Riv. Ital. Paleont.	v. 88	n. 2	pp. 295 – 318	Marzo 1983

PRELIMINARY PALEOMAGNETIC INVESTIGATIONS ON PLEISTOCENE SEQUENCES IN LOMBARDY NORTHERN ITALY

ARMELLE BILLARD*, VACLAV BUCHA**,
JOSEF HORACEK** and GIUSEPPE OROMBELLI***

Key–words: Stratigraphy, Paleomagnetism, Pleistocene, Lombardy.

Riassunto. Ricerche paleomagnetiche preliminari su successioni pleistoceniche in Lombardia.

Depositi loessici, paleosuoli e depositi lacustri in Lombardia sono stati analizzati dal punto di vista della stratigrafia paleomagnetica. I depositi loessici di Copreno ed i loess e i paleosuoli di Cascina Lina e di Barlassina, attribuiti al Pleistocene superiore e medio, appartengono interamente all'Epoca a Polarità Normale Brunhes. Così pure i depositi loessici di Pontida, già datati radiometricamente, appartengono all'Epoca Brunhes. I depositi lacustri inferiori di Bagaggera appartengono all'Epoca a Polarità Inversa Matuyama, mentre i soprastanti depositi sabbioso–limosi appartengono all'Epoca Brunhes. A Leffe l'intera successione sino ai livelli lacustri più recenti appartiene all'Epoca Matuyama. Queste osservazioni comportano una attribuzione cronostratigrafica differente da quella in precedenza accettata. In particolare pongono in evidenza che il "ferretto" non è un livello cronostratigraficamente valido, almeno con il ristretto significato attribuitogli in passato.

Abstract. Paleomagnetic measurements have been carried out in continental sediments of Northern Italy. The loess deposits of Copreno, the loess and paleosols of Cascina Lina and Barlassina, and the lacustrine sediments of Pontida all belong to the Brunhes Normal Polarity Epoch, in agreement with their previous chronostratigraphic classification. The lower lacustrine sediments of Bagaggera, previously attributed to the antepenultimate glaciation, belong to the Matuyama Reversed Polarity Epoch, while the overlying sandy–loamy sequence belongs to the Brunhes. At Leffe the entire sequence up to the top of the lacustrine sediments belongs to the Matuyama Epoch, being in such way older than previously admitted. These paleomagnetic results prove that the "ferretto" is a complex of paleosols of different age, ranging from Lower to Middle Pleistocene.

Introduction

Paleomagnetic research on glaciated and non glaciated areas of Europe has been carried out within the framework of the IUGS–UNESCO International Geological Correlation Program, Project 73/1/24 "Quaternary glaciations in the Northern Hemisphere". A first study to obtain a detailed pattern of changes and reversals of the geomagnetic field during the Upper Pliocene and Pleistocene has been carried out in Italy in the Stirone river basin (Bucha et al., 1975; Bucha, 1976 a, b). The obtained results can be used for further paleomagnetic correlations of Quaternary deposits as well as for the study of the mutual re-

* Laboratoire de Géographie Physique, L.A. 141 C.N.R.S., Paris.
** Geofyzikalni Ustav, Ceskoslovenska Akademie Ved, Praha.
*** Istituto di Geologia dell'Università di Milano and Centro di Studio per la Stratigrafia e Petrografia delle Alpi Centrali, CNR, via Mangiagalli, 34 Milano.

lations between changes in the geomagnetic field and climatic fluctuations (Bucha & Sibrava, 1977).

In addition, paleomagnetic investigations were made on several lacustrine sequences (Leffe, Bagaggera, Pontida) and loess–like sediments (Cascina Lina, Barlassina, Copreno) from Lower to Upper Pleistocene in Lombardy, in the southern flank and piedmont of the Alps. This area provides suitable field conditions for a detailed subdivision and a revision of the Quaternary Alpine stratigraphy. Paleosols and weathering profiles are strongly differentiated on top of glacial and fluvioglacial sediments of different age. A large number of Lower to Upper Pleistocene lacustrine sediments dammed by moraines or terraces have been reported in the region (see particularly Venzo, 1952, 1955). Loess–like sediments with intercalated paleosols were frequently found superposed on top of stepped terraces connected with moraines. Paleontological and prehistorical data have been reported. In this geological context, paleomagnetic measurements in connection with other studies should allow to determine some geochronometric clues in the stratigraphic succession.

The field investigations were carried out by A. Billard at Leffe, Cascina Lina, Barlassina and Copreno, by G. Orombelli at Bagaggera, Pontida and Copreno. Sampling was made by V. Bucha and J. Horacek. The paleomagnetic measurements were carried out at the Geophysical Institute of the Academy of Sciences in Prague. Jelinek's spinner magnetometer JR–3 has been used for the evaluation of samples, according to the technical procedures as described in Bucha and Horacek (1973).

The Plio–Pleistocene sequence of the Alpine southern border in Lombardy

At the southern border of the Alps in Lombardy, marine Pliocene sediments are observed along a few scattered and small outcrops, followed by a sequence of continental sediments, part of which is related to the development of large alpine glaciers which extended onto the piedmont or remained inside the mountain valleys.

In the studies relative to Lombardy (particularly Penck & Brückner, 1909; Venzo, 1948, 1950, 1955; Riva, 1957; Gabert, 1962; Fränzle, 1965; Ugolini & Orombelli, 1968; Chardon, 1975) the stratigraphic sequence of the continental sediments is established as follows:

– fluvio–lacustrine sediments attributed to Villafranchian;

– conglomerates in superposition or lateral transition to the fluvio–lacustrine sediments. In the region such conglomerates are named "ceppo". They are referred to different ages from Villafranchian to Mindel, according to the various authors;

– glacial and fluvioglacial sediments classified as Mindel, Riss and Würm after Penck (in Penck & Brückner, 1909). Later some indications were given about similar but older sediments attributed to Günz (Levy, 1915; Nangeroni, 1929, 1954) (1).

All the above mentioned authors admit that a thick red soil called "ferretto" developed during the Mindel–Riss interglacial and is a characteristic feature for the Mindel deposits, although Penck (1909, p. 789), Levy (1915, p. 348) and later Venzo (1965, p. 33) allowed for the existence of more than one "ferretto" of different age.

After a study of the paleosols and weathering profiles developed at the upper part of the outwash terraces and a differentiation of the overlying loess–like sediments (Billard, 1973, 1975, 1977), the stratigraphic sequence was found to be more complicated than previously admitted. A larger number of glacial / interglacial cycles was identified. The so–called "ferretto" turned out not to be a specific soil formed during a single interglacial period: "ferretto" soils developed during interglacial periods probably from Lower Pleistocene to the lower part of Middle Pleistocene. Then the intensity of weathering gradually decreased leading to a progressive change in the characters of paleosols.

Loess and loess–like sediments north of Milano

Sections exhibiting loess and loess–like sediments are mainly located on top of fluvioglacial terraces. According to Penck's interpretation (in Penck & Brückner, 1909), the classical stratigraphic subdivision in the area extending from the external Como moraines to the northern suburbs of Milano is as follows:

– "low terraces" connected with "young moraines" and attributed to Würm;
– "high terraces" connected with "old moraines" and attributed to Riss;
– "higher terraces" with "ferretto" surfaces, attributed to Mindel.

On the basis of the geomorphological data and characteristics of superposed fossil soils developed on the gravels and overlying loess–like sediments, Billard (1973, 1977) subdivided the so–called "ferretto" surfaces into 5 different terraces classified 1 to 5 from the older to the younger one, and related to 5 different glacial stages.

