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Response times in bio- and isotope-stratigraphies to Late-Glacial climatic shifts – an example from lake deposits

By BRIGITTA AMMANN¹⁾

ABSTRACT

Changes in vegetation, insect assemblages and oxygen-isotope ratios between 14,000 BP and 9,000 BP and their climatic interpretation are summarized for Lobsigensee, a site in the Swiss lowland. A *Juniperus* peak, the first occurrence of *Typha latifolia*, a first find of *Donacia cinerea* and a shift in $\delta^{18}\text{O}$ all point to rapidly increasing temperatures at around 12,600 BP. A second rise in temperature is recorded by vegetation and oxygen isotopes at around 10,000 BP.

$\delta^{18}\text{O}$, beetles and waterplants seem to reflect the climatic change with no or very short response-times. *Corylus*, however, arrives after a long lag, which may partly be due to slow dispersal, partly to high seasonality (very cold winters) during the Younger Dryas (11,000 to 10,000 BP).

In order to understand the biotic response to a changing climate, it is necessary to study not only closely tracing species, but a variety of taxa with different life-cycle characteristics.

ZUSAMMENFASSUNG

Vom Lobsigensee im Berner Mittelland werden Veränderungen der Vegetation, der Insekten-Fauna und der Sauerstoffisotopen-Verhältnisse sowie deren klimageschichtliche Interpretation für den Zeitraum 14 000–9 000 BP zusammengefasst. Um 12 600 BP fallen eine rasche Ausbreitung des Wacholders (*Juniperus communis*), erstes Auftreten von Breitblättrigem Rohrkolben (*Typha latifolia*) und erste Funde des Schilfkäfers (*Donacia cinerea*) mit einem Sprung in der Kurve des $\delta^{18}\text{O}$ der Seekreide zusammen; alle diese Beobachtungen deuten auf einen raschen Temperatur-Anstieg. Ein zweiter solcher Anstieg wird aus den Veränderungen der Vegetation und des $\delta^{18}\text{O}$ um 10 000 BP gefolgt.

$\delta^{18}\text{O}$ im präzipitierten Karbonat, Käfer und Wasserpflanzen scheinen Klimaveränderungen ohne oder mit sehr kurzer Verspätung zu registrieren. Die Hasel *Corylus avellana* dagegen wandert mit einer Verzögerung von über 3500 Jahren ein, nachdem die Sommertemperaturen bereits hoch genug waren. Diese Verspätung kann z.T. durch langsame Wanderung (langsame Samenverbreitung), z.T. durch hohe Kontinentalität (sehr kalte Winter) während der Jüngeren Dryas (11 000–10 000 BP) bedingt sein.

Um die biologischen Antworten auf Klimaveränderungen zu verstehen, ist es notwendig, nicht nur die rasch reagierenden Arten, sondern Arten mit möglichst verschiedener Lebenszyklus-Charakteristik zu untersuchen.

Introduction

Rapidity and amplitude of past climatic changes are often inferred from changes in biotic assemblages or oxygen-isotope ratios. The latter are of great relevance because they can be studied and compared in stratigraphical archives as different as ice cores, ocean cores and lacustrine cores. Biotic changes may or may not be induced by cli-

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matic changes and may follow them with or without time lag. These differences have been discussed since the early days of pollen analysis and are of great ecological as well as climatological interest (IVERSEN 1944, 1954, 1960, 1964).

BIRKS (1981) reviewed the possibilities and limitations of both the floristic or "indicator-species" approach and of the vegetational or "multivariate" approach in order to extract climatic information from pollen stratigraphical data. For the latter especially a classical question is crucial: Is vegetation in equilibrium with climate? (WEBB & BRYSON 1972, BIRKS 1981, DAVIS 1984, RITCHIE 1986, WEBB 1986, PRENTICE 1986). RITCHIE (1986) distinguishes and illustrates four categories of climatic variation with different time scales and vegetational response. He also emphasizes the relevance of the spatial and temporal scales. Moreover he discusses four response modifiers: topographic diversity and soils, life-cycle characteristics, hysteresis and anthropogenic factors. WRIGHT (1984) reviewed biotic and isotopic responses to climatic changes in a broader context.

