POLLEN SEQUENCE OF THE TLALOQUA CRATER
(LA MALINCHE VOLCANO, TLAXCALA, MEXICO)*

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The Tlaloqua crater is situated some 25 km north-east of Puebla at an altitude of about 3,100 m on the western slope of the 4,461 m high Malinche volcano. It is surrounded by a light mixed forest, chiefly composed of *Abies religiosa, Pinus montezumae* and *Alnus firmifolia*. The treeless bottom of the crater has a diameter of 150-200 m. Within the crater we find a well, dug by the Malinche Commission. From there a trench, 1.5 to 2 m deep, leads northwards to the border of the crater. The upper samples for pollen analysis could be taken directly from the trench wall. Then sampling was extended below the trench bottom by a chamber sampler; two 1.3 m cores were taken from two sites about 30 m apart. The sandy-gravelly subsoil below resisted further drilling with this sampler.

The stratigraphic sequence of the profile is as follows (see Fig. 4): below about 40 cm of soil, well stratified pumice is encountered to a depth of 1.7 m. The upper layers of the gyttja below that pumice are black and partly wet, the lower ones are brown, solid and more or less sandy. The occurrence of pollen of aquatic plants like *Potamogeton, Myriophyllum, Lemna* and *Utricularia* proves that there are indeed organic limnic sediments; *Pediastrum* was preserved, too. The gyttja lies on sandy-gravelly layers.

The oldest sediments were found in the profile Tlq. II (Fig. 1). What is particularly striking in the diagram apart from the dominance of *Pinus* among the trees, is the extremely high percentages of nonarboreal pollen below 2.1 m (Here it must be mentioned that in this diagram the basic pollen sum is made up of the pollen of trees; the percentages of herbs and shrubs are calculated on this arboreal pollen basis. Therefore the NAP percentages may exceed 100 %). As can be seen, the NAP percentages in this zone mostly amount to more than 200 %, and even more than 300 % is reached. The NAP flora is dominated by Gramineae, the rest consists mainly of Compositae, other families or genera altogether come up to 10-20 % only.

The results of surface pollen analysis show how we are to interpret these high percentages of non-arboreal pollen. Values of 200 % and more were found only in areas which are today devoid of forests. Surface samples, collected in various forest types yielded much lower NAP percentages (5-40 %). But that means that the surroundings of the crater were non-forested when these sediments rich in NAP were deposited.

Reforestation then must have happened rapidly because within only 10 cm of profile (between 2.1 and 2.0 m) the NAP values decrease to a tenth of the former values. An idea of how far that time dates back is given by the radiocarbon dating of a sample taken from the black gyttja which, on account of its pollen spectrum, corresponds to a depth of about 1.7 m and which gave a C-14 age of $7{,}970 \pm 70$ B.P. (sample no. Ki-745). Therefore reforestation occurred more than 8,000 years ago.

It is useful to deal now with some research results of Heine (1973a-c, 1975) who thoroughly investigated the Late-Quaternary history of the Malinche volcano. Heine has pointed out that there were four glaciations on the Malinche volcano during Late Pleistocene and Holocene. One of these glaciations, called M III, ocurred between 10,000 and 9,000 (years) B. P., and the glaciar advanced twice during this time. Moraines of both advances were found by Heine in the neighbourhood of the crater. Furthermore, Lauer (1973) assumed that the upper limit of the forest (nowadays at 3,900 m on the Malinche) was 600-800 m lower at the time of the M III glaciation. Both the observation of Heine and the assumption of Lauer allow us to presume that the crater must have been situated close to the upper limit of the forest, during M III.

Supported by the C-14 date of our profile we can doubtless correlate the zone rich in NAP with the M III glaciation or a part of it. During this time the crater was situated clearly above the upper limit of the forest as is proved by the high percentages of NAP. Obviously reforestation started at the beginning of a warmer and drier climate following the M III glaciation.

As mentioned above, the NAP flora consists principally of Gramineae and Compositae. Among the last ones *Artemisia* occurs consistently. The pollen of Chenopodiaceae or Amaranthaceae, Caryophyllaceae, Umbelliferae, Cyperaceae, *Plantago*, Geraniaceae, *Thalictrum* and other Ranunculaceae is found also rather regularly. Less frequent is the pollen of Labiatae, Fabaceae and Brassicaceae. The vegetation of that time obviously corresponded largely to the one which can be found today, according to the statements of Beaman (1965) and Ern (1972a,b) in the zone between the upper limit of forest and an altitude of about 4,300 m. Surface samples from these elevations ought to yield pollen spectra similar to those of our fossil samples rich in NAP. This is still to be verified.