Three sections have been selected for this study (Fig. 1). The Copreno section is located at the top of a "high terrace", classically dated as Riss, with one interglacial fossil soil on top of the gravel underlying the loess cover.

The Barlassina and Cascina Lina sections are located at the top of two "higher terraces". Since Penck (in Penck & Brückner, 1909) both have been classically dated as Mindel. But they are obviously not of the same age, as 2

(1) Glacial and fluvioglacial deposits attributed to Günz have been also reported by Penck (1909, p.873) on the Lombard side of the Garda morainic amphitheatre.

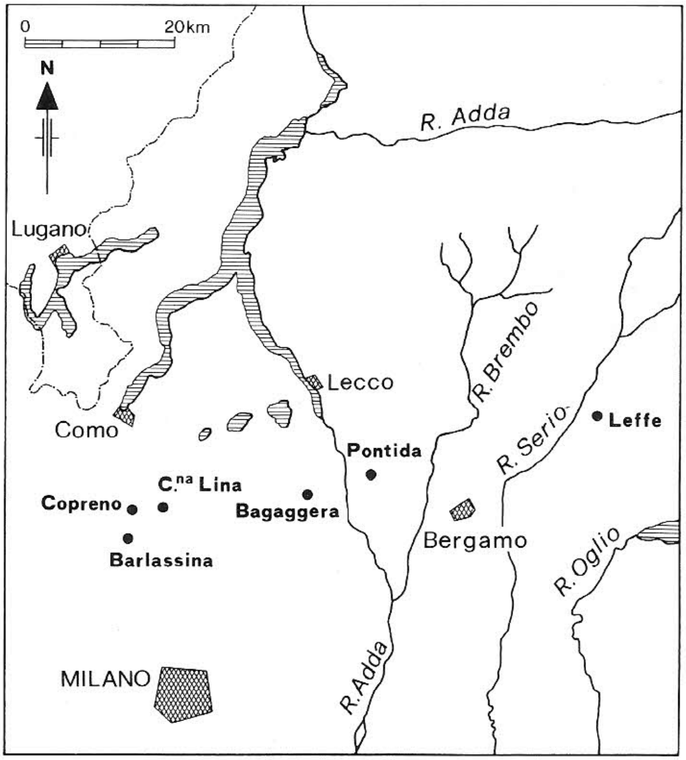

Fig. 1 — Index map of central Lombardy showing the location of the studied sections.

interglacial fossil soils developed on the gravel and loess–like sediments of Barlassina terrace, whereas 3 interglacial fossil soils developed on the gravel and loess–like sediments of Cascina Lina terrace. The Barlassina terrace is related to the antepenultimate glacial stage. It would be classified as Mindel or as Riss I in the Alpine nomenclature. The Cascina Lina terrace is referred to the preceding glacial stage.

Geological data.

Copreno. The loess section of Copreno is exposed along a road cut at the top of a fluvioglacial terrace on the west side of the river Seveso, about 20 km north of Milano (Fig. 1). This section has been first studied by Orombelli (1970) and later by Billard (1973, 1977). According to both authors, the sequence is composed of at least three main loess accumulations, with a total thickness of about 4 m. On the basis of stratigraphical and pedological evidences the entire loess sequence is attributed to the last glaciation.

The section of Copreno (Fig. 2) can be summarized as follows, from top downward:

1) fine–sandy silt loess, brown to brownish yellow in color (2.00 m); on this loess sheet a postglacial *sol brun lessivé* is developed, with a *solum* thickness of about 1.40 m;
2) fine–sandy silt loess, yellowish brown in color, coarser at the base (0.90 m); this loess sheet is subdivided by weakly developed interstadial soil profiles, and shows evidence of involutions and frost cracks;

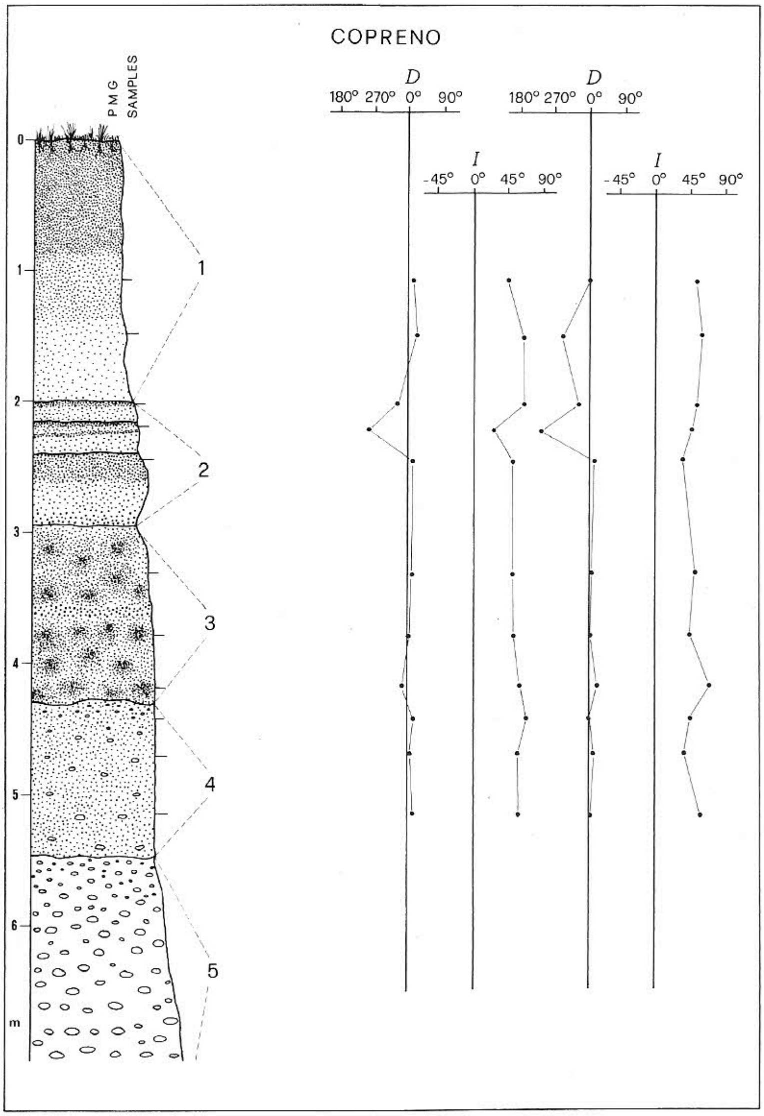

Fig. 2 – The loess section of Copreno: stratigraphy and paleomagnetic measurements. Large numbers refer to the description in the text; D, magnetic declination; I, magnetic inclination.

3) yellowish brown, mottled, sand and sandy silt loess (1.35 m);
4) brown to reddish brown silt loam, with scattered quartz pebbles (1.20 m); this layer has been interpreted as an interglacial (last interglacial) soil or soil sediment;
5) dark brown to brown sandy gravel, interpreted as a fluvioglacial deposit (3,10 +m).

The sequence is entirely leached of carbonates and oxidized. At present the Copreno section is believed to be one of the best preserved records of the Würm loess south of the Alps.

