

Late Quaternary chronology of the Allier terrace sediments (Massif Central, France)

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Abstract

The Late Quaternary terrace chronology of the middle Allier basin (Limagne, Massif Central, France) has been reconstructed by means of terrace (chemo)lithostratigraphy and with Th/U disequilibrium and ¹⁴C datings. The 25 m terrace level (Wb) has a Late Saalian age. The Weichselian terrace levels Xa and Xb (20 and 10 m) contain at least four different lithostratigraphical units: one Middle Pleniglacial, two Late Pleniglacial and one Younger Dryas. The oldest Holocene ZY terrace sediments have Atlanticum ages. Timing of Allier incision and sedimentation during the Late Pleniglacial and Late Glacial appears to be mainly climate-related. Major fluvio-glacial sediment fluxes from melting glaciers on the Mt. Dore and Cantal at the end of the Late Pleniglacial caused a strong rise of the Allier river bed level. This rise of approximately 20 m in the Limagne seems to have contributed to the formation of lakes like Marais de Ravel and the Grand Marais. Fluvial dynamics in the Allier basin seem to be mainly climate controlled.

Introduction

River terraces provide long, but fragmentary, continental records of changing geo-environments. To the geomorphologist, a flight of terraces seems to suggest a rather straightforward origin by alternating deposition and erosion. But the sediments of which they consist usually reveal a far more complex history. This was already clearly illustrated by Leopold et al. (1964), who showed that three terrace levels might be formed in a single valley fill, but three valley fills might also give just one terrace level. As a rule, a morphological terrace level is made up of several stacked, often incomplete sedimentary cycles, representing alternating depositional and erosional stages. A combined geomorphic and sedimentological approach is imperative to link the

history of river valleys to changing geo-environments.

This study focusses on the stratigraphy of the lower terraces of the Allier (Massif Central, France). The typical sequence of terraces in the Allier valley shows that accumulation and incision alternated repeatedly during the general valley deepening. Two terrace chronologies have been published, one by Larue (1979) and one by Pastre (1986). Both authors used indirect ways of correlating and dating terraces. Terraces are numbered according to the French classification system from Z (present river bed) to S (oldest terrace level).

Within the lower terraces of the Allier major differences in sediment composition are known (Kroonenberg et al. 1988, Larue 1977). The major difference between the present river bed and the Weichselian terrace (X) is the higher amount of

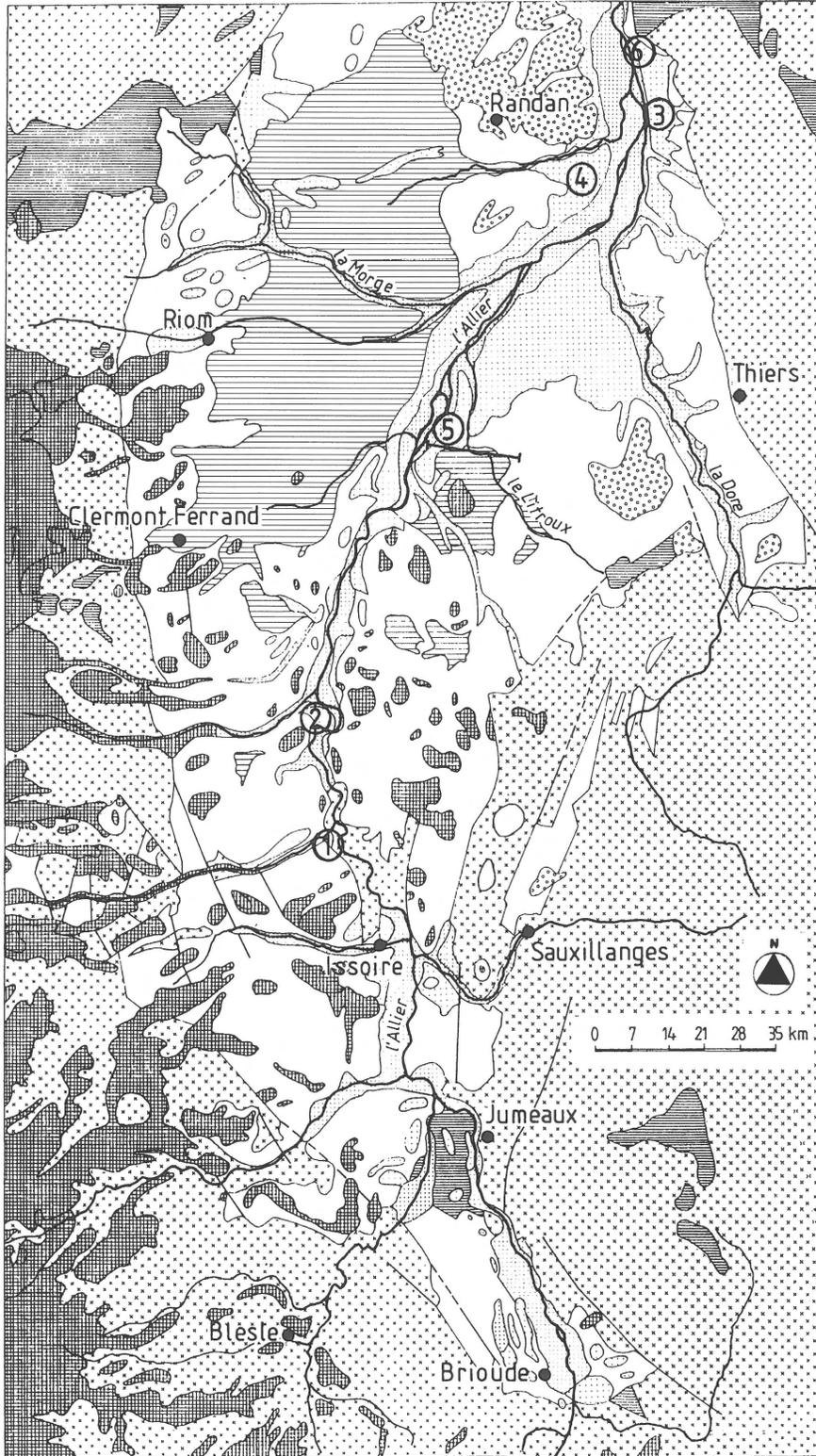


Fig. 1. a) Study area with location of key sections. 1 = Coudes, 2 = Longues, 3 = Les Jarrauds, 4 = La Bas Lachamp, 5 = Culhat, 6 = St Yorre. Legend in Fig. 1b.

basaltic fragments in the X terrace sands. This difference is thought to have a climatic origin as Late Pleniglacial sediments originated from melting glaciers in volcanic areas (Bout 1963, Kroonenberg et al. 1988, Veldkamp 1991).

