Mr. Truscott

TECHNICAL NOTES
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 138

DETERMINATION OF THE VALUE OF WOOD FOR STRUCTURAL PURPOSES.

Communication from the Material Testing Laboratory
of the Royal Technical High School at Stuttgart.

By Richard Baumann.

From Technische Berichte, Vol. III, No. 4.

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DETERMINATION OF THE VALUE OF WOOD FOR STRUCTURAL PURPOSES.*

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For more than a century, the employment of wood for structural parts subject to stress has undergone a rapid and continual decline, its place being taken by iron and steel. About ten years ago, however, owing to special requirements, a change began to take place, which was accelerated by the war.

The application of wood to building purposes is limited by the fact that it is much less uniform in its physical characteristics than either iron or steel. The properties of any particular kind of timber often vary considerably between one log and another and even between two parts of the same log, so that great uncertainty exists as to the maximum stresses permissible without risk of failures. Some technical experts in the timber industry claim that they are able to judge the value of wood from its appearance and its behavior when worked (from the shavings, etc.). Experts, however, who can do this, are naturally few and it is not always safe to rely on their judgment, which is chiefly founded on experience gained in an entirely different class of wood working, where a good appearance and smoothness of surface are of

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* From Technische Berichte, Vol.III, No.4, pp. 97-100. (1918). This communication is intended for engineers, who without possessing botanical knowledge, employ timber for the production of highly stressed parts and who are, therefore, interested in obtaining numerical data on its physical properties, to which little attention is given in botanical literature.

more importance than strength.

In coniferous woods it is customary to attribute special significance to:

1. The width of the annual rings, timber with narrow annual rings being considered superior to that with wide rings.
2. The density of the air-dried wood, greater strength being expected of heavier timber.
3. The ratio between compression strength and density, necessitating the determination of the compression strength and the cutting out of test pieces.

The following article, founded on experimental results, is designed to be of assistance in forming an estimate of the value of timber, based on its structure. It is limited to the consideration of sound straight-grown timber, tested in the direction of the fibers. The influence of defective growth, disease, etc., and the results of tests perpendicular to the fibers will not at first be discussed.

The cross-section of coniferous woods is made up of light rings interposed between hard dark rings, in which the finger nail will make an impression. The transition from one component to the other takes place either gradually (e.g. pine) or abruptly (e.g. fir, Oregon pine, etc.). Fig. 1 shows a cross-section of a Bosnian pine, the few annual rings of the portion under examination being quite broad. Fig. 2, a section through the same timber on a larger scale of magnification (12-fold), is produced from a thin shaving by transmitted light, and shows the appearance under a microscope of a smoothly planed piece of cross-cut timber. The annual ring in the middle of Fig. 2 begins at S; the wood in the immediate vicinity of this point grew in the springtime (early wood) and is more porous. This particular ring ends at A; the wood of summer and autumn (late wood) is closer meshed and hence is darker colored, as seen in Figs. 1 and 2. The transition from early wood to late wood takes place gradually. In the middle of the ring a few large pores are visible. These are sections through resin ducts or canals. In addition to these pores, roughly radial lines, marked M M, are observed. The nature of this structure is more clearly brought out under larger magnification. Fig. 3 (150 mag) shows at Y Y the boundary between the late wood A of the old year and the early wood S of the new year. The cells of the autumn wood are narrower, thicker walled and shorter in the direction of the radius than the spring wood. The pith or medullary rays M are composed of cells pointing in the direction of the radius of the trunk. The remaining wood also consists of cells which lie in a direction parallel to the axis of the trunk. Fig. 4 (30 mag) shows this in a longitudinal section in a circumferential direction. It also shows the length and arrangement of the wood cells, as well as sections of radial marks (some of which, in the middle of the micro-photograph, consist of resin ducts). With larger magnification (Fig. 5 - 150 mag) the inner structure of the wood cells appears, showing numerous circular spots, which, however, will not be further dealt with here.

Wood consists principally of crosswise interlaced series of cells, most of which run in the direction of the trunk axis (ordinarily called wood fibers) while others are arranged in a radial direction (pith rays or markings). The wood fibers show very different wall thickness and structure according to the growth (Figs. 2 and 3) and hence different powers of resistance.