Barlassina. The loess–like sediments and flood loam sequence of Barlassina is located at the surface of terrace 5, also called Barlassina terrace, 25 km N of Milano. The section has been studied by Billard (1973, 1975, 1977) and can be described as follows from top downward (Fig. 3):

1) loess–like sediment, brown at the top to yellowish downward, about 70–90 cm thick, in which the postglacial *brun lessivé* soil moderately evoluted is developed;
2-1) fine sandy loess–like sediment, about 30 cm thick, in which a pale grey strongly leached horizon is developed, which tongues into the underlying horizon;
2-2) strong brown–yellow loess–like sediment in which the Bt–B horizon of a *lessivé* soil is developed; strong prismatic overstructure underlined by the tonguing of the overlying horizon; thickness about 80 cm;
3-1) pale brown, fine silty flood loam with fragipan structure; subhorizontal layers of pale grey sandy silt which tongue into the underlying horizon; few scattered pebbles; thickness about 30 cm;
3-2) reddish brown flood loam, with scattered pebbles, in which the Bt horizon of a *lessivé* soil is developed; strong prismatic overstructure underlined by the tonguing of the overlying pale grey layers; thickness of about 2 m. Another section, located in the same clay pit, exhibits the underlying fluvioglacial gravel of Barlassina terrace, with the base of the reddish brown *lessivé* soil already observed in flood–loam 3–2.

The entire Barlassina sequence is leached of carbonates. The micromorphological analysis demonstrates the evidence of 3 superposed *lessivé* soils. Fossil soils 3–2 and 2–2 are more evoluted than the postglacial soil 1 developed at the top of the section. Therefore they are interpreted as interglacial soils. The formation of each was followed by a glacial period with development of a "cryodégradé" horizon strongly leached of clay and iron, then fossilization occurred under another loess, submitted later to the same cyclic evolution.

Cascina Lina. The Cascina Lina sequence is located at the surface of terrace 4, also called Meda terrace (25 km N of Milano). Loess–like sediments, gravel deposit and soils have been described by Ugolini and Orombelli (1968) and later by Billard (1973, 1977). The Cascina Lina section exhibits the following sequence from top downward (Fig. 4):

1) silty loess–like sediment about 1 m thick, brown at the top to yellowish downward; evidence of a postglacial *brun lessivé* soil weakly developed;
2-1) fine sandy loess–like sediment, about 30 cm thick in which a pale grey strongly leached horizon is developed and tongues into the underlying horizon;

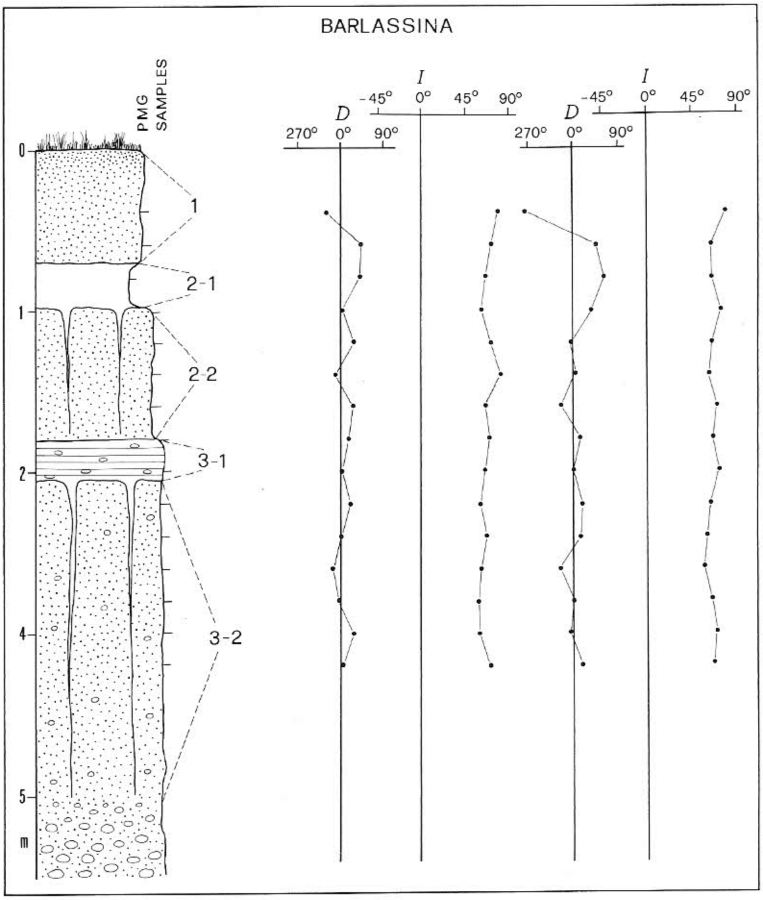

Fig. 3 — The Barlassina section: stratigraphy and paleomagnetic measurements. Large numbers refer to the description in the text; D, magnetic declination; I, magnetic inclination.

2-2) brown to brownish yellow loess—like sediment with development of the Bt—B horizon of a *lessivé* soil; strong prismatic overstructure underlined by the tonguing of the overlying horizon; thickness about 70—80 cm;

3-1) pale brown loess—like sediment with a fragipan structure; layers of pale grey sandy silt, horizontal then tonguing into the underlying horizon; thickness about 1.50 m;

3-2) reddish brown loess—like sediment with development of the Bt—B horizon of a *lessivé* soil; strong prismatic overstructure underlined by the tonguing of the overlying pale grey layers; thickness about 1.50 m;

4) bright red to orange flood loam with development of the Bt horizon of a *lessivé* soil; presence of scattered weathered pebbles; thickness about 60—70 cm.

Another section exhibits the underlying fluvioglacial gravel of Meda terrace, on top of which is developed the same bright reddish *lessivé* soil as in sediment 4 of Cascina Lina.

The entire Cascina Lina sequence is completely leached of carbonates. The micromorphological studies put in evidence the same litho–pedologic evolution as in the previous section, but 4 superposed *lessivé* soils are developed here in place of 3. A lithostratigraphic correlation is made between the sediments 1, 2 and 3 of the two sequences. Therefore flood–loam 3 and the underlying fluvioglacial gravel of the Barlassina terrace are believed to be contemporaneous with loess–like sediment 3 of Cascina Lina. Flood loam 4 of Cascina Lina and the underlying fluvioglacial gravel are attributed to the previous glacial period.

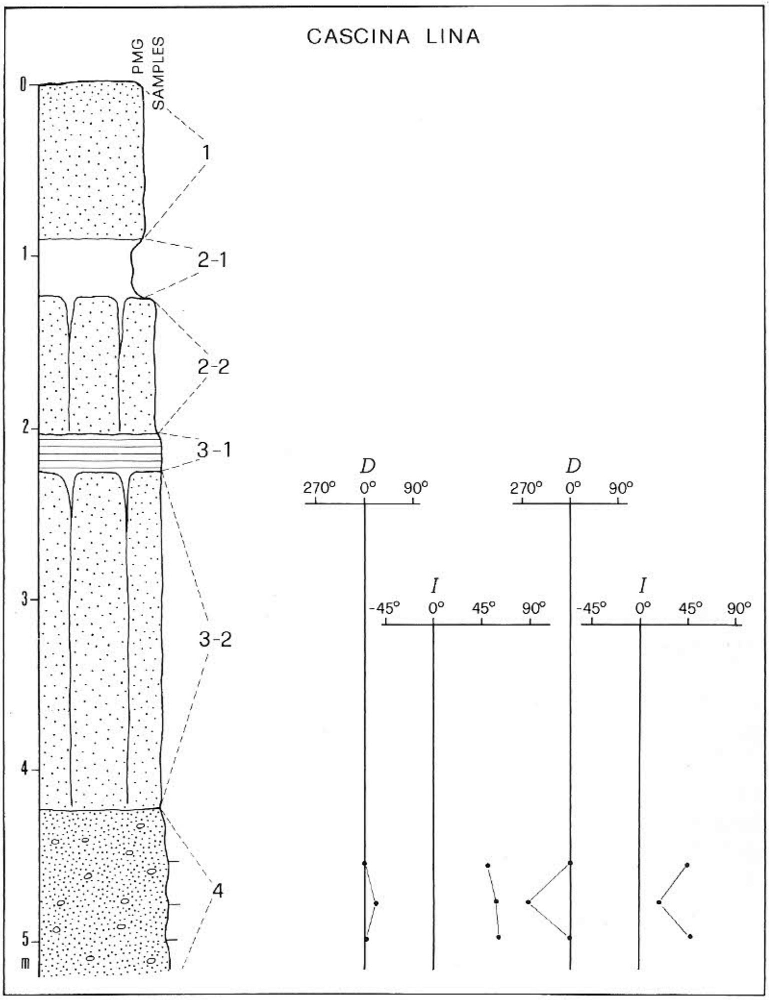

Fig. 4 – The Cascina Lina section: stratigraphy and paleomagnetic measurements. Large numbers refer to the description in the text; D, magnetic declination; I, magnetic inclination.