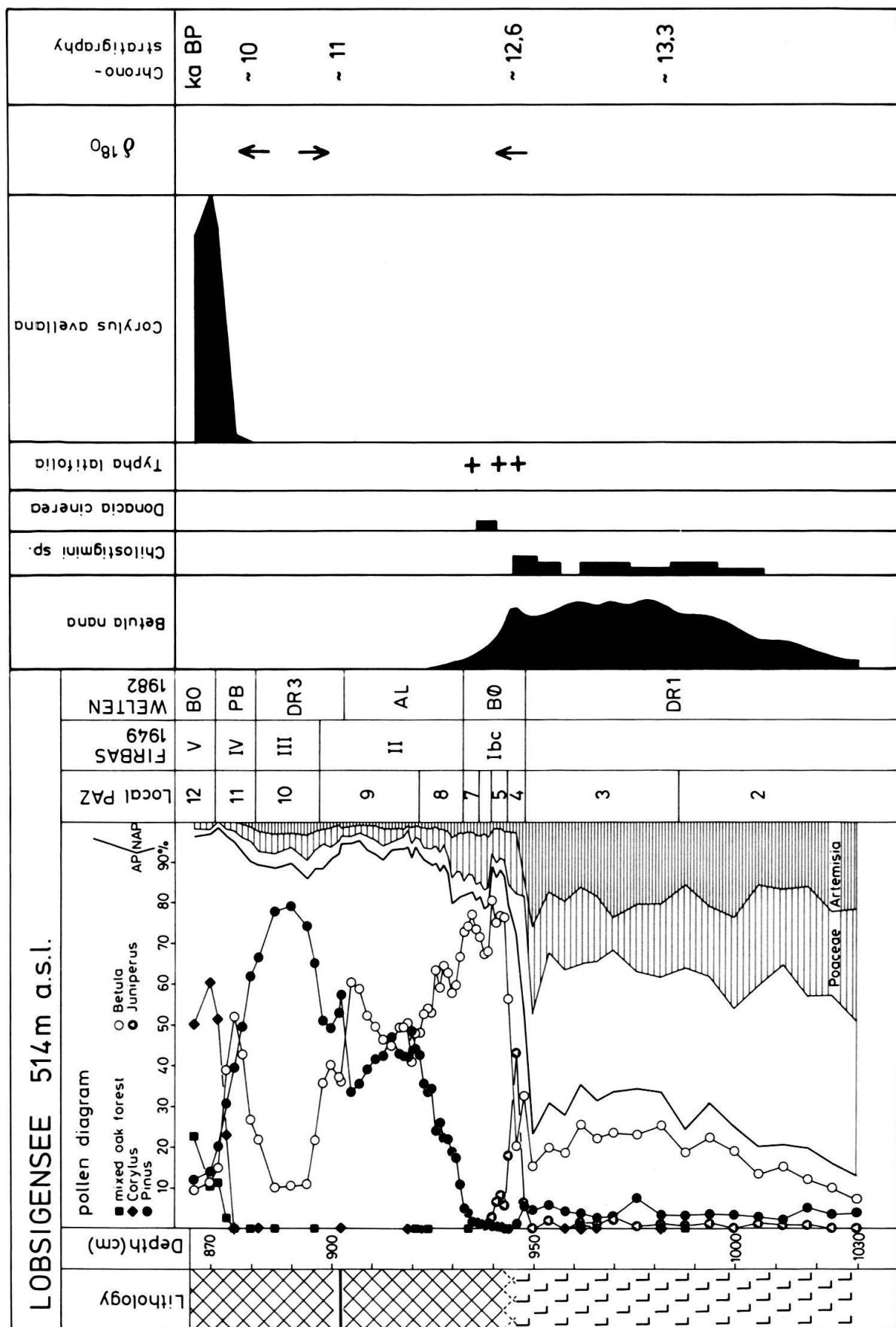
In the following, an example from the Late-Glacial and its transition to the Holocene is presented where several groups of organisms and oxygen isotopes were studied in the same cores of lake sediment.

Site and methods

The Swiss contribution to the IGCP 158 B on "Paleohydrology of the temperate zone in the last 15,000 years: lake and mire environments" (BERGLUND 1986) consists of a transect from the Jura mountains to the Plateau and across the Alps (LANG 1985). In this transect the pond of Lobsigensee was chosen as a reference site for the Swiss Plateau. Lobsigensee is a kettle-hole lake on the gently folded Molasse 15 km NW of Bern. It has no surface inlet and a small outlet that only functions as an overflow. Today its surface is 2 ha and its maximum depth 2.7 m. In the early Late-Glacial it had at least 10 ha surface and 17 m maximum depth. Twelve cores along two transects through the basin were taken by Livingstone corers modified according to MERKT & STREIF (1970). All cores were analysed for pollen (AMMANN 1985, 1989). The littoral cores were studied for beetles, caddis flies (ELIAS & WILKINSON 1983, 1985), chironomids (HOFMANN 1983, 1985), molluscs (CHAIX 1983, 1985) and $\delta^{18}\text{O}$ of carbonates, whereas profundal cores were analysed for chironomids (HOFMANN 1983, 1985), ostracods (LÖFFLER 1986) and fossil pigments (ZÜLLIG 1985, 1986). While stratigraphies based on the two last-mentioned remains generally reflect the history of nutrients and of