But it is quite sure that during the last period of the Pleistocene, the alpine grassland (= Zacatonal according to Miranda and Hernández X., 1963) covered and area clearly larger than nowadays. In this connection it may be mentioned that Rzedowski (1975), in view of the effects of the Pleistocene glaciations is of the opinion that "a simple temperature descent of 4-5⁰... would have been sufficient to extend the area of grasslands over wide surfaces of northeastern and northwestern Mexico". Such a temperature descent of 4⁰ actually happened during the M III glaciation (Lauer 1973).

The percentages of Maydeae pollen grains (long axis 60 um and more) are given in the diagram in a separate column. The question whether these grains originate from *Tripsacum, Euchlaena* or maize can be answered only partly. Most likely *Tripsacum* is

not present. This results from the average size of 79.1 um received by measurements of 100 of such Maydeae pollen grains. (According to Barghoorn et al., 1954, the genus *Tripsacum* has an upper extreme of 64.0 um; Tsukada, 1964, reports an upper extreme of 70.5 um in *Tripsacum lanceolatum*). Moreover, all fossil Maydeae pollen grains from the Tlaloqua crater, as far as investigated with phase-contrast light, showed a pattern typical of maize and teosinte (cp. Irwin and Barghoorn, 1965). But the problem of whether maize or teosinte or even both are represented could not be resolved by phase-contrast microscopy.

Fig. 2 shows the results of size frequency studies of Maydeae pollen grains*). We can see that the curve of the fossil Maydeae pollen grains from the Tlaloqua crater has a position between the curves of *Euchlaena mexicana* on the one hand and two modern races of maize (cultivated in Europe) on the other, through with a distinct tendency to teosinte. (According to Barghoorn et al., 1954, the average size of teosinte pollen varies between 79.3 and 86.4 um with an upper extreme of 102 um; Tsukada, 1964, reports and upper extreme of *Euchlaena mexicana* pollen of 89 um. In the races of maize, investigated by Barghoorn et al. the average range fluctuated between 87.2 and 122.8 um with extremes of 72.0 and 141.7 um).

The results of size frequency studies of fossil maize pollen grains from profiles of lake Acuitlapilco (4 km south of Tlaxcala) are given in Fig. 2, too. As these grains originate from young sediments (at a maximum perhaps 1,000 years old) from a region occupied by men for a long time, we can surely say that these fossil grains are indeed pollen grains of cultivated maize. We can see that its curve of size distribution lies below that of modern maize but above that one of the fossil Maydeae pollen grains from the Tlaloqua crater.

These size frequency studies do not allow a definite conclusion. Indeed, it is more probable that the fossil Maydeae pollen grains from the Tlaloqua crater originate from *Euchlaena*, but we cannot completely exclude a possible participation also of maize. In that case it must be pollen of wild maize, because it has been accepted until now that the cultivation of maize began at about 3,500 B. C., but these fossil Maydeae pollen grains are more than 8,000 years old. Here it may be mentioned that four very old fossil pollen grains of wild maize were found by Bartlett et al. (1969) in a sample of a core from the Gatun basin in Panama which is between 6,230 and 7,300 years old. Their size varied from 100 to 110 um. (The single Maydeae pollen grain from the Tlaloqua crater exceeding 100 um was 103 um in size).

The question of whether investigations by the scanning electron microscope could be of decisive help in this problem has not been aswered yet. But according to studies of the distribution and ecology of teosinte and *Tripsacum* (Wilkes, 1972) it seems, however,

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*) Silicone oil was the mounting medium for the pollen grains of *Tripsacum* and *Euchlaena*. According to Faegri and Iversen (1964) the measured sizes were multiplied by a conversion factor of 1.25. Perhaps, the values thus obtained are somewhat too high compared with the sizes of the other Maydeae pollen grains mounted in pure glycerol.

quite sure that the Maydeae, with its well dispersed pollen did not grow in the immediate vicinity of the crater, but that the pollen was carried upwards by wind from lower elevations.

During the M III glaciation the upper zone of the forest certainly consisted of pines just as today, for pine pollen mostly amounts to more than 80 % during the time rich in NAP. *Alnus* and *Quercus* play a comparatively minor part. Presumably, their pollen originated from forests at a lower level.