Sampling has been done only in the Cascina Lina flood loam which is older than the Barlassina sediments (Fig. 4).

Paleomagnetic data.

The paleomagnetic measurements put in evidence values of magnetic declination D close to zero and positive values of magnetic inclination I in the entire sequences of Copreno, Barlassina and Cascina Lina. The investigated sediments fall into the range of the Brunhes Paleomagnetic Epoch. This conclusion is in conformity with the Upper and Middle Pleistocene age indicated by the geological study. It points out the complexity of the upper part of the Middle Pleistocene where several glacial and interglacial stages, clearly differenciated at Barlassina and Cascina Lina, have to be distinguished.

Pleistocene lacustrine sediments in Lombardy

Pleistocene lacustrine sediments are very common at the southern margin of the Lombard Prealps and in the piedmont area. Proglacial lacustrine sediments related to the last glaciation (and less frequently to the penultimate glaciation) can be found in the large moraine amphitheatres of the Ticino and Adda glaciers, or in lateral valleys dammed by moraines. In non glaciated areas lacustrine sediments attributed to the Lower–Middle Pleistocene were formed in basins caused by alluvial damming and/or by tectonic activity. Three lacustrine sequences have been sampled for paleomagnetic investigations: Pontida (Bergamo), Bagaggera (Como) and Leffe (Bergamo).

Pontida.

Geologic data. The Würmian lacustrine deposits of Pontida (Bergamo), 15 km to the SSE of Lecco (Fig. 1), were sedimented in a small proglacial lake, dammed by a lobe of the Lecco piedmont glacier, entering the valley of S. Martino, at the foothills of the western Bergamasc Prealps (Desio, 1928; Venzo, 1948, 1955; Riva, 1957; Gabert, 1962). The lake was closed downvalley, on the eastern side, by the end moraine of S. Giacomo (307 m) and upvalley, on the western side, partly by the end moraine of Drizzago (310 m) and, for a longer distance, by the glacier terminus itself. This is proved by the presence of ice–contact, partly collapsed, deltaic deposits along the western margin of the lacustrine sediments (Alessio et al., 1979).

In two large clay–pits an upward coarsening regressive sequence of glaciolacustrine sediments is exposed, with a total thickness of about 20 m (Fig. 5).

From top downward:

1) coarse fluvioglacial sandy gravel with horizontal bedding (4 m); in the sampled section (Fig. 5) only 1 m was left by the excavation work;
2) ice–contact deltaic sand and gravel, composing foreset beds dipping ESE with an inclination up to 28° (5 m);
3) laminated silty clay and silt, gray or olive in color, with scattered ice–rafted pebbles and cobbles; locally the lacustrine sediments are in lateral contact with deltaic collapsed sand and gravel (12–15 m);
4) basal till of variable thickness;
5) bedrock (Cretaceous sandstone).

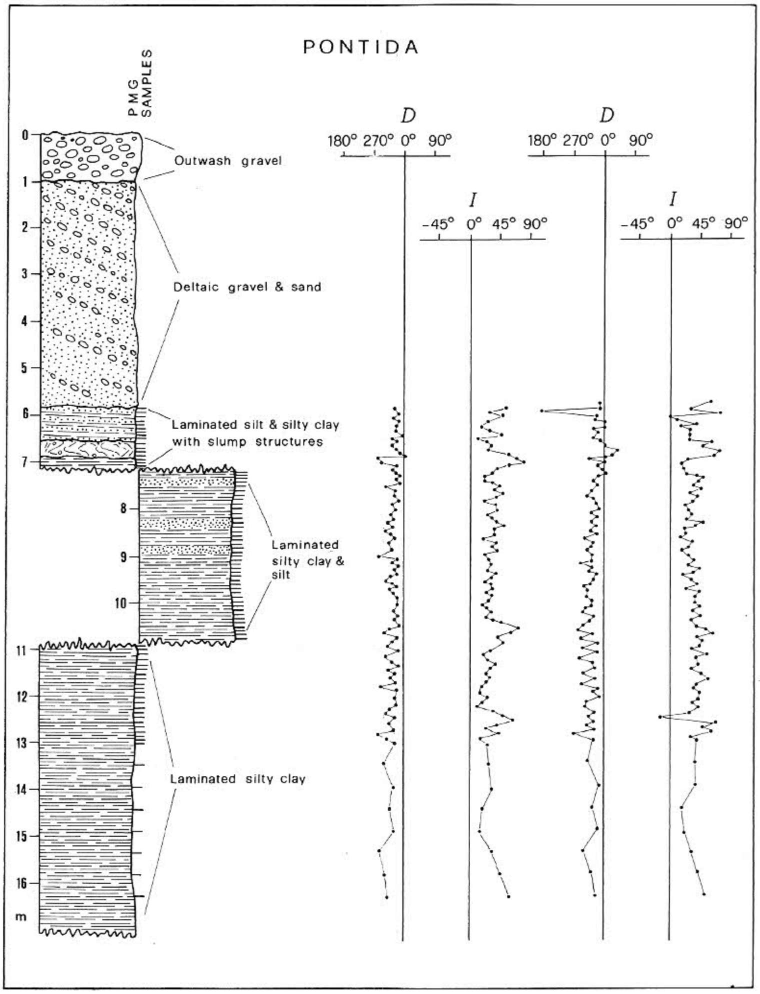

Fig. 5 – The lacustrine sequence of Pontida: stratigraphy and paleomagnetic results. D, magnetic declination; I, magnetic inclination.

In the clay–pit of Bondi, immediately to the north of the Lecco–Bergamo road, in the upper part of the lacustrine laminated clay and silt, organic remains were collected, which were dated 17,700 ± 360 ^{14}C yr B.P. (Orombelli, 1974; Alessio et al., 1979). This age, according to the stratigraphic relationships, must be referred not only to the lacustrine sediments but also to the remnants of glacial and ice–contact deposits damming upvalley the lake. In this way the position of the glacier front, at this time of the lacustrine sedimentation, is also dated.

In the clay–pit of Drizzago, immediately to the south of the Lecco–Bergamo road, the lacustrine bottom sediments were sampled for paleomagnetic investigations, along a section about 12 m thick (Fig. 5).

According to the field evidence the time span recorded by this lacustrine section should be rather short (10^2 – 10^3 years). A high sedimentation rate is in fact supported by the following reasons:

a) the small size of the lacustrine basin compared with the large dimension of the damming glacier;

b) the vicinity of the sampled section to the ice–contact delta front (about 200 m);

c) no real varves were observed; the thickness of the laminae or beds ranges from 10^1 to 10^2 mm. Graded beds up to 25 cm thick, attributable to turbidity currents, are very frequent;

d) other proglacial lacustrine sediments of comparable age and environment in the nearby area show rhythmytes of an average thickness of the order of 10 mm.