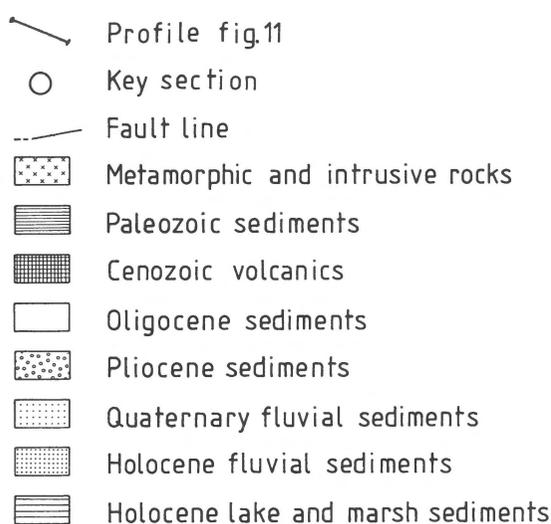
Previous bulk-geochemical studies of Allier sands showed that basaltic rock fragments determine the TiO_2 , Fe_2O_3 , MgO , CaO and P_2O_5 content in Allier sands (Kroonenberg et al. 1988, Veldkamp 1991, Veldkamp & Kroonenberg 1993). Changes in bulk geochemical sand composition are well illustrated by the CaO content, concentrated in basaltic rock fragments, K_2O content, concentrated in crystalline rock fragments, and Na_2O concentrated in sodic plagioclase. CaO and K_2O contents are virtually independent of grain size because their host minerals are found in almost all grain size fractions in equal proportions. The amount of Na_2O is grain-size dependent as plagioclases are enriched in finer sand fractions due to selective abrasion (Veldkamp 1990).

In this paper a new and more elaborated Late Quaternary terrace (chemo)lithostratigraphy is presented with new ^{14}C and U/Th datings allowing a more precise timing of Allier dynamics. Finally, a first comparison is made with Quaternary fluvial dynamics in other NW European fluvial systems.

Study area

The middle Allier basin is situated in central France and comprises the upper part of the Loire drainage basin (Fig. 1). The Allier drains the Limagne rift valley and the surrounding Hercynian crystalline Massif Central. The majority of the rocks in the Massif Central are gneisses and granites. Paleozoic sedimentary rocks and acid volcanic rocks occur locally. Some residual flint occurrences suggest Mesozoic sedimentation in the Massif Central. At the start of the Alpine orogeny in the Tertiary, many grabens like the Rhône, Loire and Limagne grabens, opened up in the Massif Central. Sedimentary infill of these tectonic depressions started immediately. The Limagne rift valley which mainly subsided during the Oligocene, was filled with marls, limestones, sands and clays during the Oligocene and Miocene. Volcanism started along fault zones in the Miocene and continued till recent times. Cantal volcanism reached its climax between 9 and 6 million years ago, while the Mont Dore volcano had its most active phase between 3 and 1 million years ago. Late Quaternary and Holocene volcanism took mainly place in the Chaîne des Puys, which like the Mont Dore is situated directly west of the Limagne.

The Allier basin is underlain by volcanic rocks (22%), crystalline basement rocks (58%) and basement-derived Oligocene sediments (20%). The higher parts of the Allier basin, notably the Cantal and Mont Dore volcanoes, were subjected to severe glaciation (Veyret 1980). Allier terrace deposits are gravelly and sandy sediments poor in clay. Gravel composition reflects the different lithologies within the Allier basin. This composition is not linearly correlated with basin lithology; usually the volcanic components predominate while the Oligocene rocks are rare. Common heavy minerals of the Allier terrace deposits are augite, green and brown hornblende, olivine, micas and opaques (Van Dorsser 1969, Rudel 1963, Pelletier 1971, Pastre 1986, Tourenq 1986). The opaque component, which can comprise more than 50% of the fine sand fraction, is predominantly composed of basaltic rock fragments (Kroonenberg et al. 1988).



Legend for Fig. 1a.

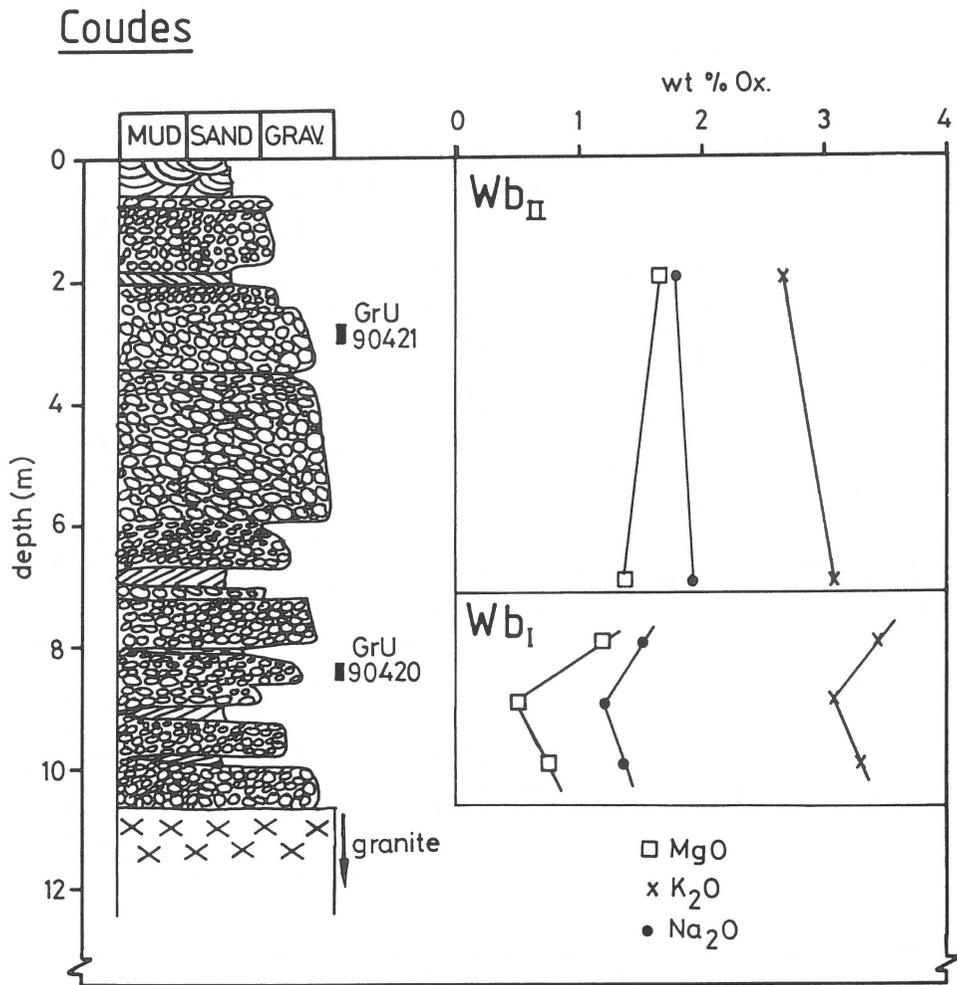


Fig. 2. Key section through sediments of the Wb terrace at Coudes, with U-Th-dated travertine samples and geochemical composition.

