

# Frost ring distribution at the upper tree line in Mongolia

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## Introduction

The only thing common to all definitions of frost rings is the more or less anomalous tissue that appears intra-annually and parallel to tree rings (Schweingruber 2001). Frost rings can be identified on well prepared surfaces of increment cores, cross sections and on micro-sections. The position of the frost damaged tissue in relationship to the tree-ring boundary is determined by the season in which the frost event occurred. It is therefore possible to distinguish between damaged rings caused by late and/or early frosts.

The prime aim of this study is to conduct research about the frequency and distribution of frost-ring formation across the mountain areas of Mongolia. By means of a regional and inter-regional comparison, it will be determined whether characteristic regional distribution patterns of frost-ring frequency exist and whether these can be used to identify the temporal and spatial variability as well as changes of climate in Mongolia.

According to the present state of knowledge, Mongolia is situated at the fringe or the intersection of different atmospheric circulation systems, the influence and extent of which can vary from year to year (Zhang & Lin 1992, Yatagai & Yasunari 1994, 1995). However, the spatial and temporal variability of climate in Mongolia is not sufficiently represented by the relatively sparse network of meteorological stations. At altitudes at which the forests of the Taiga and mountain woodland steppe predominate, no meteorological stations are present. This lack of climatic data hinders the verification of the climatic causes of frost ring formation. Due to the unequivocal anatomical appearance, however, it is likely that the occurrence of such anomalies in *Larix sibirica* Ledeb. at the upper tree line of the Mongolian mountains is exclusively the result of frost events.

A regionalisation of frost ring chronologies will be used to draw conclusions about the occurrence and spatial extent of extreme climatic events such as late and early frosts, thus contributing to the establishment of a differentiated climatic regionalisation.

## Materials and methods

At the upper tree line of the Turgen-Kharkhiraa- and Khangai Mountains in Mongolia, frost rings were studied at 13 sites (Fig. 1). The forests consist exclusively of Siberian larch (*Larix sibirica*) and are restricted to slopes exposed to the North (Treter 1996, 1999, 2000a, 2000b).

