87 and G1/90), or of sediments with a 1 cm^3 volume (profile T1/90). Samples were collected from the same levels as for other analyses.

30 cladoceran species belonging to 6 families were found in the Late-Glacial sediments studied. Species composition and abundance suggest slightly different character of this period in comparison with interpretations obtained from earlier lake-sediment data from North and Central Poland (Błędzki 1987, Szeroczyńska 1985, Bińka et al. 1991).

In the sediments of Lake Gościąż (profiles G1/87, G1/90, and T1/90) the abundance of Cladocera remains was relatively low, and only in profile T1/90 it exceeded 1000 specimens per 1 cm^3 in the Allerød period. The presence of other fauna remains, such as Chironomidae and Turbellaria was also noted, but their abundance was very low.
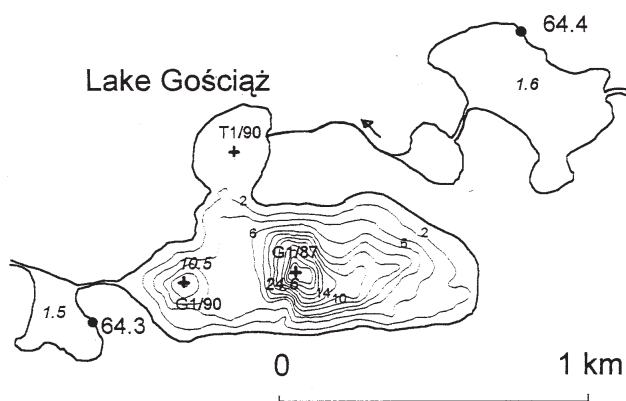

Fig. 7.29. Location of the investigated profiles (G1/87, G1/90 and T1/90) in Lake Gościąż.

Between 3 and 7 slides per sample needed to be examined (Chapter 4.7).

Results of the studies are presented in diagrams of absolute concentration (Figs 7.30, 7.32, 7.34) and also in the diagrams of percentage composition of all species (Figs 7.31, 7.33, 7.35) for comparison of their abundance. The results were compared with those from other Late-Glacial lakes (Bińka et al. 1988, 1991, Błędzki 1987, Flössner 1990, Frey 1958, 1961, Goulden 1964a,b, Hofmann 1977, 1978a,b, 1983, 1986, Jones & Tsukada 1981, Szeroczyńska 1985, 1991, 1993a,b, Whiteside 1970).

Description of profile G1/87

Laminated sediments of profile G1/87 consist mostly of gyttja containing a considerable amount of carbonates. The profile reveals a distinct annual lamination.

In the sediments studied, Cladocera species from the families Bosminidae, Daphnidae, and Chydoridae dominated. These species are particularly good for correlations and allow some ecologic and climatic conclusions.

On the basis of curves of absolute abundance (Fig. 7.30), analyses of the interdependence of percentage participation of the species, percentage composition of Chydoridae (Fig. 7.31), and climatic preferences of Cladocera, the following phases of Cladocera development were distinguished in profile G1/87:

Phase I (samples 1–30, 12,857 to 12,659 cal BP) corresponds to the initial period of the lake development, when species of Bosminidae, especially *Bosmina coregoni* and *B. longirostris*, were dominant. Littoral species occurred in rather small numbers, the dominant one was *Alona affinis,* which lives preferentially on aquatic plants. Worth noticing is the presence of *Leptodora kindtii* and *Camptocercus rectirostris*, suggesting clear-water conditions. The appearance of *Alona quadrangularis* and *Pleuroxus* indicate a mild climate.

Phase II (samples 31–84, 12,653 to 11,508 cal BP). The upper limit of this long-lasting phase was marked by the abundance of *Bosmina coregoni* and *B. longirostris*, as well as the *Daphnia longispina*-group (Figs 7.30 and 7.31). An almost complete absence of the *Camptocercus rectirostris* and *Pleuroxus* may suggest a cooling of the climate, but their traces observed in the sediment from 11,895–11,508 cal BP imply climatic warming at the decline of phase II. The dominant species were planktonic forms, such as *Bosmina coregoni* and *Daphnia longispina*-group. Species from the littoral group (Chydoridae) occurred also frequently, and their abundance was even higher than during phase I. Great variability in the abundance of several species was the basis for the division of this phase into subphases a, b and c.

Subphase a (samples 31–61, 12,653 to 12,377 cal BP) was a period of development of most species found in the