Of particular interest is the occurrence of *Picea*, a genus encountered in México today according to Martínez (1963) only at a few relict stations. (The nearest site of *Picea chihuahuana*, the total numbers of wh'ch according to Gordon, 1968, may consist of only a few hundred individuals, is situated 900 km north-west of the Malinche volcano; *Picea mexicana*, also very rare, is found some 700 km to the north). The pollen of *Picea* occurs below about 2 m in every sample; there it is even somewhat more frequent than *Abies* pollen. Above the 2 m level, *Picea* is no longer found (In each sample of the profile, 1000 arboreal pollen grains were scanned; usually 500 were counted). It is remarkable that the extinction of *Picea* coincides with the rapid decrease of the NAP curve. Certainly this coincidence is not accidental. According to Heine the climate was cooler and more humid that today during the two M III glacial advances. Such a climate may have been the precondition for the former presence of spruce at the Malinche volcano, as is also evident in the studies of ecology of *Picea chihuahuana* by Gordon (1968). When the climate became drier and warmer after the M III glaciation, *Picea* was not able to persist any longer and died out.

The extinction of *Picea*, together with the rapid decrease of the high NAP values marks a distinct incision in the diagram. As in other Pleistocene profiles from the central Mexican highlands *Picea* pollen was also found (Clisby and Sears 1955, González Quintero, 1971; Ohngemach 1973; 1976) but not in Holocene profiles (Sears, 1952, Hutchinson et al., 1956; Ohngemach, 1973; 1976), it seems therefore legitimate to take the level marked by the extinction of *Picea* as the boundary between Pleistocene and Holocene vegetation. This transition can be distinctly seen in the Tlaloqua diagram. Provided that our diagram starts shortly after the beginning of M III glaciation at 10,000 B.P. one reaches an age of some 8,500 years for this transition, if one takes further into account a C-14 date (ca. 8,000 B.P.) for the *Alnus* maximum at 1.7 m together with the supposition of a constant sedimentation rate. This agrees well a fixation of the Pleistocene Holocene boundary based on geological palaeontological findings at 9,000 B. P. in the Mexican highlands (Heine and Heide-Weise, 1973).

In the Pleistocene zone of our diagram besides *Quercus* and *Alnus* some other holarctic deciduous trees are met with among which *Fagus* and *Liquidambar* are of particular interest. Indeed, their pollen is found with very low values but rather regularly. The region nearest to the Malinche where these trees grow today is situated on the eastern slope of the Sierra Madre Oriental. If their pollen occurred only sporadically,

long-distance transport from that region would account for it. But their rather consistent occurrence allows us the assumption that these trees once could be met with in the basin of Puebla itself, perhaps along stream banks or on the lowest slopes of the Malinche. Another objection to long-distance transport from the Sierra Madre Oriental is that, at least nowadays, such a pollen transport does not occur or is not noticeable, for no pollen of *Fagus* or *Liquidambar* could be found in the many surface samples collected in the valley of Puebla itself and in the valley of El Seco east of the Malinche. *Liquidambar*, today much more frequent and more widespread than *Fagus*, occurs for the first time in samples from the border of the highlands with values between 0.1 and 0.2 %. The pollen of *Fagus* is only found in the recent pollen rain of the immediate neighborhood of its present occurrence, with percentages as low as in the fossil samples from the Tlaloqua crater. As both diagrams of the Tlaloqua crater show, *Fagus* and *Liquidambar*, unlike *Picea*, were also able to persist in the Holocene for some time; this is especially true for *Liquidambar*.

The lower spectra of the pollen diagram Tlq. I (Fig. 4) cover once more the Pleistocene-Holocene boundary as is proved by the decrease of the NAP values, at first still exceeding 300 %, and by the disappearance of *Picea*. After the retreat of the M III glaciation and along with the increasing warmth, the forest is reaching higher elevations again, so that already some time before 8,000 B. P. the Tlaloqua crater was surrounded by a rather dense pine forest as low percentages of nonarboreal pollen and high values of *Pinus* show. A comparison with the present circumstances allows us to presume that this forest was composed of *Pinus hartwegii*.

This presumption may be supported by the following circumstantial evidence: according to statements of Ern (1972a) *Pinus hartwegii* is preferably infected by the parasite *Arceuthobium globosum* ssp. *graudicaule* Engelm., which belogs to the family Loranthaceae. These findings could be confirmed by observations made by the author in the Malinche region (Sánchez, 1969, mentions that *Arceuthobium globosum* ssp. *graudicaule* is a parasite on pines). The pollen of *Arceuthobium* is easy to identify. We can see that in both diagrams the pollen curve of *Arceuthobium* reaches its highest values shortly after the decrease of the curve of nonarboreal pollen but still before the percentages of *Pinus* diminish (see Fig. 1 and 4).