Fig. 1. Selected biostratigraphies compared to oxygen-isotope ratios and radiocarbon age. The rapid shift of the AP/NAP curve in the pollen diagram reflects the reforestation at the beginning of the Bölling biozone, which is characterized by a dominance of tree-birches. The distinction between dwarf birch and tree-birches is based on both pollen size statistics (GAILLARD 1983) and macrofossils (TOBOLSKI in AMMANN & TOBOLSKI 1983). The finds of the caddis flies *Chilostigmata* spp. and of the beetle *Donacia cinerea* and their climatic interpretation are discussed by ELIAS & WILKINSON 1983. Oxygen isotopes are studied by EICHER & SIEGENTHALER 1983, EICHER 1987. The chronostratigraphy follows OESCHGER et al. 1985 and ANDREE et al. 1986.

The line in the column of lithology indicates the volcanic ash from Laach. Biozones: BO = Boreal, PB = Preboreal, DR 3 = Younger Dryas, AL = Alleröd, BÖ = Bölling, DR 1 = Oldest Dryas.



oxygen supply in the water body, the insect groups mentioned can be useful for attempts to reconstruct the local and regional climate. The methods of sampling and analysis are described in the original papers.

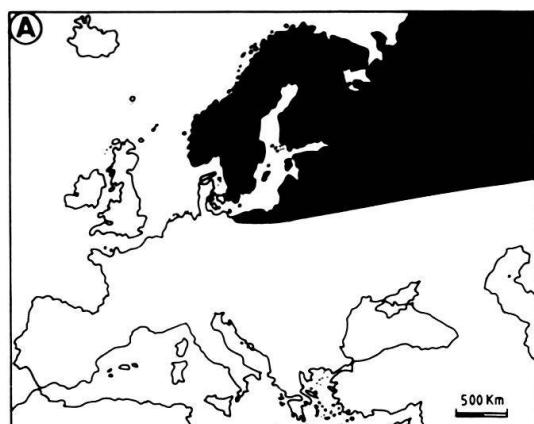
Results

Fig. 1 summarizes results from pollen-, insect- and oxygen isotope-analysis relevant for the climatic interpretation of the period from before 13,300 to after 10,000 BP.

The lithologic change from clay to fine-detritus gyttja at a depth of 945 cm coincides with the reforestation which is reflected by the jump in the AP/NAP-curve and the juniper peak (Local pollen assemblage zone PAZ 4). Before the reforestation the Oldest Dryas biozone (DR1) is poor in trees and rich in heliophilous taxa growing in a mosaic of steppe and tundra. At the transition from the local PAZ 2 to 3 the dwarf birch *Betula nana* expands and forms, together with willows, a shrub tundra. It is during this Oldest Dryas biozone that *Chilstigmini* spp. (including the most frequent *Chilstigma siebaldi*) and other caddisflies and beetles occurred which ELIAS & WILKINSON (1983, 1985) describe as boreal to boreo-montane in their modern distribution. Fig. 2 shows how similar the present distributions of *Betula nana* and *Chilstigma siebaldi* are. The two species co-occurred during the younger part of the Oldest Dryas. From the assemblage of Coleoptera and Trichoptera found in these deposits ELIAS & WILKINSON 1983, 1985 can estimate a mean July temperature of 10–12 °C. In the early Bölling biozone (Ibc) pollen and macrofossils of *Betula nana* decrease (GAILLARD 1983, TOBOLSKI in AMMANN & TOBOLSKI 1983) and *Chilstigmini* disappear (ELIAS & WILKINSON 1983). At the same level the first pollen grains of *Typha latifolia* (local PAZ 4 to 7, AMMANN 1989) and a first shift in the oxygen-isotope ratio is found (local PAZ 4, EICHER & SIEGENTHALER 1983, SIEGENTHALER & EICHER 1985). In local PAZ 6 the temperate beetle *Donacia cinerea* was recorded by ELIAS & WILKINSON 1983, 1985. They conclude from the assemblage starting in PAZ 6 that the mean July temperature was 14–16 °C (see band α in Fig. 2). Temperature requirements of *Typha latifolia* (cat-tail or great reedmace) are discussed by IVERSEN (1954), VASARI (1962) and KOLSTRUP (1980): it may grow at a mean July of 12–13 °C but is more common with at least 15 °C mean July temperature.