Materials and methods

Various lower terrace deposits have been investigated thoroughly by studying all available exposures along terrace scarps and in gravel and sand pits. Based on these sedimentological field observations and on measured bulk geochemical sand compositions a lithostratigraphy was made.

Sampling, laboratory treatment and measurement of the sands followed the procedure of Kroonenberg et al. (1988). Bulk element concentrations of SiO₂, TiO₂, Fe₂O₃, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O and P₂O₅, were measured with X-ray fluorescence spectroscopy.

Special attention was paid to lithological discon-

tinuities associated with paleosols and cryoturbated sediments/paleosols. The lithostratigraphy was elaborated at sites where dating proved possible. Organic-rich sediments were dated with ¹⁴C and travertines with both the ¹⁴C and Th/U disequilibrium methods.

There are three main groups of lower terrace levels, from old to young: W, X and ZY. The individual *morphological terrace levels* are indicated by an 'a' or 'b' (e.g. Wb and Xa) and different *lithostratigraphic units* by Roman numbers (e.g. X_{IV} and Wb_I). The studied part of the W terrace is the Wb level at 25 m above the actual Allier. The studied X levels, Xa and Xb, occur at 20 and 10 m, respective-

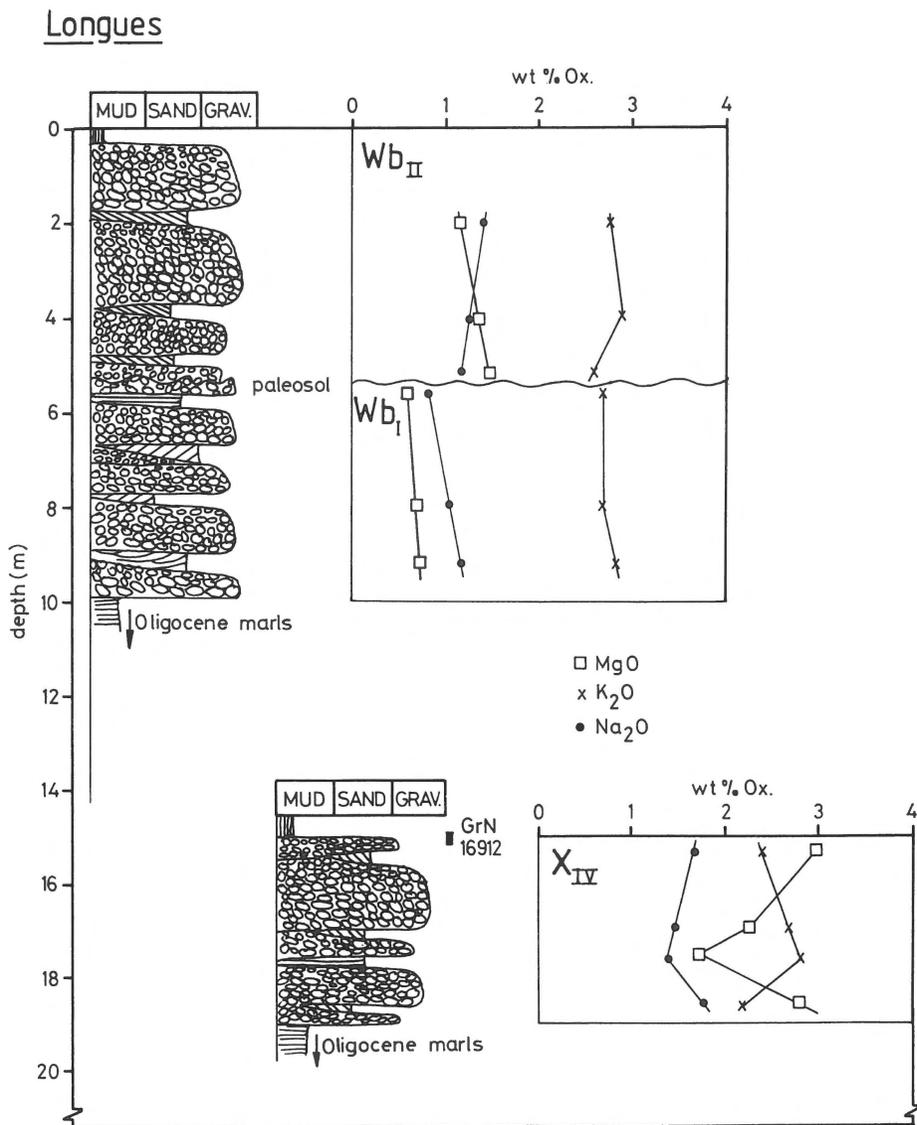


Fig. 3. Key section through Wb and X terrace sediments at Longues.

ly. The ZY level occurs between 7 m and the present river bed.

Terrace lithostratigraphy

Wb terrace sediments

Near the Allier-Couze Chambon confluence at Coudes (Fig. 1, no. 1), the 25 m terrace is well exposed along the national road RN 9. At this key sec-

tion, terrace sediments are found in a former gully incised in granite. These sediments have a maximum thickness of about 10 m. Two main units can be distinguished (Fig. 2). The lower unit, Wb_I, is poorer in volcanic clasts (less MgO and more K₂O) than the overlying Wb_{II}. Wb_I sediments were slightly weathered before they were buried under Wb_{II} sediments. Both Wb lithostratigraphic units are impregnated with travertine from nearby former springs.

The 25 m terrace level was originally dated as

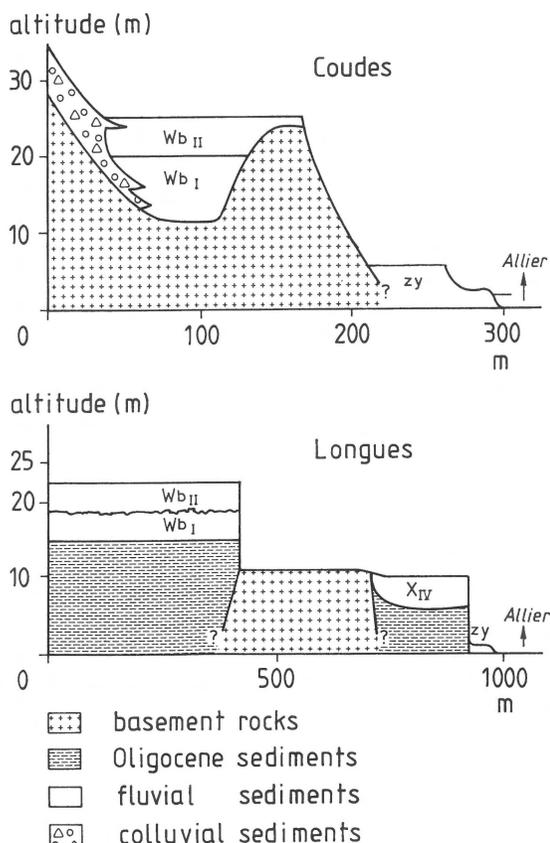


Fig. 4. Morphology and schematical lithostratigraphy for the Wb terrace level.