Pollen analyses of some surface samples from the *Pinus hartwegii* zone of the Mt. Orizaba gave the same picture: similar values of *Arceuthobium*, high percentages of *Pinus* and very low values of nonarboreal pollen (Fig. 3). This agrees perfectly with the thesis that *Arceuthobium globosum* ssp. *graudicaule* in fact a specific parasite of *Pinus hartwegii*. In this case we may infer the presence of the host *(Piñus hartwegii)* from the ocurrence of the parasite *(Arceuthobium globosum* ssp. *graudicaule*.

Evidently the region around the crater was only a transit station to higher elevations for the *Pinus hartwegii* forest, for it is soon replaced by an *Alnus* forest. That *Pinus hartwegii* has disappeared is also shown by the curve of *Arceuthobium* which diminishes

to insignificant values (see Fig. 1 and 4). It is still unclear why *Alnus* increased in such a striking manner. One might think of local effects (for example of a disastrous fire by which the especially fire-resistant *Alnus firmifolia* could have been favoured to such a high degree) or of an increase of *Alnus* in the course of a normal vegetational change. The latter assumption might be strengthened by the fact that in the profiles from the maar of Jalapasquillo (some 75 km east of Puebla) *Alus* also increases temporarily after the extinction of *Picea*. therefore obviously at about the same time as at the Tlaloqua crater (Ohngemach, 1973; 1976). It is possible that *Alnus*. because of the minor elevation of the maar (2.400 m). does not reach so high values at Jalapasquillo (only about 10 %).

While the profile Tlq. II ends with the dominance of *Alnus*. the pollen diagram Tlq. I (Fig. 4) shows that alder plays an important part in the region around the crater for a long time even through it diminishes temporarily because of an increase of pine and a first ascent of fir. During the period rich in *Alnus*. NAP continues to have low values. Whereas the gyttja has a very high content of generally excellently preserved pollen, it is scarce or even absent in the pumice deposits between 1.6 and 0.8 m, so that the percentages of this zone cannot be easily compared with the others. Therefore they are not given in the diagram. Above this zone *Alnus* occurs once more with considerable values before it is replaced by a remarkable increase of *Abies*. Fir reaches a maximum of 38 %; this percentage exceeds such values as found in surface samples from present *Abies* forests. The coincidence of *Abies* maximum and nonarboreal pollen minimum proves that there must have been a very dense *Abies* forest. Constituted almost exclusively of Gramineae, a few high NAP percentages during the increase of *Abies* may depend on local effects.

When and why this optimum development of *Abies* forests occurred can only be assumed again. According to Heine (1973a-c; 1975) there occurred on the Malinche volcano at around 2,000 B. P.. the M IV glaciation, a clearly minor glacial advance compared with M III (its moraines can be found above the present upper limit of forest). Heine assumes increased precipitation during this time, the temperature was probably somewhat lower, too. Such a climate may have favoured *Abies*. since it likes air moisture; moreover, fir is rather cold-resistant as is proved by its present occasional advances up into the *Pinus hartwegii* zone (according to Ern, 1974, up to a maximum of 3,700 m above sea level). Thus the ecological requirements of *Abies* might have been most perfectly met by the M IV glaciation.

Pollen diagrams of profiles from the lake of Acuitlapilco (Ohngemach, 1973; 1976), mentioned above, prove that the maximum of the *Abies* phase really dates back more than 1,000 years. This lake is situated at an altitude of 2,250 m in the western foreland of the Malinche just 20 km from the Tlaloqua crater. In the diagrams that cover the last 1,000 years approximately, *Abies* is represented usually with 1-2%, that is to say with the same low values as in the recent pollen rain around the lake. However, such a marked time of *Abies* as can be seen in the diagram Tlq. I must have influenced contemporaneous pollen records from Acuitlapilco, too.

38

OHNGEMACH, POLLEN SEQUENCE OF THE TLALOQUA CRATER

The end of the pollen sequence from the Tlaloqua crater is characterized by the decrease of *Abies* and a gradual transition to a vegetation as is encountered in this elevation nowadays. On account of the lack of thickness of the sediment, it is impossible to point out the beginning of human influénce on the forest, e.g. charcoal-burning and pasturing in the forest, which doubtless caused the present conditions. The new occurrence of Maydeae pollen grains that represent maize cultivation in the foreland or on the lower slopes of the Malinche, should still be mentioned.