In conclusion it is possible that the investigated Pontida section represents a time span of hundreds to a few thousand years, around 18.000 years B.P.

Paleomagnetic data. The paleomagnetic measurements gave values of declination D mainly between 300° – 330° and positive values of magnetic inclination I along all the lacustrine section of Pontida. Relatively low values of magnetic inclination observed can be compared with the decrease corresponding to the interval between 12,000 and 16,000 years, as described from several sections in Czechoslovakia (Vracov, Komorany near Most, Valca) and some localities in Italy (Bucha, 1976 a; 1977a, b). On the basis of geological, radiometric and paleomagnetic data the age of the Pontida deposits belongs to the youngest part of Late Pleistocene.

Bagaggera.

Geologic data. The lacustrine sediments of Bagaggera (Como) are located in Val Curone, a small valley on the eastern side of the hill of Montevecchia (479 m), about 15 km to the south of Lecco (Fig. 1). According to Venzo (1948, 1952, 1955) the lacustrine sequence cropping out in the Bagaggera clay pit was as follows, from top downward:

a) reddish brown clay (5 m);
b) grey laminated clay with remains of Fishes and shells of *Unio* (9 m);
c) light grey clayey sand, rich in logs and *strobili* of large conifers (*Abies alba*), with pollens of *Abies*, *Pinus* and *Fagus*, and with bones of *Cervus* (2 m);
d) blue–grey laminated clay (3 m).

The same author thought that the lacustrine basin of Bagaggera should have been dammed by the piedmont glacier of Lecco during the Mindel glaciation. He attributed the entire sequence to the late Mindel – early Mindel/Riss, on the basis of the presence of a "ferretto" soil on the top of the sequence.

The same opinion was maintained by Gabert (1962). Chardon (1975) described a section in the clay pit of Bagaggera; he attributed to a Mindel moraine the damming of the Curone valley but referred to Riss sand and clay beds that he supposed to pass laterally to the lacustrine sediments described by Venzo, and not more exposed.

At present the lacustrine sediments of Bagaggera have been almost completely excavated and only few remains are exposed on a wall of the clay pit. Fig. 6 shows the section sampled for paleomagnetic investigations. This sequence, about 9 m thick, is composed, from top downward, of:

1) reworked material (by excavation works) (0.50 m);
2) laminated sand and silt, yellowish brown, with channel structures and with intercalations of greyish brown silty clay (3.30 m);
3) massive brown silty clay, passing downward to light olive grey laminated silty clay (0.50 m);
4) olive grey sand, with a basal layer of fine gravel, made up of angular clasts of chert and quartz (1.50 m);
– unconformity;
5) strong brown, light brown and olive grey laminated silty clay, with deformation structures (1.30 m);
6) grey laminated silty clay and clay with rare thin intercalations of grey sand (1.60 m).

On another wall of an excavation recently made for a pipe–line, at about 50 m from the sampled section, a complete sequence of the deposits and soils overlying the lacustrine sediments is exposed. Taking into account the two sections the stratigraphic sequence of Bagaggera is composed of: a) a lower lacustrine unit, oxidized in the uppermost part, cropping out with a thickness of about 3 m, truncated by an erosional surface and covered by b) a polycyclic complex of cross laminated sand with lenses of gravel and silty clay units, interrupted by erosional surfaces; in the upper part a paleosol is developed with thick reddish brown clay coats; c) a superposed strong brown loam with reddish brown clay coatings; d) a loess cover at the top, containing Upper Paleolithic artifacts.

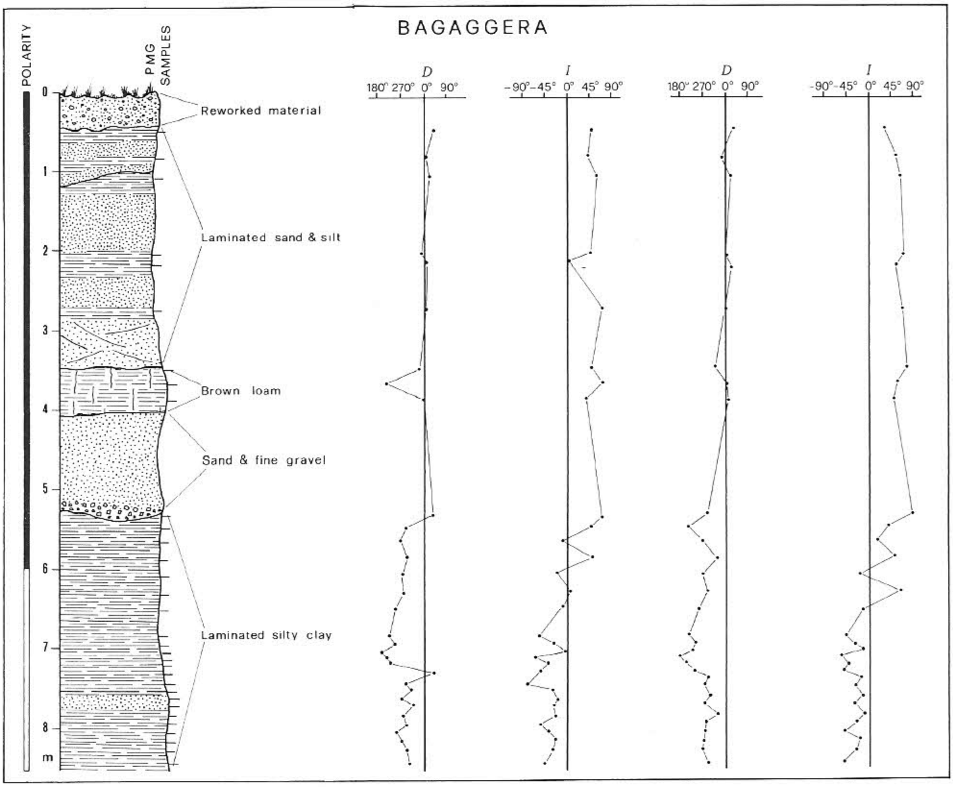

Fig. 6 — The lacustrine and alluvial sequence of Bagaggera: stratigraphy and paleomagnetic results. D, magnetic declination; I, magnetic inclination.

As far as the cause of the damming of the lake is concerned, the following observations can be made. The lacustrine deposits of Bagaggera are closed downvalley by a flat dissected terrace, of an altitude of 310 m, and about 25 m higher than the adjacent Würm outwash plain. At the base of the terrace scarp a coarse conglomerate crops out, made up by subrounded to rounded cobbles and boulders up to 40 cm diameter. The clasts are composed almost entirely of calcareous sandstone and limestone of local provenance. On the basis of the lithologic composition this conglomerate can be correlated with the lower member of the "Ceppo of Adda", a formation which crops out in the gorge of the river Adda, about 6 km to SE (Orombelli, 1979).

At the top of the terrace, in an excavation 3.5 m deep, a deeply weathered gravel, yellowish red in color, was observed, with rounded pebbles and cobbles up to 20 cm diameter. Scattered clasts of micaschist, gneiss, amphibolite, quartzite and porphyrite are still recognizable; the clasts of limestone and of calcareous sandstone are completely leached of carbonates. The lithologic composition of the weathered gravel indicates a prealpine provenance. No pebble of exclusively Alpine provenance of the upper Adda drainage (coarse grained granite and diorite, serpentinite) has been observed.