Late Pleniglacial on the basis of fossils and artefacts found on and in the travertine capping of this terrace (Daugas & Tixier 1978). Although a Weichselian age was attributed originally to both terraces, radiometric dating shows otherwise. Travertine, impregnating both units at Coudes, was dated with the disequilibrium Th/U method at $119\,000 \pm 13\,000$ BP (GrU-90420) for Wb_I, and $93\,000 \pm 5\,000$ BP (GrU-90421) for Wb_{II}.

As the travertine shows no stratigraphic discontinuity between the two units, it must have been deposited later than Wb_{II} sediments. These sediments were almost unweathered before travertine impregnation started indicating that they are only slightly older than the oldest travertines. The oldest travertines give therefore only an approximate age for the Wb_{II} sediments. Wb_I sediments were already weathered before travertine impregnation took place. Travertines impregnating sediments of a

nearby 50 m terrace have Th/U ages up to $160\,000 \pm 10\,000$ BP (GrU-90418). If the Wb_I sediments already existed at 160 000 BP they should have been impregnated with these older travertines. Since Wb_I sediments are only impregnated with younger travertines, it seems likely that they were deposited between 160 000 and 120 000 BP. Consequently both Wb units seem to be Late Saalian.

At Longues (Fig. 1, no. 2) another terrace level at about 25 m above river level is found. This terrace displays a similar (chemo)lithostratigraphy as the Coudes key section (Fig. 3). Wb_I sediments are poorer in volcanic clasts (less MgO and more K₂O) than overlying Wb_{II} sediments. They are weathered and soil formation like clay illuviation took place (A.G. Jongmans, pers. comm.). These paleosols were locally cryoturbated before they were buried under Wb_{II} sediments. They clearly evidence a time lag between the deposition of the two Wb units. At Longues, terrace sediments are also impregnated and covered with travertines. Travertines capping the Wb terrace sediments at this site were preliminarily dated by Kroonenberg et al. (1989) with the non-equilibrium Th/U method, giving Middle Pleniglacial as a minimum age for the Wb sediments. The Wb terrace lithostratigraphy of the two key sections at Coudes and Longues is schematically shown in Fig. 4. The two sites are only 7 km apart. Based on similarities in lithostratigraphy, bulk geochemistry and geographical position, the Wb terrace sediments at both sites are thought to belong to the same terrace unit and to have Saalian ages. The Wb_{II} sediments are not much older than 120 000 years while an age between 120 000 and 160 000 BP is attributed to the Wb_I sediments.

X and ZY terrace sediments

For the younger X and ZY terrace levels, fragmentary paleontological, palynological, archeological and ¹⁴C datings evidence that they were formed during the Weichselian and Holocene (Rudel 1953, Lambert et al. 1980, Raynal 1984). An important key section for the X terraces is situated at Les Jarrauds (Fig. 1: no. 3; Fig. 5), where all four Weichselian lithostratigraphical units are represented.

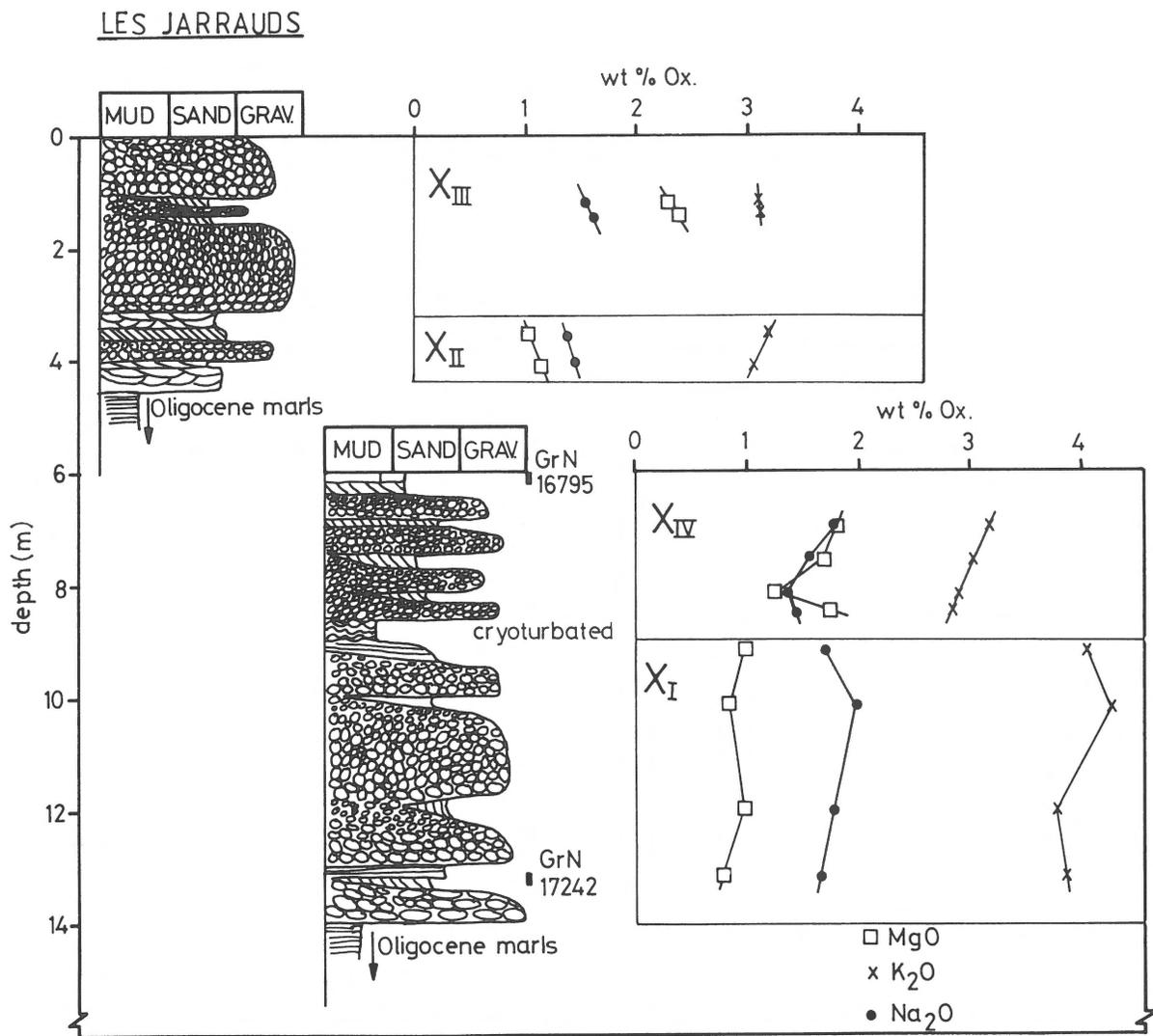


Fig. 5. Key section at Les Jarrauds through Xa (upper) and Xb (lower) terrace levels (lithostratigraphic units X_I, X_{II}, X_{III}, X_{IV}).