The climatic cooling of the Younger Dryas biozone (III) is visible in the NAP curve of the pollen diagram and in the decrease of the $\delta^{18}\text{O}$ curve but not in the Coleoptera and Trichoptera assemblages. ELIAS & WILKINSON (1983, 1985) compare this result with data from Britain where the temperature depression at the beginning of the Younger Dryas, inferred from beetle remains, is marked (see curve β in Fig. 2). This

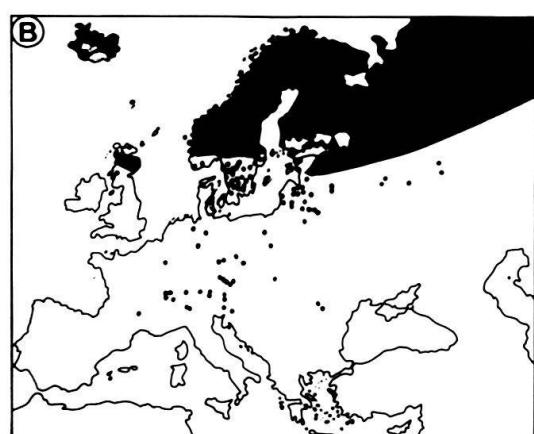
Fig. 2. Comparison of biogeographical ranges of four species with the dated temperature curve and the isotopic shifts. (A) Map of modern range of the caddis fly *Chilstigma siebaldi* (ELIAS & WILKINSON 1983). (B) Map of modern range of the dwarf birch *Betula nana* (after TRALAU in WALTER & STRAKA 1970). (C) Map of modern range of the beetle *Donacia cinerea* (after ELIAS & WILKINSON 1983). (D) Map of modern range of the hazel *Corylus avellana* (after MEUSEL et al. 1965). (E) Dates of occurrence or immigration of the four species mentioned and of the water plant *Typha latifolia*. The band labelled α represents the estimated mean July temperature for Lobsigensee, the curve β for Britain after COOPE 1977. (F) The three shifts in the oxygen-isotope ratio on the time scale of (E), after EICHER & SIEGENTHALER 1983.



CHILOSTIGMA sieboldii



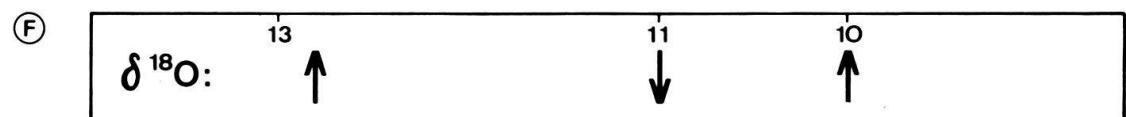
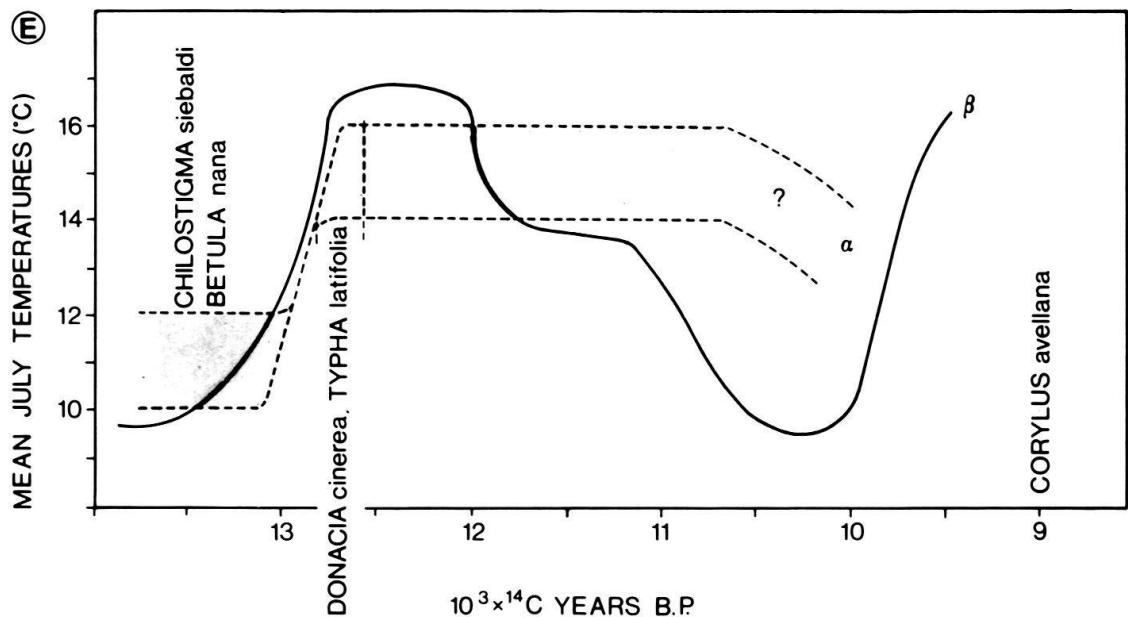
DONACIA cinerea