In order to obtain figures for a comparison of the hardness of the wood at different parts of the annual rings, the cone test was employed. For the purpose of determining the hardness at different points of one and the same annual ring (a very narrow area) a cone point of 90° was pressed with a load of 2.2 kg (4.85 lb) against the cross-section, so as to produce only small impressions. As hardness number, the ratio of the pressure in kg. to the area of indentation, is taken. From the curves of the hardness numbers across six annual rings of the Bosnian pine under consideration, it is clearly seen that the hardness of the early wood S is only a fraction of the late wood A. The smallest observed value is 2.24 and the greatest 15.2 kg/mm^2.

For further investigation, flat strips 0.5 to 1.2 mm thick and 5 to 9 mm wide were split off from different parts of one of the annual rings and their tenacity determined. The following values were obtained:

	Early wood		Late wood	
	kg/cm^2	lb/in^2	kg/cm^2	lb/in^2
	480	6827.5	1594	22673
	430	6116.3	1116	15874
	604	8591.3	1352	19231
	490	6969.8	1490	21194
Mean	501	7126.2	1388	19743

On testing additional strips from other annual rings, the tenacity increased to 2343 kg/cm^2 (33326.8 lb/in^2), i.e. about the same value as for annealed copper. Rods of 15 mm diameter from the same tree, which on account of their larger cross-section contained wood from several annual rings, gave 517, 558 and 684 kg/cm^2, (7353.8, 7937 and 9729 lb/in^2), or a mean tenacity of 586.3 kg/cm^2 (8339.5 lb/in^2). These values correspond approximately to the indication obtained above by the cone test, that the annual rings consist of hard and soft components (Fig. 6), when it is considered that the tenacity of the complete annual ring must be somewhat smaller than the sum of the tenacities of its parts, because the instant of fracture, and hence the breaking load, is determined by the weaker part and therefore the tenacity of the stronger part is not fully utilized.

In the soft Bosnian pine wood under investigation, the proportion of hard late wood was a comparatively small part of the year's growth. For this reason, similar experiments were carried out with Oregon pine which has narrow rings, a much smaller spring zone and an abrupt transition from early to late wood, as shown in Fig. 7 (1.2 mag). Fig. 8 gives in a similar manner to Fig. 6, the hardness values as obtained by the cone test. The mean is 21.6 kg/mm^2 (30580 lb/in^2) for the hard portion with a maximum of 24.3 kg/mm^2 (34563 lb/in^2) falling to w minimum of 2.75 kg/mm^2 (3911 lb/in^2) for the soft portion, hence similar to the values for the pine wood investigated - minimum 2.24 kg/mm^2 (3186 lb/in^2).

Tensile tests with strips 0.4 to 0.5 mm (.0157 to .0197 in) thick and 1.4 to 4.4 mm wide, split from the hard portions, gave the following results: 4980, 4200, 4395 and 4056 kg/cm^2 (70835.5, 59741, 62514.5 and 57692.5 lb/in.^{2}); mean 4408 kg/cm^2 (62696 lb/in^2) values usually obtained with good ingot iron, which is, however, much tougher. Rods of 15 mm (.59 in.) diameter, the section of which contained several annual rings gave tensile strengths of 1122 and 1217 kg/cm^2 (15959 and 17311 lb/in^2). The results of these experiments show the considerable difference in the tenacities of the hard and soft portions of the annual rings, as well as the high tenacity of the hard parts.* They also demonstrate that an estimate of the tensile properties of the wood can only be obtained when the ratio between the hard and soft parts of the individual rings is taken into consideration, which, from the botanical point of view, might be expected.

This point of view is the more worthy of consideration, since the formation of the annual rings is influenced by many conditions, so that rings with little late wood and rings with a large amount of late wood may occur contiguously in the same tree.** This consideration attains importance, if general conclusions are to be drawn from the results and experiments with test-pieces taken

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*That wood fibers attain the tenacity of ingot iron has been shown by the writer in previous experiments with bamboo (Mitteilungen über Forschungsarbeiten, published by the Verein deutscher Ingenieure, Vol. 131, p. 46, in which tensile strengths of 3063 to 3843 kg/cm^2 were found for the outer layers.

**It is known that weathering, damage to a tree, blight and other circumstances cause the formation of several rings within a calendar year. For the purpose under discussion, each definitely formed ring is naturally considered an annual ring even if it were actually formed in a shorter period than one year.

from the wood in the usual manner and containing only a small part of the trunk section.