The highest terrace level, Xa, lies at approximately 20 m above the present river bed. This terrace level consists of two lithostratigraphic units. The gravelly top unit, X_{III}, is characterized by a high-basaltic (high MgO and low K₂O) sand and gravel content. This unit locally overlies a more sandy unit, X_{II}, relatively poor in basaltic fragments. In the terrace scarp at the transition to the lower Xb terrace level, Oligocene clays locally crop out below the X_{II,III} deposits, indicating that incision occurred before the X_{IV} sediments in the lower terrace level, Xb, were deposited.

Like Xa, the Xb terrace level (10 m above the present river) has usually two main lithostratigraphic units, viz. relatively basalt-rich sediments (X_{IV}) overlying a basalt-poorer sediment (X_I). Locally basalt-poor X_{II} sediments are intercalated between X_I and X_{IV} sediments. This suggests that X_I sediments are older than all sediments in the upper terrace level, and that X_I represents the oldest known X sediments. The X_I sediments are weathered and locally a paleosol (preliminarily classified as a Luvisol, A.G. Jongmans pers. comm.) is found at the contact with the overlying sediments (X_{II}, X_{III}

upstream Allier-Dore confluence

downstream Allier-Dore confluence

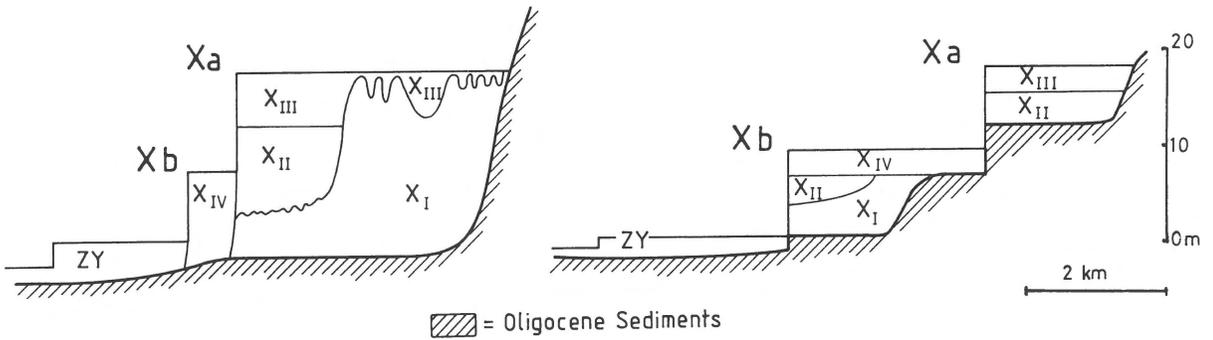


Fig. 6. Morphology and schematical lithostratigraphy for the Xa and Xb terraces.

and X_{IV}). An organic-rich clay layer at the base of the X_I unit was ¹⁴C dated at 29 560 ± 330 BP (GrN-17242), i.e. Middle Pleniglacial. The pollen content of this layer suggests a climate colder than today (Tufféry 1986).

The four distinguished Late Weichselian units are also found at other sites. Their general characteristics are schematically shown in Fig. 6 and described below.

X_I: This lithostratigraphic unit, XW according to Kroonenberg et al. (1988), consists of gravelly sedi-

ments relatively poor in volcanic components. Its thickness changes from almost 20 m to less than 3 m. This unit is a weathered and strongly dissected relict of a former terrace level at about 20 m above present river level. It is found in both X terrace levels Xa and Xb.

South of Maringues and west of La Bas Lachamp (Fig. 1 no. 4) uneroded remnants of this 20 m terrace are found. The upper 1–2 m of the X_I sediments are commonly disturbed by cryoturbation and large frost wedge casts (Figs 7, 8). A cryoturbated clay layer in the upper 2 m of this unit (Fig. 7) west of La

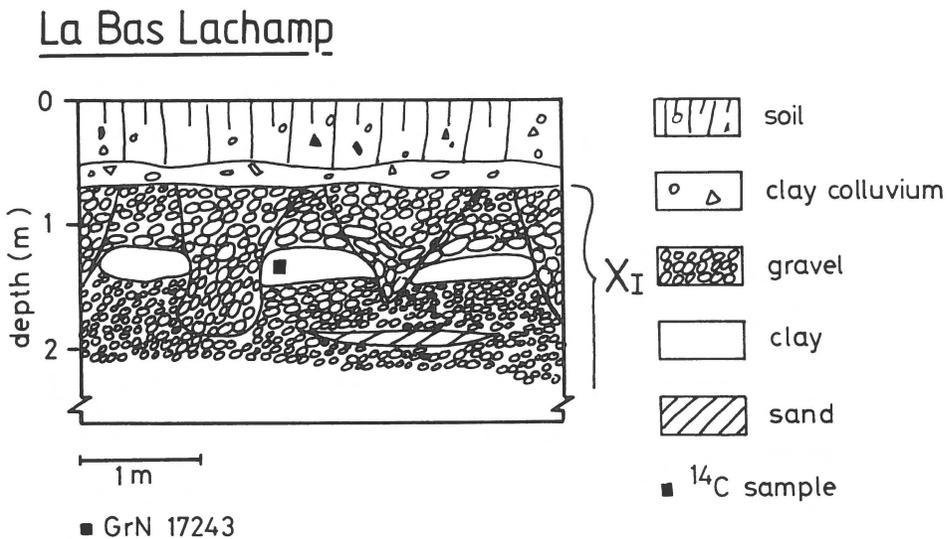


Fig. 7. Cryoturbation of the top X_I sediments at La Bas Lachamp.