Therefore on the basis of both morphology (flat terrace) and lithology (conglomerate and weathered gravel of local or prealpine provenance) a direct damming of the Bagaggera lake by the Adda glacier (Lecco piedmont glacier) can be excluded, whereas an alluvial damming is put forward.

Paleomagnetic data. The Bagaggera section shows a clear reversal in magnetic inclination from negative values in its lower part to positive values all along the middle and upper part. The Brunhes–Matuyama boundary should consequently be present in this section. Because the reversal occurs near the change from grey to brown oxidized silty clay and because the section is not continuous it is better to say that the lower lacustrine unit is older than the Brunhes–Matuyama boundary (or possibly of the same age at the top) while the sediments overlying the major unconformity are younger.

Leffe.

Geologic data. The lacustrine sediments of Leffe are located in a small intra-alpine basin at an altitude of about 500–490 m at the top (Fig. 7). The basin is now open at its SW extremity on the left bank of river Serio. The surrounding mountains are mainly formed of Upper Triassic dolomite and limestone and Upper Mesozoic porphyritic quartz–diorite dykes and stocks.

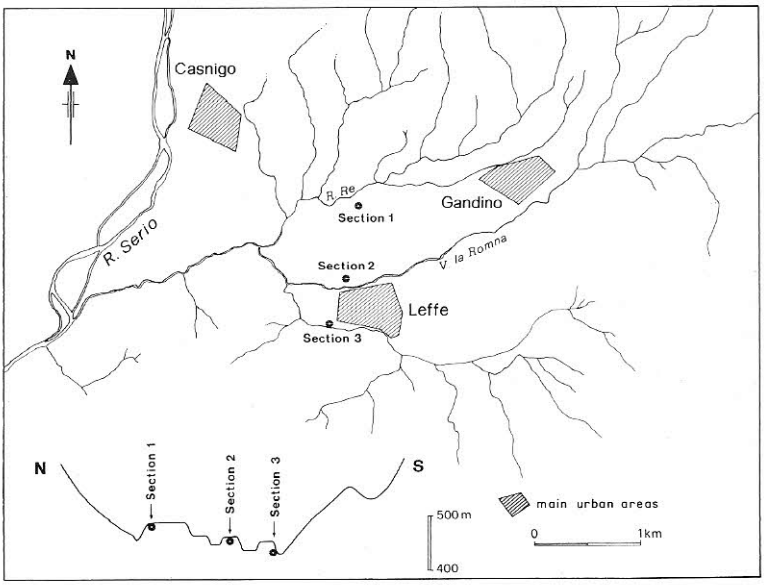

Fig. 7 – Sketch map of the Leffe area showing the location of the investigated sections.

The lacustrine sediments of Leffe are composed of laminated marl, clay, silty and sandy clay, with lignite layers and intercalations of thick and discontinuous beds of gravels and sand often strongly indurated. Lake sediments, deposited in shallow to moderately deep water, alternate with lignite formation and with coarse fluviatile or deltaic deposits more often observed at the periphery of the basin. The total thickness of the lacustrine and fluviatile sediments remains unknown as the bedrock has not been reached underneath, but is larger than 100 m.

The damming of the lake is believed to be an effect of the river Serio gravel accumulation, indurated into a conglomerate which forms the very high Casnigo terrace (altitude around 500 m, 110 m above the river Serio) and closes the Leffe basin on its west downvalley border. As already noticed by Venzo (1953, fig. 3), the conglomerate rests on top of the limestone bedrock which outcrops at the altitude of 490 m near Casnigo. Behind this dam, the Leffe basin is likely to be located in a tectonic unstable area.

A mammal fauna was discovered in the lignite mines at different levels of the lacustrine sediments. A Lower Pleistocene age has been accepted (Ambrosetti et al., 1980). The fauna collected in an upper clay layer (Vialli, 1956) might belong to the transitional period between Lower and Middle Pleistocene (Heintz, personal communication) but a revision appears necessary.

The palynological study was first produced by Lona (1950), and completed by Lona and Follieri (1957) for the upper part of the sequence. The lowermost part of the sequence was studied later by Lona (1963) and Lona and Bertoldi (1973). Ten main cold climatic phases were observed and tentatively attributed to different glaciations and stadials from Donau to Mindel. Venzo (1950, 1953, 1965a) and Lona and Follieri (1957) pointed out the existence of a thick and strongly evoluted "ferretto" on top of the lacustrine sediments and of the damming Casnigo terrace. The fact was considered as a chronostratigraphic reference and a Mindel age was consequently given to the upper part of the sequence.

Although the evidence of climatic fluctuations in the continental sediments of Leffe is of major interest, the chronostratigraphic interpretation remains questionable. Much uncertainty still exists in the definition of the Alpine Penck's stratotypes. A correlation between the Leffe lacustrine sediments (with significant climatic changes) and the fluvioglacial terraces of Bavaria is highly tentative. Moreover the dating of the top of Leffe sequence as Mindel, based on the presence of a "ferretto", is strongly doubtful althought admitted by many authors who have worked in North Italy.

The palynological sampling was made close to the central part of the basin in the lignite mine of S. Lucio and in the two clay pits located about 500 m more to the SW. The deepest lacustrine sediments were sampled in two boreholes, down to an altitude of about 390 m a.s.l. The total thickness of the sampled sediments was 60 m. In the western part of the basin Venzo (1961) observed lacustrine sediments as deep as 440 m, with a lignite bank at the base. This bank can tentatively be correlated with the two lignite layers of the S. Lucio mine, as Venzo (1950, 1961) suggested a reduced thickness for the marginal lacustrine deposits.

Sections and wells used for the palynological studies are not available any more. The sampling for paleomagnetic investigations was made along sections excavated into three different topographic levels. The corresponding sediments have been considered to be regularly but not continuously superposed, as a gap exists between each section. They are located along a transversal section going across the Leffe basin from NNE to SSW (Fig. 7).

Section 1 (1 km W of Gandino; 0.5 km S of Cazzano S. Andrea; altitude 490 to 470 m) is excavated in the higher level of the Leffe sequence, very close to the clay pit located above the S. Andrea mine (Venzo, 1950, 1961) with a same altitude at the top. It has to be subdivided into 3 subsections.

The sampling started in subsection 1–1, at 490 m, very close to the top of the lacustrine sediments, under a mound of artificially reworked red weathered material (Fig. 8). Therefore the «ferretto» top soil has not been sampled. Description is summarized as follows from top downwards:

1) laminated grey fine sand and yellowish silty clay with small load deformations. Interbedded fine sand locally cemented. Total thickness 2 m;
2) grey to yellowish laminated silty clay. Intercalations of some cross laminated coarse to middle sand with reworked clay clasts. Total thickness 2 m;
3) grey to pale yellow laminated silty clay (laminae 1 mm to 1 cm). Some thin cemented fine sand beds. Total thickness 5 m.

Directly underlying this sequence, a coarse sediment extends, composed of sandstone at the top and conglomerate at the base (Fig. 9). The total thickness is 4.50 m. Beds of pale brown silt, silty clay and greyish blue silty sand are intercalated in the conglomerate. Sampling was done in these intercalated fine grained sediments which form the second subsection 1–2, at an altitude of 475 to 470 m (Fig. 9).

The third subsection 1–3 (silty and sandy clay layers) is located a little further west, along the road from Gandino to Villa Giuseppina at an altitude of about 470 m.

A Mindel age, based on the presence of a "ferretto" at the top, has been given by Venzo (1950, 1961), Lona and Follieri (1957), Lona (1963) and Lona and Bertoldi (1973) to this entire upper sequence.