As a typical example, experiments with pitch pine may be cited, a section of which is shown in Fig. 9 (1.2 mag). A part of the plank shows broad and another part narrow rings. For the purpose of the experiment the log was cut into two parts, one of which contained chiefly broad rings, and the other chiefly narrow rings. The results of the tests obtained were as follows:

	Part with broad rings preponderating.	Part with narrow rings preponderating.
Coefficient of Elongation in bending.	1 : 147,000 = 6.82 millionths	1 : 118,000 = 8.50 millionths
Transverse strength.	1260 kg/cm^2 17922 lb/in^2	986 kg/cm^2 14025 lb/in^2
Energy required for fracture.	0.5 $kg\text{-}m/cm^2$ 23.33 $lb\text{-}ft/in^2$	0.3 $kg\text{-}m/cm^2$ 14 $lb\text{-}ft/cm^2$

According to the observations made above, one would have expected the narrow-ringed wood to be the more resistant. On the contrary, this table shows that the broad-ringed portion is the stronger. The change of shape under the same stress is smaller in the ratio of 6.82 : 8.50 = 0.8 and the tensile strength in bending is 1.28 times greater, while the resistance to impact is also greater. The explanation of this is apparent when the two portions are examined under the microscope. Fig. 10 (12 mag) shows that in the narrow annual rings, the fraction of the hard late wood is much smaller than in the wide rings. This is very clearly shown by Figs. 11 and 12 (150 magnification).

The decisive factor in determining the tenacity of similar wood is not, therefore, the breadth of the annual rings; but the proportion of hard to soft constituents in them. This applies to all coniferous woods (e.g., fir trees), because they generally possess a similar structure. Figs. 13, 14, 15 and 16 (1.2, 12 and 150 mag) show the sectional appearance of fir. The piece with narrow rings of late wood (Fig. 13) showed a strength of 421 kg/cm^2 (5983 lb/in^2) under compression; while the tree with broad late wood (Fig. 14) gave compression strength of 711 kg/cm^2 (10113 lb/in^2).

It appeared probable, therefore, that, as previously mentioned, the quality of the wood could be estimated in almost the same way by means of the density. Actually, this amounts in wood with narrow late rings to 0.42 g/cm^3 (.24 oz/in^3), and in wood with broad late rings, to 0.62 g/cm^3 (.36 oz/in^3). Figs. 9 and 10 also show that the structure of the wood in the same tree may vary considerably. The tree may contain a part of poor quality, without any indication of this in the mean density, though immediately apparent to the eye on examination of a planed section.

Certain leaf-bearing trees possess similar properties. For example, experiments carried out on ash wood may be cited. A log was cut from a twisted trunk so that different annual rings occurred at one end from those at the other end. One end contained mostly narrow rings, while at the other, there were both broad and narrow rings. See Figs. 17 to 20 (1.2 and 12 magnifications). The test results contained were:

	Part with broad and narrow annual rings.	Part with narrow rings only.
Coefficient of elongation in bending.	1 : 980,000 = 10.21 millionths.	1 : 583,000 = 17.14 millionths.
Tensile strength.	1038 and 1520 kg/cm^2 14765 " 21620 lb/in^2	702 kg/cm^2 9985 lb/in^2
Compression strength.	674 kg/cm^2 9587 lb/in^2	443 kg/cm^2 6301 lb/in^2
Energy required for fracture.	0.5 kg-m/cm^2 23.33 lb-ft/in^2	-

In this wood, which contained large open vessels in large numbers in the spring zone (See the pores in Figs. 19 and 20), the proportion of the large-pored spring wood was responsible for the small resistance of the narrow-ringed portion of the log. For the purpose of comparison, Figs. 21 and 22 (1.2 and 12 mag) show sections through superior quality ash wood, which gave the following values:

Coefficient of elongation in bending -	1 : 174,000 to 1 : 163,000 = 5.75 to 6.15 millionths.
Tensile strength -	1787 and 1505 kg/cm^2 25418 and 21407 lb/in^2
Compressive strength -	802 to 833 kg/cm^2 11408 to 11849 lb/in^2
Energy required to fracture -	1.2 and 1.4 kg-m/cm^2 56 and 65.3 lb-ft/in^2

A comparison of Figs. 19, 20 and 22 shows that in the case of ash also, examination of the section with regard to the proportion of small and large-pored parts permits an estimation of the strength of the wood to be made, and the variation of the wood in the same tree is immediately apparent to the eye.*

Conditions are different in those leaf-bearing trees (such as lindens), which show an approximately uniform distribution of pores throughout the whole annual ring, for which Fig. 23 (12 magnification) serves as an example. These and other timbers will be dealt with later, as regards the behavior of the different types of wood when subjected to stresses perpendicular to the fibers.