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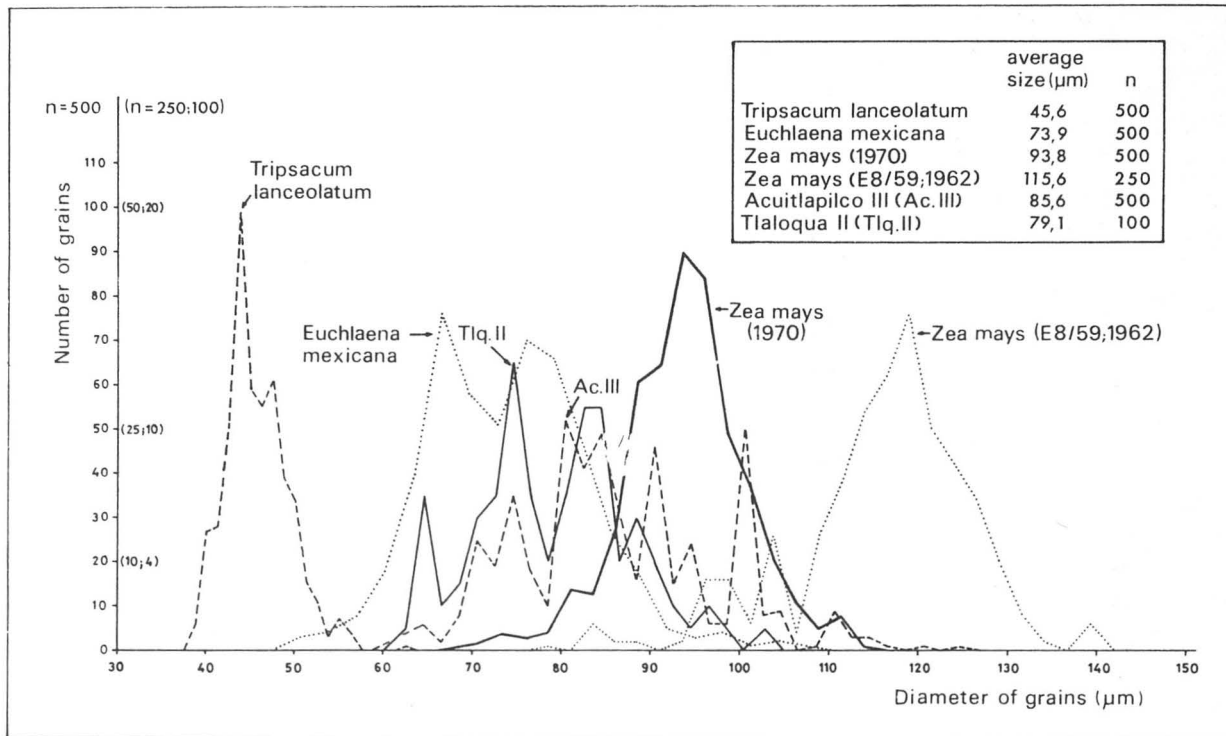WILKES, H. G. 1972. Maize and its wild relatives. *Science* 177:1071-1077.

Fig. 1 Pollen diagram Tlq. II of the Tlaloqua crater (3,100 m).