Culhat

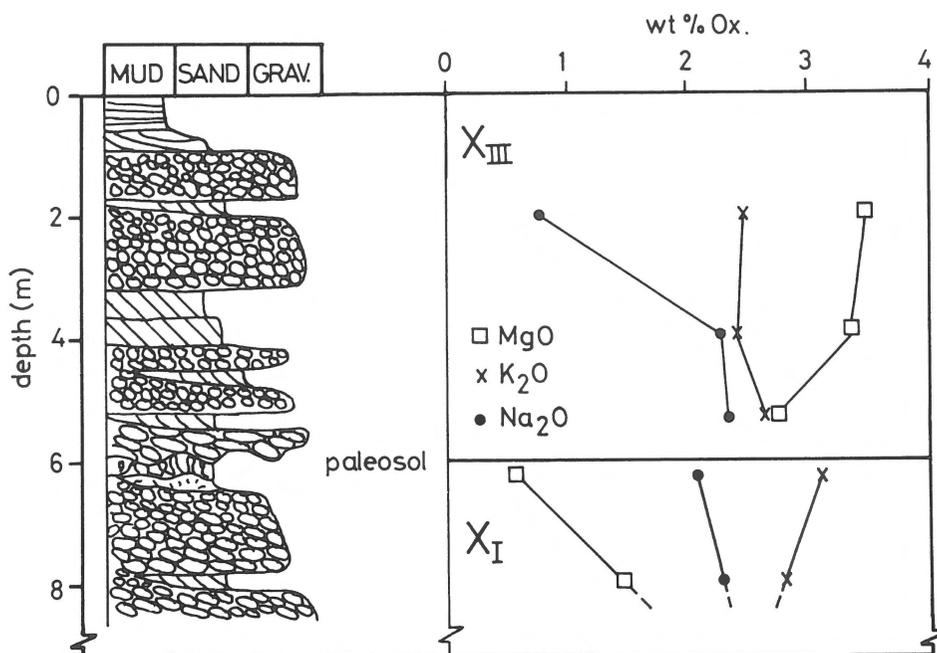


Fig. 8. Section in X_{III} sediments overlying cryoturbated paleosol in X_I sediments at Culhat. Note increase of MgO in X_{III} .

Bas Lachamp has a ^{14}C age of $16\,585 \pm 250$ BP (GrN-17243) which gives a minimum age for the X_I sediments and a maximum age for the last major cryoturbation activity in the X_I sediments.

X_{II} : This lithostratigraphic unit, the 'crystalline X terrace' according to Larue (1977), predominantly consists of sandy sediments with a low volcanic content. It occurs very locally on top of the X_I and below the X_{III} and X_{IV} sediments, and has a thickness ranging from 3 to less than 1 m. This unit is found in terrace level Xa as well as in Xb (Fig. 6). Its sediments are unweathered and yielded no pollen or other datable material.

X_{III} : This lithostratigraphic unit usually forms the top layer of the Xa terrace level (± 20 m above river level), and consists of gravelly sediments very rich in volcanic components. It overlies both X_I and X_{II} units. These sediments, which lack any datable material, are closely related to deglaciation in the upper Allier basin and have a fluvio-glacial origin (Bout 1963, Kroonenberg et al. 1988). The X_{III} sedi-

ments locally buried (Fig. 1, no. 5) some strongly cryoturbated paleosols in X_I sediments (Fig. 8) indicating a maximum age for the X_{III} sediments of approximately 16 500 BP (age of buried cryoturbated clay in paleosol in X_I sediments).

Correlation of the Allier sediments with the Late Pleniglacial sediments in the Artière basin in the western Limagne suggests that the age of the X_{III} unit is between 11 500 and 41 000 BP (Lenselink et al. 1990). This pre-Allerød age was confirmed by an observation near Lempdes, 10 km E of Clermont-Ferrand, where X_{III} sediment is buried under the same trachy-andesitic Allerød ash as that dated in the Ravel and Artière basins (Kroonenberg et al. 1987, Lenselink et al. 1990, Juvigné et al., in press). Therefore, the X_{III} unit was deposited between 16 500 and 11 500 BP.

X_{IV} : This lithostratigraphic unit is the top layer of the Xb terrace level (± 10 m above river level) and consists of gravelly and sandy sediments rich in volcanic components (Fig. 9). An organic clay block of a buried paleosol at the basis of the X_{IV} sediment

St. Yorre

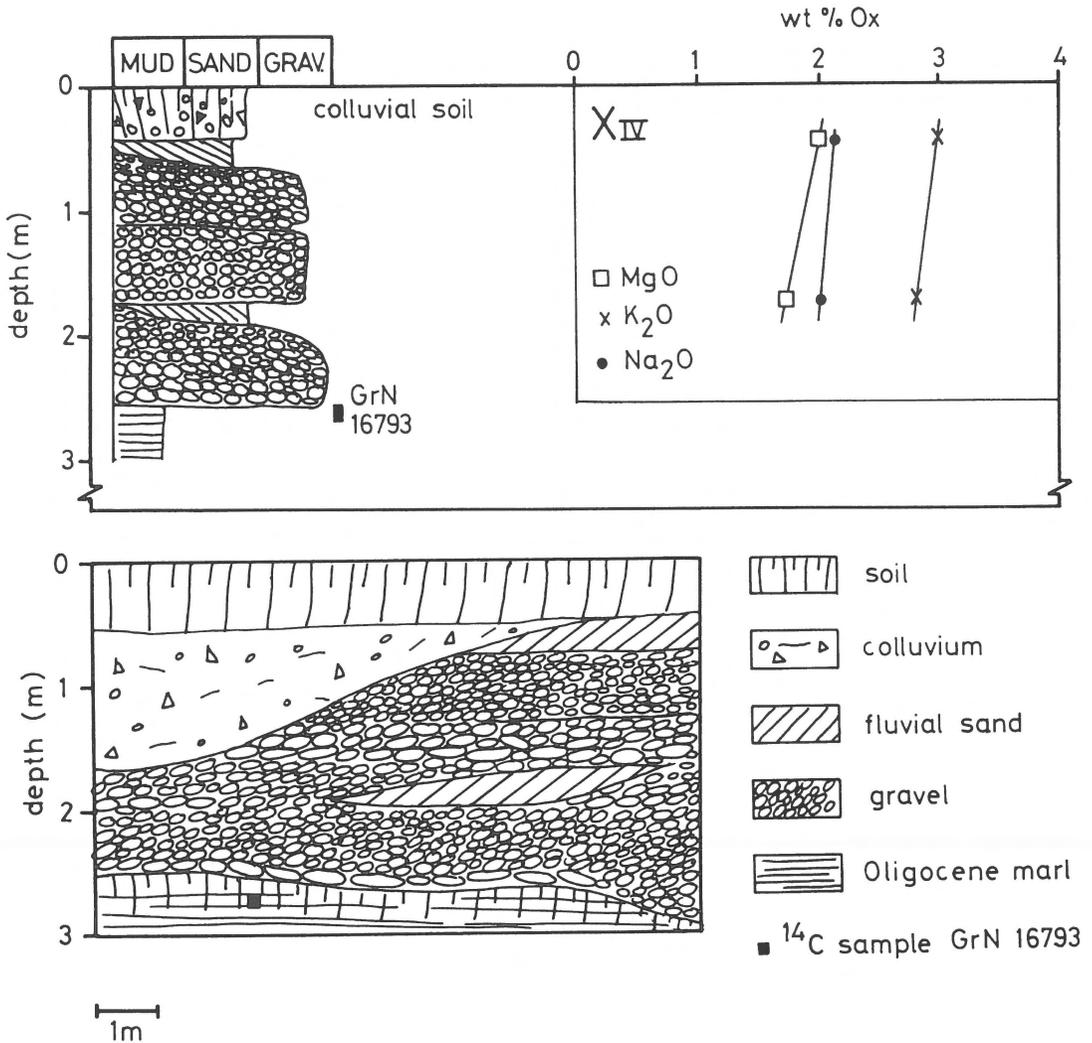


Fig. 9. Upper part: key section in X_{IV} sediments at St Yorre. Lower part: Face view of same section.