Section 2 is located NW of Leffe with an altitude of 465 m at the top. Under slope deposits with large clasts of sandstone, laminated blue clay and yellowish silty and sandy clay beds are intercalated with a sharp contact into

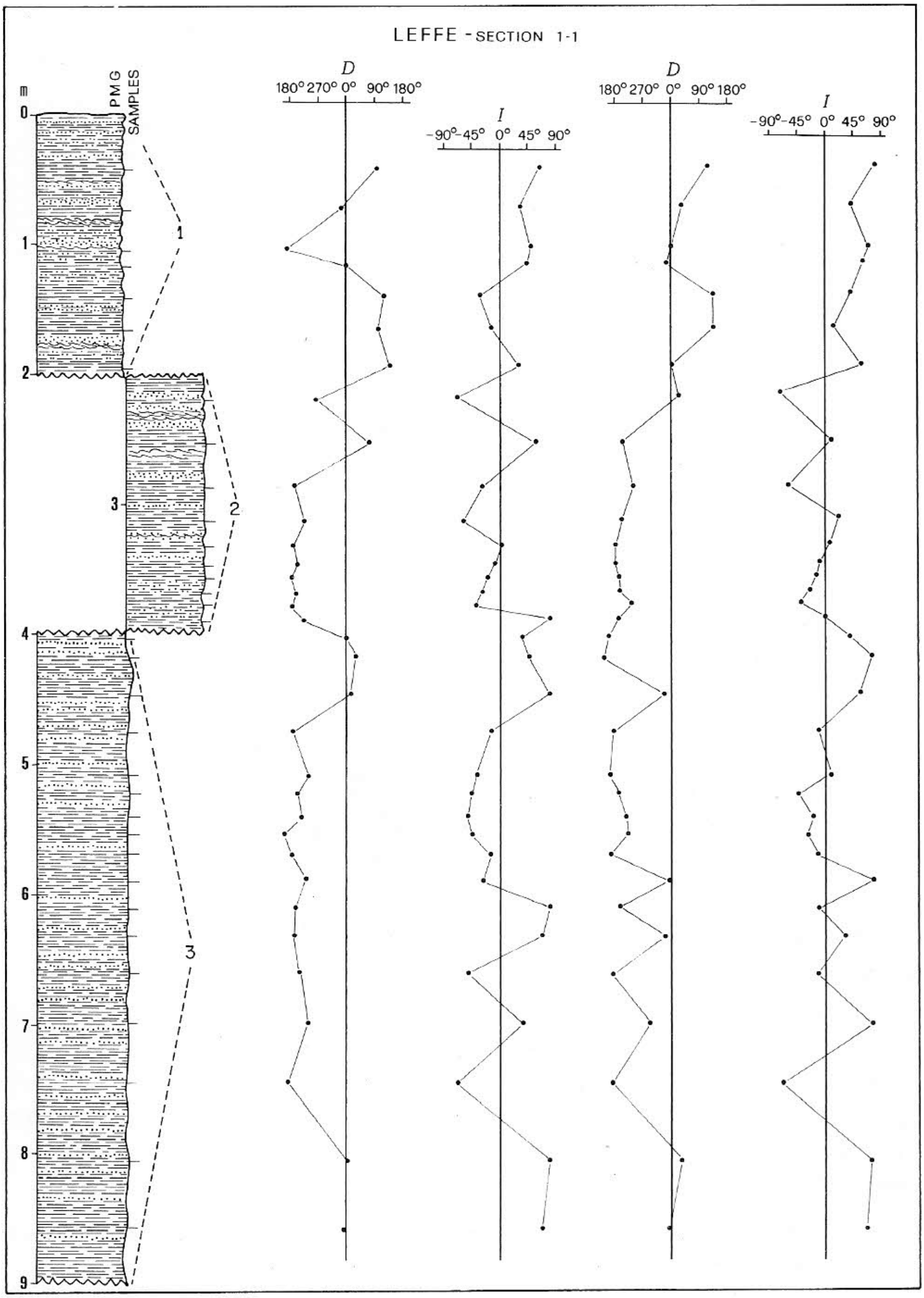

Fig. 8 – The uppermost part of the lacustrine sequence of Leffe (section 1–1): stratigraphy and paleomagnetic measurements. Large numbers refer to the description in the text; D, magnetic declination; I, magnetic inclination.

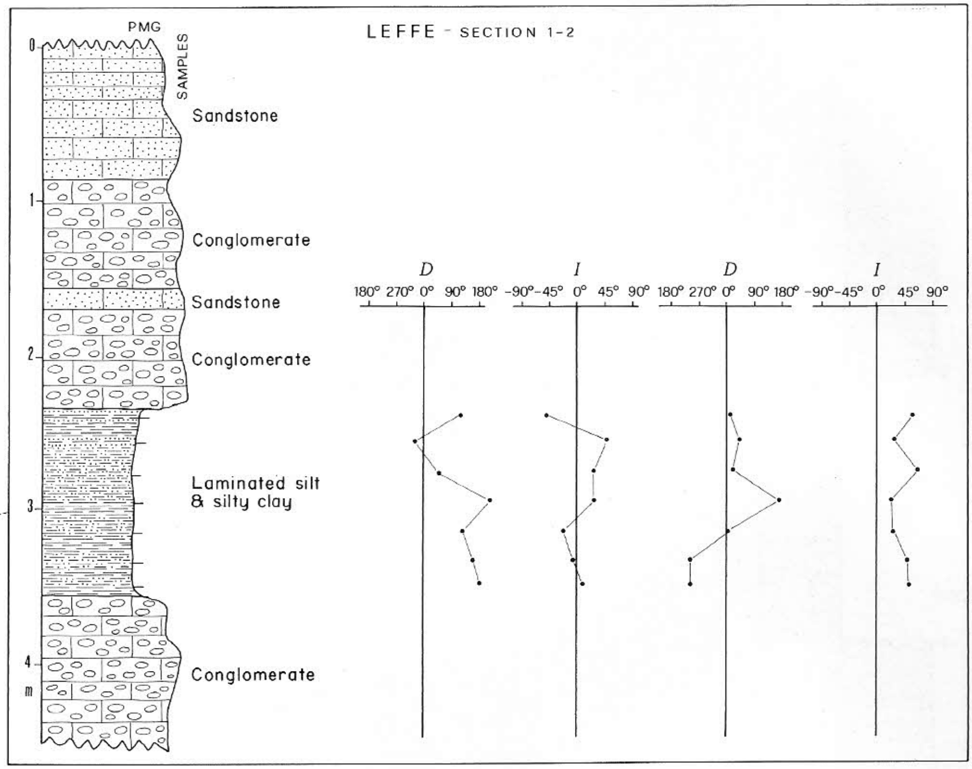

Fig. 9 — Section 1—2 of Leffe: stratigraphy and paleomagnetic measurements. D, magnetic declination; I, magnetic inclination.

thick layers of conglomerate (Fig. 10), The sampling was made in the fine grained sediments at the altitude of about 463 to 460 m.

Section 3 (0.5 km S of Leffe; altitude about 430 m) is located S of Leffe at the base of the scarp cut into the basin by a tributary of river Serio. A thick strongly indurated conglomerate extends from 453 to about 440 m and overlies a sequence of laminated marl which have been sampled only at the lowest part of the scarp where a clear section is exposed (430 m at the bottom). From top downwards the sampled sequence is as follows (Fig. 11):

- thinly laminated light yellow marl. Presence of undetermined Mollusc fauna. Sediment observed on a thickness of 2—2.50 m but continuing upwards;
- laminated marl with very thin beds and laminae alternately grey and yellow at the top, olive grey and blackish in the lower part. Presence of undetermined Mollusc fauna. Thickness 80—85 cm;
- compact black lignite layers. Observed on a thickness of 30—40 cm but continuing downwards.