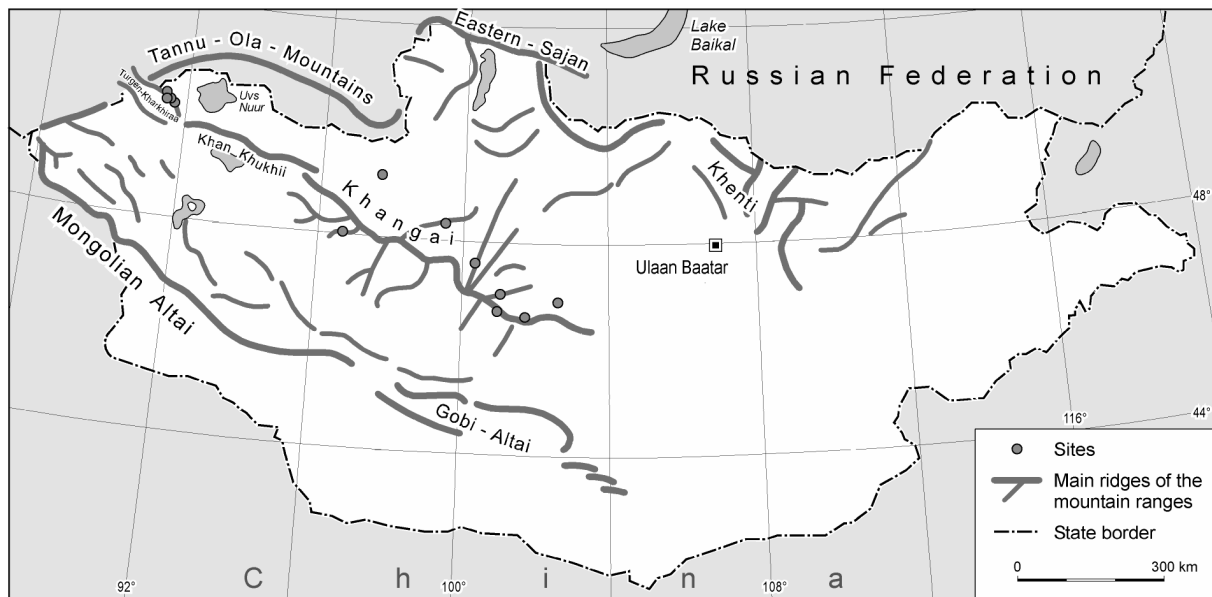


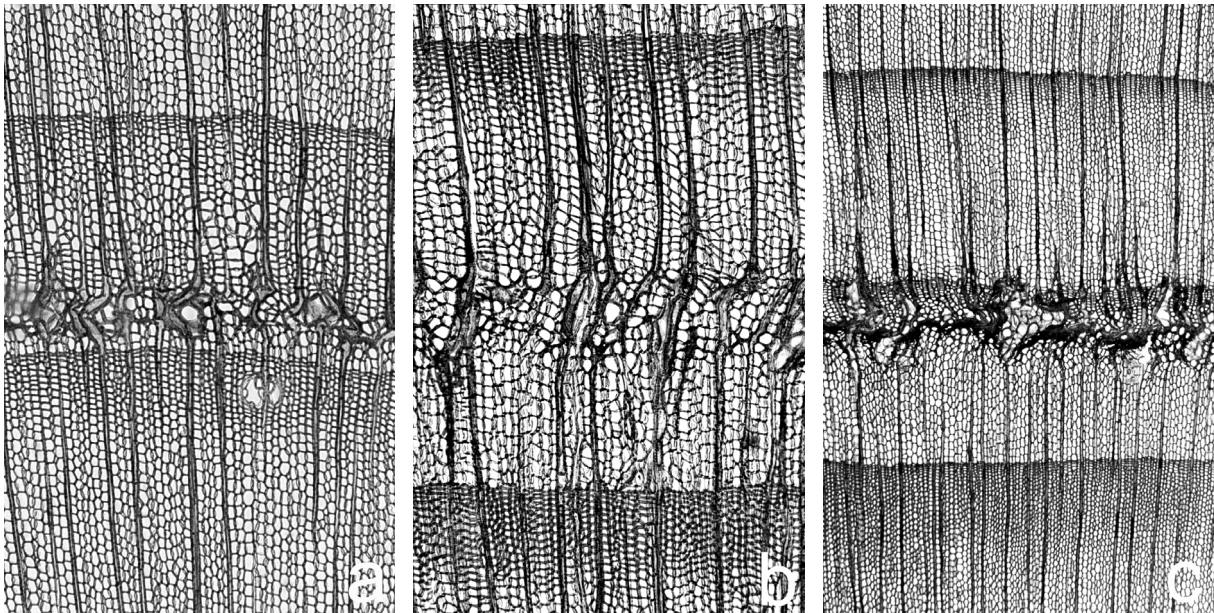
Figure 1: Location of the monitoring sites in the mountain areas in Mongolia

All sites are characterised by nearly the same age class (30-70 years) and a similar open stand structure. Two sampling methods were applied. Sampling of cores and cross sections of all trees within a study plot of 200-400 m<sup>2</sup> was carried out to get insight into the frequency, varying intensity and spatial distribution of frost damage occurrence. Alternatively, sampling of randomly selected trees (minimum of 10 trees per site) was done at most of the sites to decipher regional disparities in the occurrence and intensity of frost events.

The dendrochronological analysis and interpretation of cores and cross-sections followed commonly used procedures: (a) measurement of tree-ring width using a LINTAB measuring table, (b) determining the age of the cambium taking into account the sampling height, (c) synchronisation and cross-dating of the tree-ring curves using TSAP and COFECHA software and (d) the compilation of site chronologies by using ARSTAN. Frost rings were identified under the binocular and accurately dated on the basis of the synchronised tree-ring curves. In addition, micro-sections were prepared from some cross-sections (see also Fig. 2). Finally, the relative frequency of frost ring occurrence was determined.

## Results and interpretation

In the study area, frost rings are found predominantly in earlywood. Only incidentally, e.g. in the years 1940, 1957, 1971 and 1972, do frost rings occur in latewood. An exact determination of the year of formation is difficult if the frost damaged tissue occurs in the late latewood or early earlywood. Two frost rings occurring in the same year were only found at some sites in the area of the Turgan-Kharkhira Mountains. They correspond to the year 1968. One frost ring is located within the earlywood, the other at the transition zone from earlywood to latewood. The location of the frost rings within the annual ring of a certain year can vary within one site as well as between sites of different regions and can be traced back to individual phenological developmental stages (Fig. 2).