unit at St Yorre (Fig. 1, no. 6) has a ¹⁴C age of 11 380 ± 100 BP (GrN-16793; Fig. 9). Another paleosol in the top layer of X_{IV} at Les Granvaux, buried by a local sand fan, has an age of 7310 ± 70 BP (GrN-16795). The X_{IV} sediments were thus deposited between 11 380 ± 100 and 7310 ± 70 BP.

At Longues the X_b terrace level is found at about 8 m above river level (Fig. 4). It consists of gravelly and sandy sediments rich in volcanic components (much MgO and less K₂O), impregnated and capped with travertine. This level was dated by Raynal (1984) as Younger Dryas by means of a cor-

relation with a nearby dated archeological site. We dated organic matter of a paleosol in the top sediments buried under half a metre of pure travertine. This post-depositional organic matter has a ¹⁴C age of 9630 ± 90 BP (GrN-16912), which confirms the Younger Dryas age of the X_{IV} sediments. However, the CaCO₃ in the same sample was ¹⁴C dated at 25 200 ± 900 BP (GrN-16912). As the CaCO₃ was precipitated in and around the dated organic matter, it should be younger than the organic matter. Possibly the dated CaCO₃ contained 'fossil' carbonate from nearby Oligocene limestones.

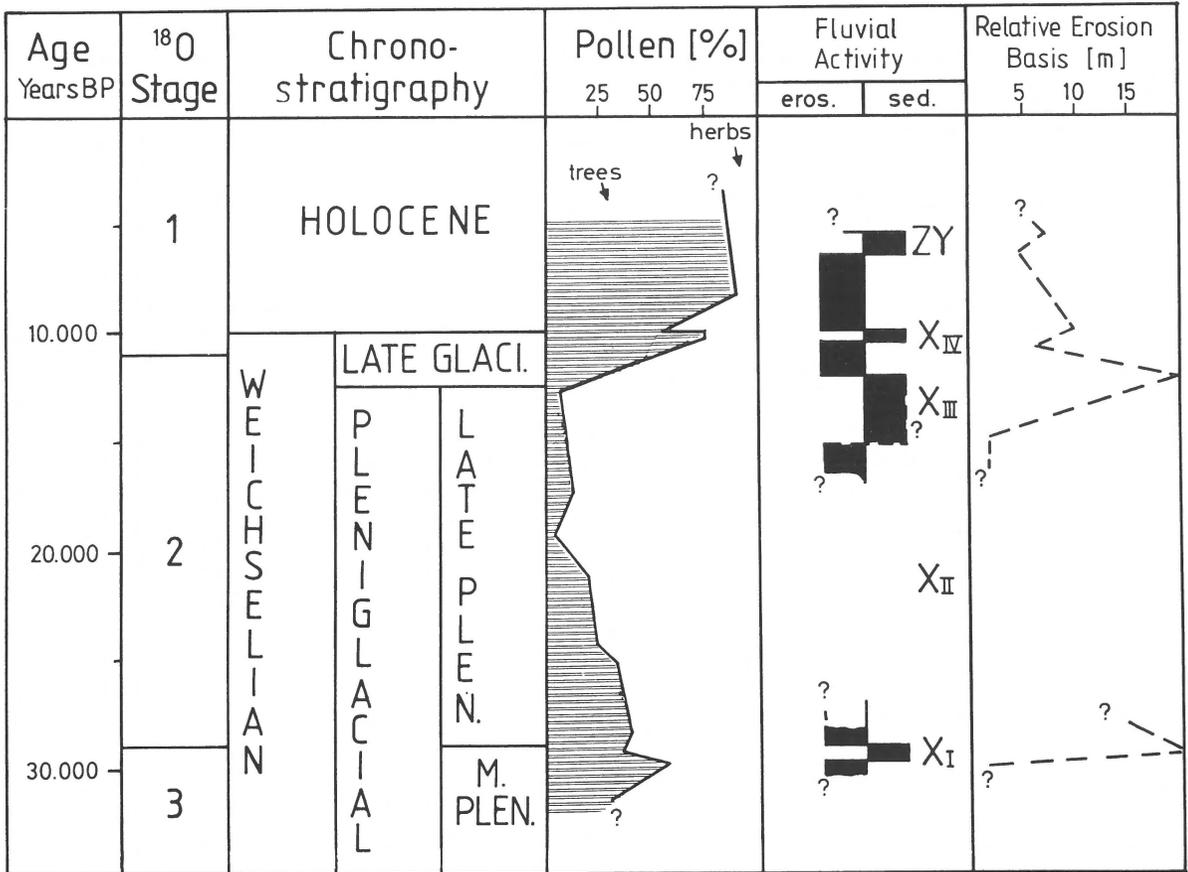


Fig. 10. Schematic chronology of the Allier Weichselian sediments. Palynology taken from different sources (see text).

ZY: This Holocene unit consists of at least three different terrace levels with predominantly sandy sediments, relatively poor in volcanic components. The oldest dated sediments from gullies incised in X_{IV} , have a ^{14}C age of 6230 ± 100 BP (GrN-16794). A similar Atlanticum age was found for the oldest Holocene terrace level (Lambert et al. 1980).

A regional reconstruction of the Late Quaternary Allier dynamics

The reconstructed chronology starts in the Late Saalian (Riss) with the deposition of the Wb_I and Wb_{II} sediments. There are not sufficient data available to correlate them with any documented climatic event or environment. On the basis of the datings presented above, a tentative reconstruction of Allier dynamics during the last 30 000 years have been

plotted in Fig. 10, together with the oxygen-isotope deep sea stages (Hays et al. 1976, Kominz et al. 1979) and the continental chronologies of Les Echets (De Beaulieu et al. 1984) and La Grande Pile (Woillard 1978, Woillard & Mook 1982). Regional sedimentological and palynological studies (De Beaulieu et al. 1982, Juvigné et al. 1988, Raynal et al. 1984, Reille & De Beaulieu 1988) were used to compile an approximative average pollen record for the study area.