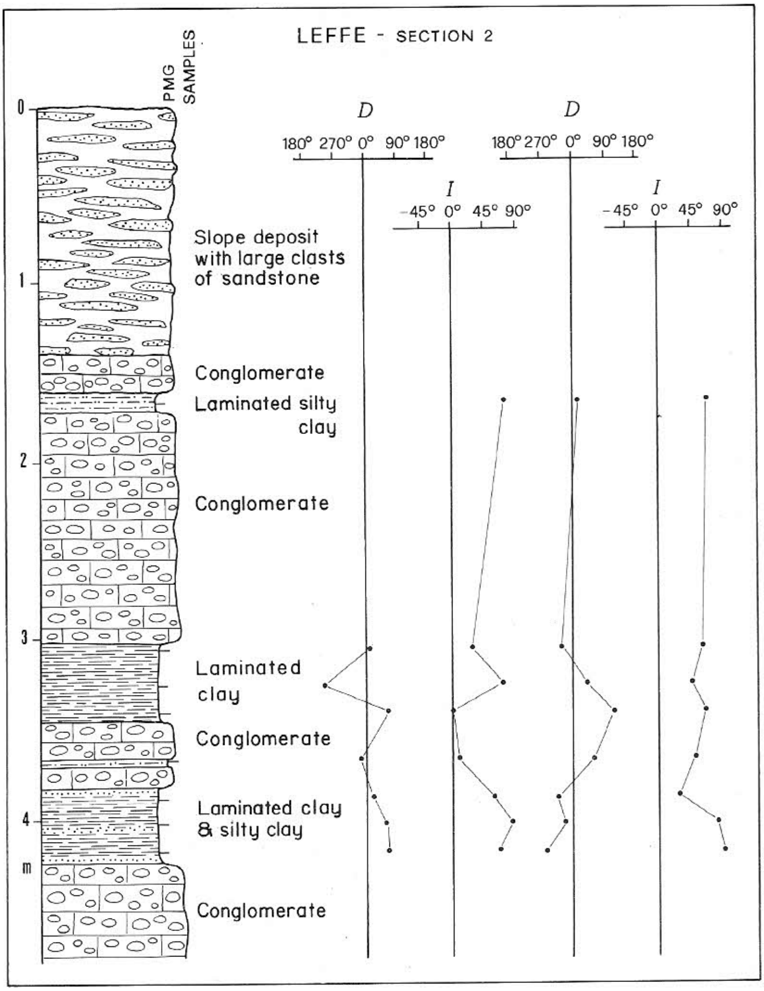

Fig. 10 – Section 2 of Leffe: stratigraphy and paleomagnetic measurements. D, magnetic declination; I, magnetic inclination.

Following Venzo's observations (1950, 1961), the lignite of the marginal section 3, located South of the basin, can be tentatively correlated to the lignite bank of the Casnigo section (altitude 440 to 430 m, western margin of the basin) and with the second lignite layer of S. Lucio mine (altitude 416 to 404 m, central part of the basin).

Paleomagnetic data. According to the interpretation of Lona (1950), Lona and Bertoldi (1973) and Venzo (1950, 1961) the Brunhes–Matuyama boundary should be underneath section 1, which had been entirely attributed to Min-

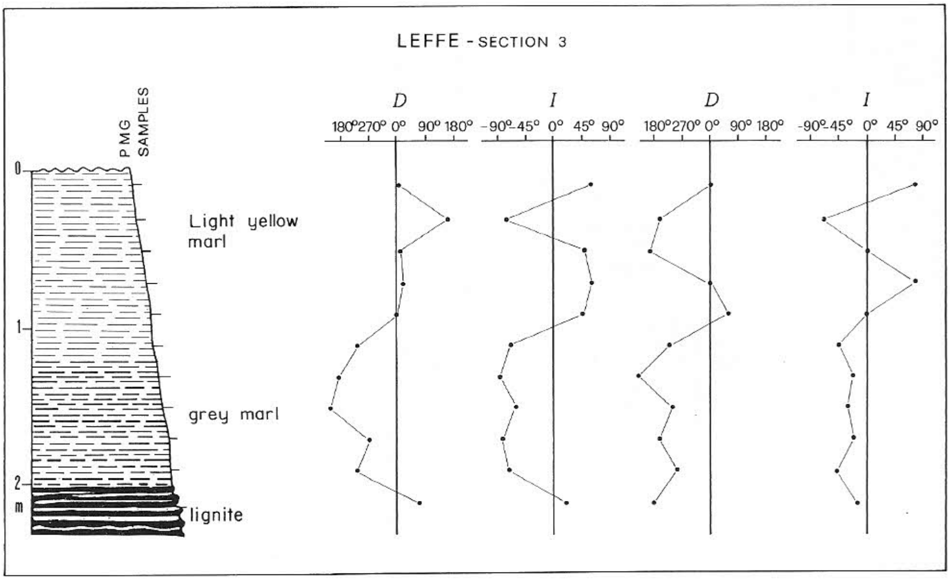

Fig. 11 – The lowermost investigated part of the lacustrine sequence of Leffe (section 3): stratigraphy and paleomagnetic measurements. D, magnetic declination; I, magnetic inclination.

del. However, the paleomagnetic investigation indicates a sedimentation of the lacustrine deposits which preceded in time the Brunhes–Matuyama boundary, because the positive values of magnetic inclination at the upper part of Leffe section seem to correspond to the event Jaramillo (Fig. 8). The oldest possible age, based on correlations with other paleomagnetic curves, may be about 1,600,000 years for the lowest investigated part of the sediments (Bucha & Sibrava, 1977, fig. 2). The age of the "ferretto" soil developed at the top has to be reexamined. It probably developed during a warm period belonging to the upper part of the Lower Pleistocene.

Concluding remarks

Paleomagnetic investigations provide interesting results for a better knowledge of the continental Pleistocene in Northern Italy. The paleomagnetic curve of the Stirone section covers practically a continuous pattern of geomagnetic changes, except in the upper part of the sequence where the geological situation has to be studied in more detail. The sections of Lombardy represent only a limited time span of the sedimentation if compared with the Stirone sequence. Nevertheless, the results make possible the preliminary correlations of paleomagnetic curves of both region. The following conclusions can be drawn for the Lombardy sections.

The Pontida lacustrine sediments and the Copreno, Barlassina and Cascina Lina loess and loess–like sediments belong all to the Brunhes Normal Paleomagnetic Epoch. At Bagaggera a reversal occurs at the top of the lower lacustrine unit, which belongs to the Matuyama Reversed Polarity Epoch. All the above lying sediments belong to the Brunhes Normal Polarity Epoch.

The Leffe sequence of lacustrine sediments all belongs to the Matuyama Reversed Polarity Epoch (with the possible exception of the not investigated red weathered superficial part).

An older age as so far supposed has to be consequently attributed to the Bagaggera lower lacustrine sequence and to the upper part of the Leffe lacustrine sediments. It has been observed in the Leffe, Bagaggera, Cascina Lina sections and also, under a moderate form, in the Barlassina section, that a "ferretto" soil can correspond to various interglacial warm periods of the Early Pleistocene up to Middle Pleistocene. As already concluded from geological evidences, the complexity of the Quaternary stratigraphy is highlighted in the piedmonts of the Italian Alps.

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