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* It should be noted that longitudinal sections are not suitable, as a rule, for the determination of comparative values, because, according as the section is more radial or more tangential to the annual rings, which are often wavy in outline, so the longitudinal strips corresponding to the annual rings become narrower or broader.

Fig. 1

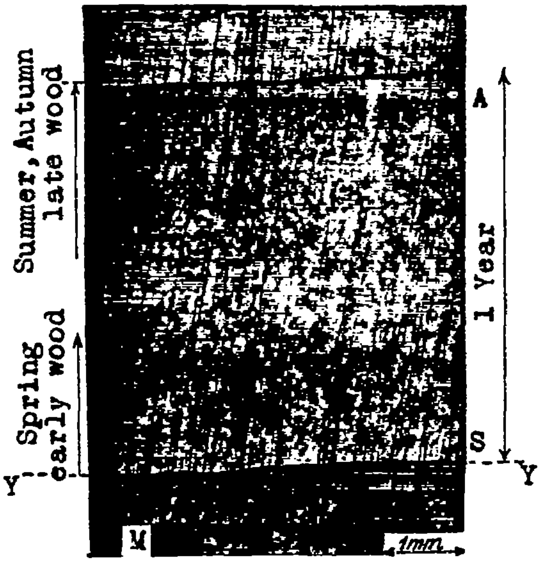

Fig. 2
12 Magnifications

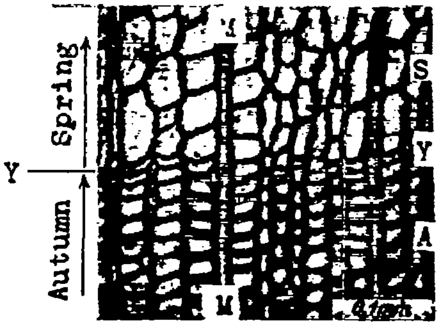

Fig. 3
150 Magnifications

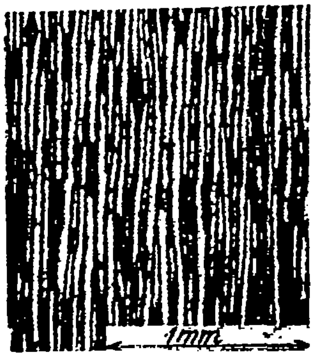

Fig. 4
30 Magnifications