The fluvial record started during the Middle Pleniglacial when the Allier had incised a deep valley probably down to its present level. During the Middle Pleniglacial X_I sediments filled the valley, up to 20 m above present river level. During the Late Pleniglacial these sediments underwent weathering and local dissection down to at least 15 m, before deposition of X_{II} sediments took place. In this period, the coldest episode of the Weichselian, the gla-

ciers had their maximum extension and a dry tundra existed in the Limagne (Veyret 1980, De Beaulieu et al. 1982, Raynal 1984). Under this severe climate, strong periglacial deformation of the upper X_I sediments and local deposition of the volcanic-poor X_{II} sediments took place. This cold period ended at the end of the Late Pleniglacial, triggering a large fluvio-glacial sediment flux from the high volcanic areas. The climatic improvement, which took place within a few thousand years, resulted in deposition of the gravelly volcanic-rich unit X_{III} (Bout 1963, Kroonenberg et al. 1988). This deposition caused a rise of 20 m of the river bed level and must have happened during catastrophic floods causing infilling of the paleo-Auzon valley (Lenseink et al. 1990) and lake formation in the Limagne by blocking of the lower tributaries Morge, Litroux, Buron and other ones. X_{III} sediments were probably dissected during the Bølling down to 15 m, after which the X_{IV} sediments were deposited during the colder Younger Dryas. These Late Glacial sediments in turn were dissected during the Early Holocene. Deposition of the ZY terrace unit in the Allier started in the Atlanticum.

The regional reconstruction of the Allier dynamics during the later part of the Weichselian (Fig. 10) allows to postulate a model for the relationship between climatic change and fluvial dynamics in the basin (Table 1).

Our model resembles that of Texier & Raynal (1984) in so far, that the Interglacial Holocene terrace sediments indeed have a finer texture than the coarse Pleniglacial and Late Glacial sediments. But within our model the most important changes in the Allier system are changes in sediment composition and volume induced by glacier melting on the Mts.

Dore and Cantal at the end of the Late Pleniglacial, a factor not considered by Texier & Raynal (1984).

The X_{III} sediments and lake formation in the Limagne

Oval-shaped, semi-closed depressions several kilometres in diameter, locally called 'marais' (marsh), occur in the lower parts of the Limagne rift valley. Within these marais, typical lake and swamp sediments are found (Kroonenberg et al. 1987, Lenseink et al. 1990). The marais sediments comprise calcareous lacustrine muds, organic-rich clays, colluvial clays and locally peat. The calcareous muds are not more than 0.5 to 1 m thick and consist of finely laminated micrite with locally shell fragments and abundant diatom skeletons. Most marais sediments were deposited in a marshy environment. The altitude of the top of the sediment fill of the marais coincides with that of the X_{III} unit in the Allier valley. Their geographical relation is schematically visualized in Fig. 11. As both the oldest lake sediments and the X_{III} sediments are intercalated between a Middle Pleniglacial cryoturbated surface and an Allerød trachy-andesitic ash (Kroonenberg et al. 1988, Juvigné et al., in press), their deposition seems to be coeval. The large X_{III} fluvio-glacial sediment fluxes might have blocked the local tributaries, causing the development of lakes, as sediment supply by the tributaries could not keep pace with the sudden 20 m rise in the Allier river bed. As the oldest dated lake sediments have an age of $12\,370 \pm 230$ BP (GrN-12891) (Kroonenberg et al. 1987) the X_{III} sediments are thought to be deposited between $16\,585 \pm 250$ and $12\,370 \pm 230$ BP.

Kroonenberg et al. (1987) explained lake devel-

Table 1. Simplified model showing relationship between climate and fluvial activity.

Climate	Fluvial activity
Glacial	Deposition of sediments with a relatively low volcanic content (less MgO and more K_2O). Cryoturbation of older terrace surfaces.
Transition from glacial to interglacial	Deposition of coarse volcanic-rich (more MgO and less K_2O) fluvio-glacial sediments. Strong rise in river bed level due to large sediment flux from melting glaciers.
Interglacial	Predominantly incision with temporary deposition of sandy sediment with a low volcanic content (less MgO and more K_2O).

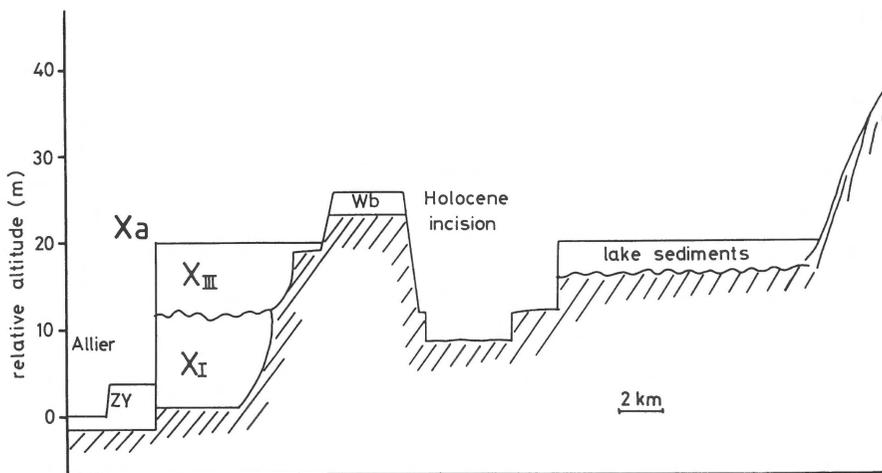


Fig. 11. Schematic morphological relation between the Xa terrace level and the lake sediments, near Culhat and Ravel.

opment by thermokarst due to permafrost degradation, a process which may have contributed to the actual lake basin morphology. Supporting evidence for the thermokarst hypothesis is the occurrence south of Issoire of a kind of marais without lake and marsh sediments, upstream the tributaries which supplied the large sediment fluxes. Apparently, both factors have played a role in lake formation in the Limagne.

Conclusions

The complex morphological and stratigraphical relationships between terrace levels and their constituting sediments in the Allier basin can be interpreted in a rather straightforward relationship between climate and fluvial dynamics. A cold-climate braided, terrace-building environment in the glacial and stadials alternates with a more meandering, eroding environment during the interglacials and interstadials. Strong fluctuations in sediment supply are related primarily to glaciation and deglaciation in the volcanic source areas of the Allier. This is reflected in sediment composition as well. Moreover, large sediment fluxes from deglaciation dammed tributary valleys, leading to the formation of lakes and marshes. Similar climate-controlled fluvial dynamics, but without glacial interference, are reported from the upstream reaches of the

Meuse (Van den Berg 1989) and Thames basins (Dawson & Gardiner 1987).

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