BETULA nana



CORYLUS avellana



contrast can be taken as an illustration of the fact that the climatic cooling of the Younger Dryas was primarily due to a shift of the North-Atlantic polar front (RUDDIMAN & McINTYRE 1981) and therefore strongest in North-West Europe, becoming weaker eastwards on the continent (WATTS 1980).

The transition from Younger Dryas biozone (III) to the Preboreal biozone (IV) is clearly visible in the pollen diagram (decrease of NAP) and in the ratio of the oxygen isotopes; both changes indicate rising temperatures at the beginning of the Holocene. During the Preboreal biozone the hazel *Corylus avellana* expands rapidly, a species with a modern distribution somewhat similar to that of *Donacia cinerea* (Fig. 2).

Two plateaux of constant ^{14}C -age are found in the age-depth relationship which coincide with the periods of greatest biotic and isotopic changes as discussed by ANDREE et al. (1986), AMMANN (1988) and LOTTER & ZBINDEN (1989).

Discussion

Fig. 2 illustrates that a species of insect and a species of shrub with similar modern distribution, map (A) and (B), occurred together before the rapid warming of the early Bölling biozone. During this biozone then, which is also characterized at its beginning by the shift in $\delta^{18}\text{O}$, the first temperate beetles arrived, a finding very similar to results from many British sites (COOPE 1977, ATKINSON et al. 1987). The oxygen-isotope ratios are thought to track temperature changes without time lag. The plant-independent beetles may have a short lag which is close to the stratigraphic resolution of our sampling. The shortness of the lag is due to life-cycle characteristics such as fast reproductive rate (COOPE 1977). The response of the water-plant *Typha latifolia* seems just as rapid as the response of the beetle. IVERSEN (1954, 1964) gave three possible reasons for the short lag of water-plants: life-cycle (every year a generation), efficient dispersal (by waterfowl) and independence from pedogenesis. This corresponds to the two first mentioned modifiers discussed by RITCHIE (1986).

It is surprising that a shrub with a modern range similar to that of the temperate beetle [see maps (C) and (D)] arrives and expands more than 3,500 years later. Thus we can conclude that hazel arrived with a very long lag. In the Late-Glacial situation this was most probably a migrational lag. Slow migration may partly be due to poor dispersal of its heavy fruits and late flowering (after about 10 years), i.e. life-cycle characteristics in the four modifiers discussed by RITCHIE (1986). The requirements of *Corylus* concerning soils are not very narrow; its modern occurrences on rock-fall slopes points to a tolerance of immature soils. Thus the conceivable lack of deep, ripe soils cannot explain the late immigration. Apart from slow dispersal of the fruits the frost-sensitivity of *Corylus* discussed by BIRKS (1973) may have caused a delay in migration: if the seasonality and continentality of the Younger Dryas was as great as suggested by ATKINSON et al. 1987, very cold winters and late frosts may have inhibited a rapid expansion of *Corylus*. Possibly its extremely rapid expansion in the early Holocene reflects the onset of milder winters. These considerations point to the possibility of using organisms for estimation of both summer and winter temperatures as IVERSEN (1944) and ATKINSON et al. (1987) did, whereas $\delta^{18}\text{O}$ measured in carbonates reflect summer temperature because carbonate precipitation ceases in autumn and winter.

If the main goal is to extract climatic signals from the biostratigraphies one would best concentrate on closely tracking species such as plant-independent beetles or water-plants. But if we are interested in understanding community ecology under a changing climate, including equilibrium or disequilibrium between communities and climate, we need to analyze as many different groups of organisms as possible. For this, lake sediments are the most promising archive.

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