Figs. 1 to 5
Bosnian pine

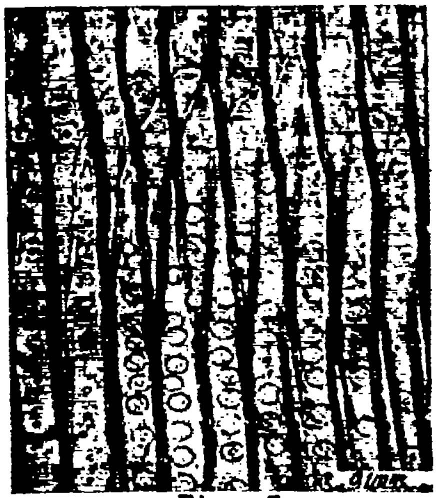

Fig. 5
150 Magnifications

1.2 Magnifications

Fig. 7
Oregon pine

Fig. 9
1.2 Magnifications

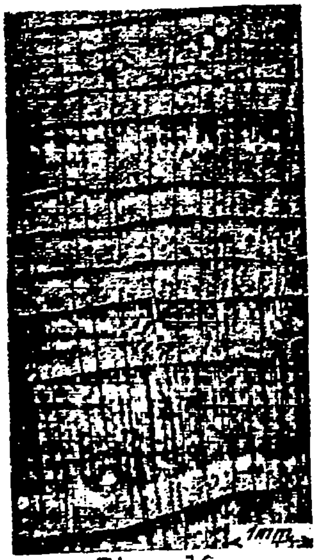

Fig. 10
.3 Magnifications

150 Magnifications

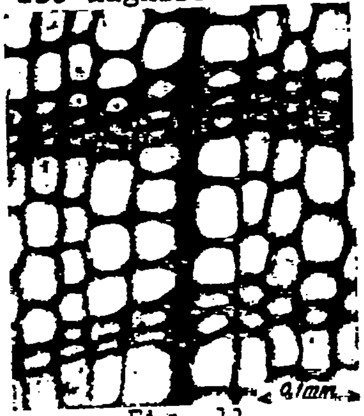

Fig. 11

Figs. 9 to 12
Pitch pine

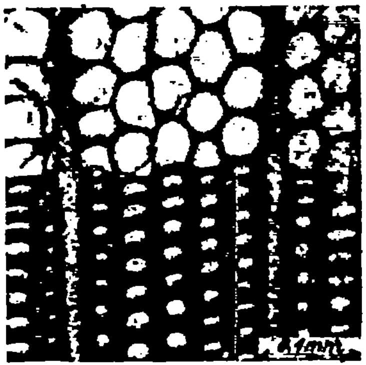

Fig. 12
150 Magnifications.

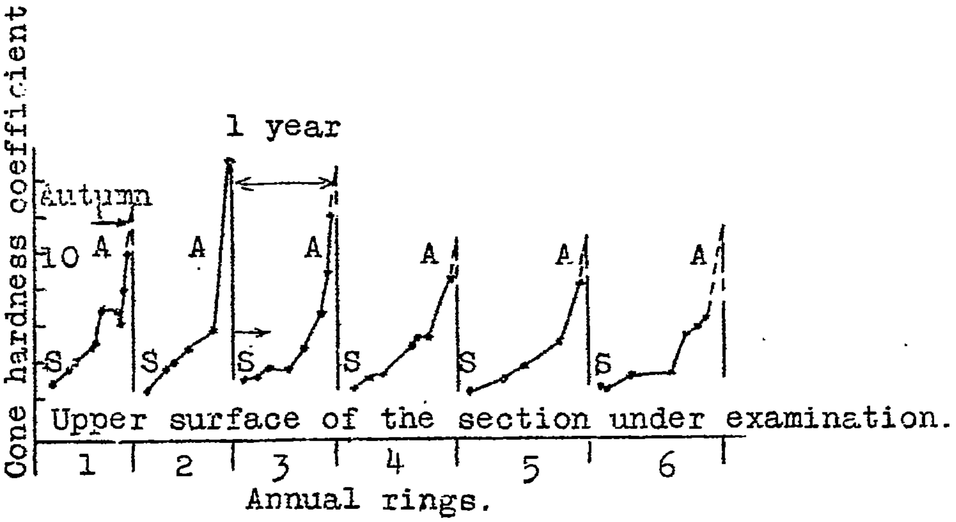

Fig. 6. Bosnian pine.

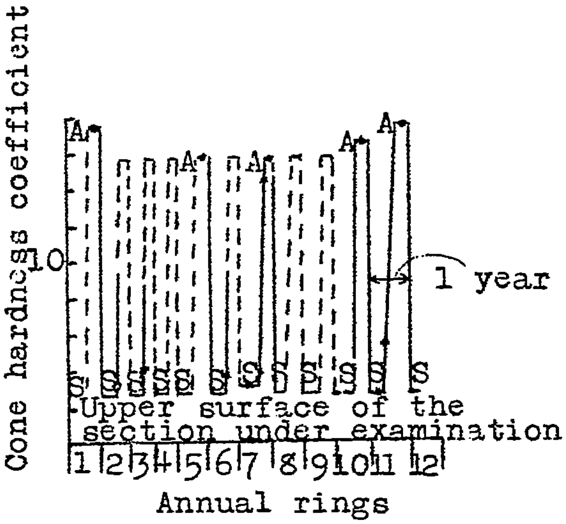

Fig. 8. Orègon pine.

Fig.13.

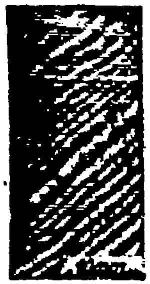

Fig.14.