Fig. 2. Size distribution of modern and fossil Maydeae pollen grains.
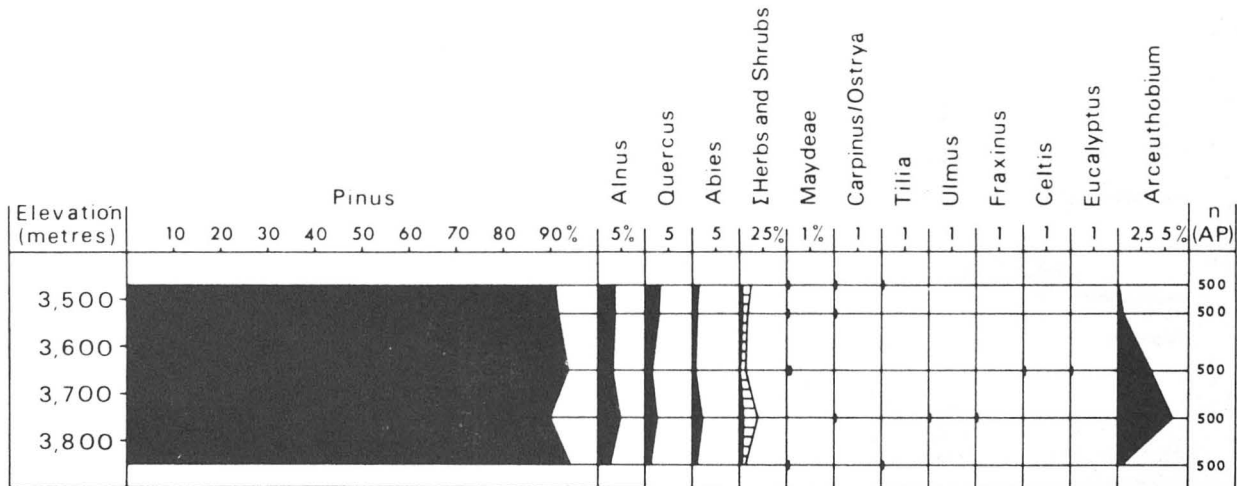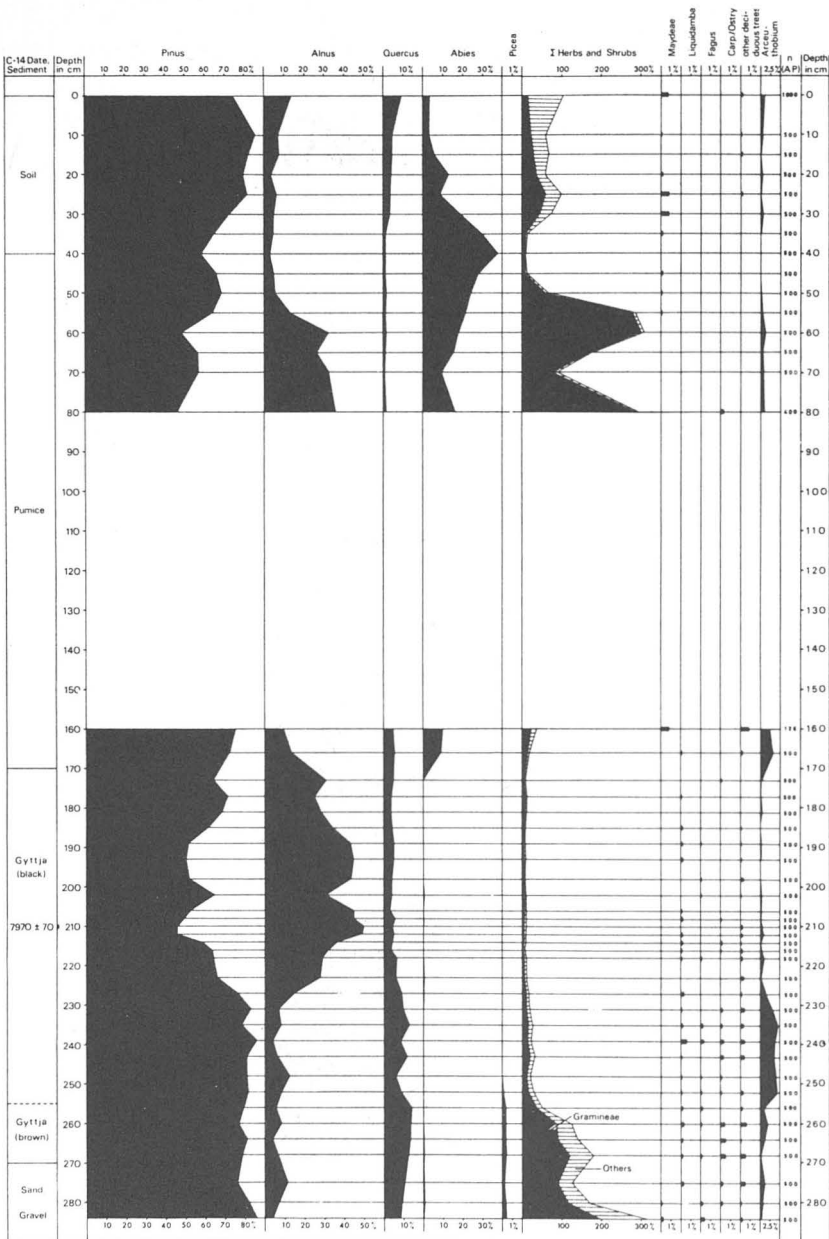
Fig. 3. Spectra of some surface samples froh the *Pinus hartwegii*

Fig. 4.–Pollen diagram Tlq. 1 of the Tlaloqua crater (3,100 m).