1.3 Magnifications

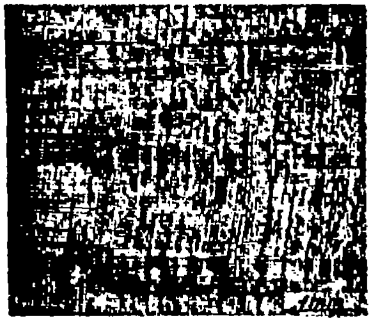

Fig.15.
12 Magnifications

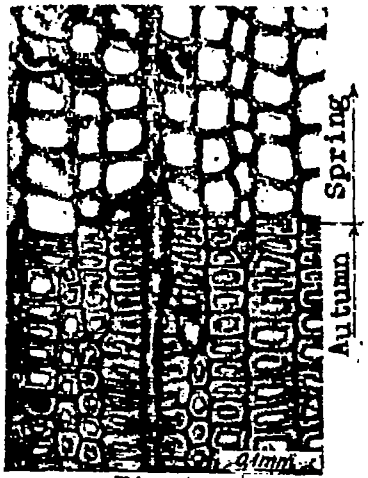

Fig.16.
150 Magnifications

Figs. 13 to 16
Fir.

Fig.17.

Fig.18.

1.3 Magnifications

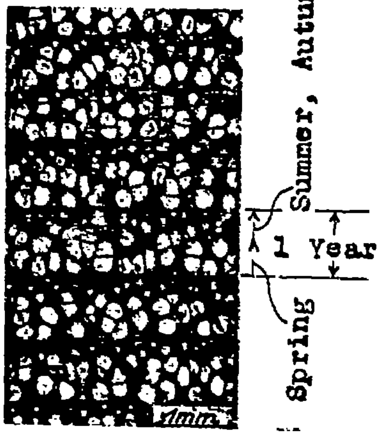

Fig.19.
12 Magnifications

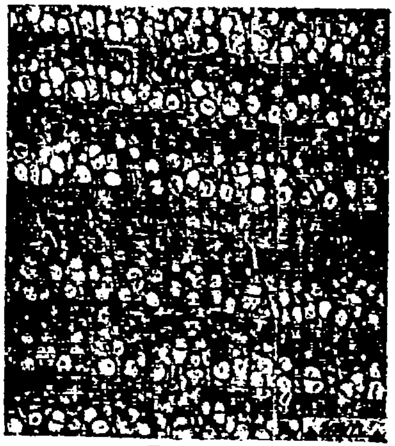

Fig.20.
12 Magnifications

Fig.21.
1.2 Magnifications
Superior quality

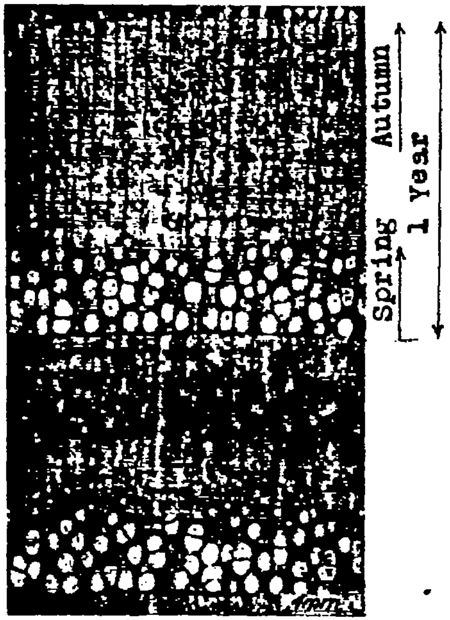

Fig.22.
12 Magnifications
Superior quality

Figs. 17 to 22
Ash.

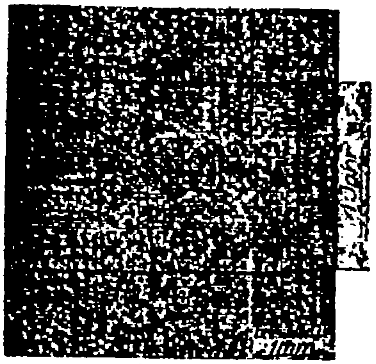

Fig.23.
12 Magnifications

Fig. 23
Linden.