*Figure 2: Examples of formation of frost rings (a) in early wood, (b) in the transition zone from earlywood to latewood, (c) in latewood*

In this study, the distribution and relative frequency of frost rings in Mongolia is restricted to the stands of trees of the 30-70 years age class. This ensures the comparability of the analysed samples. Frost-ring frequency varies significantly between different areas that were grouped as distinct mountain regions. While frost rings occur only relatively rarely in the Turgan-Kharkhira Mountains in Western Mongolia, they are more abundant in the Khangai Mountains in Central Mongolia.

Only a few years show frost rings in both mountain regions, such as 1971 and 1972 when frost rings are present in the latewood, and 1951 and 1966-1968 with frost rings present in the earlywood (Fig. 3a). These years are associated with high relative frequencies of frost rings at the individual sites in several regions. This means that these years were obviously characterised by large-scale frost events.

The contrast between the two mountain regions with respect to frost-ring frequency is pronounced. Exclusively in the Khangai-Mountain area, in all or most stands frost-ring formation occurs in 1940, 1951, 1957, 1966, 1967, 1971, 1972, 1974, 1975, 1982, 1987 and 1991 (Fig. 3b). In addition, the exclusively local occurrence of frost rings is restricted to individual sites or few sites within a limited area. With respect to different years one can therefore distinguish between supra-regional, regional, and local formation and distribution of frost rings.

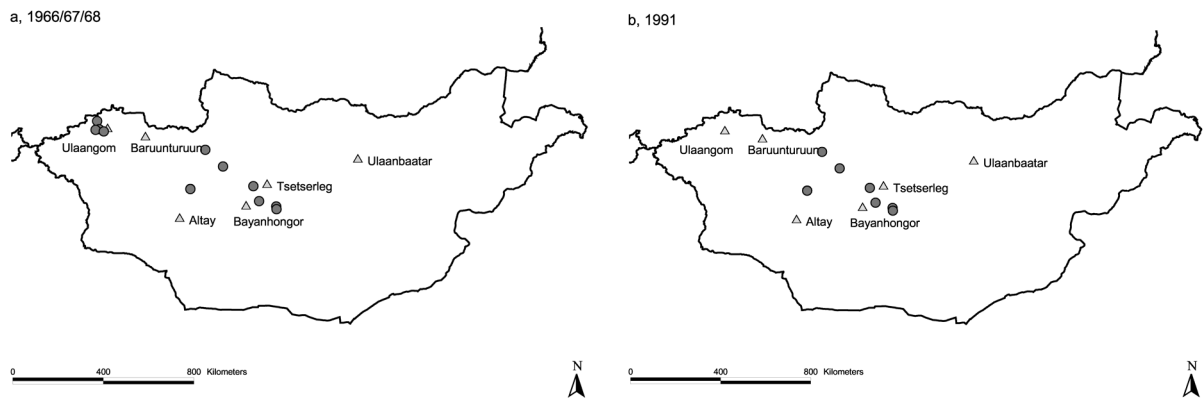


Figure 3: Examples of the distribution of frost rings for different years (a) 1966, 1967, 1968, (b) 1991

### Discussion and conclusion

A spatially comprehensive regionalisation of frost-ring years at the upper tree line of the Mongolian mountain areas relies on several preconditions:

1. The network of sample sites should, ideally, include all mountain regions with a climatically determined upper tree line. This condition has not yet been fulfilled in Mongolia. Although the results of this study are well founded, they remain preliminary as far as a complete regionalisation is concerned.
2. A complete record of the presence or absence of frost ring years at particular sites and in particular regions is only possible if all sites exhibit the same or a very similar age structure. The comprehensive study of specific sites has shown that frost rings are either very rare or completely absent when the cambium age averages 30-35 years or exceeds 40-45 years.
3. This observation indicates that damage to the cambium is the key cause for frost ring formation. In trees that exceed an age of approximately 50 years, the protective bark is so well developed that damage to the cambium does not occur and thus frost rings are also absent. This leads to a gap in the regional distribution patterns of frost rings. This gap is exclusively age dependent and not caused by regional climatic effects. For the compilation of a complete and historically accurate frost-ring chronology, it is thus imperative that trees of all age classes are considered.
4. It is at present not possible to explain why the two mountain regions differ with respect to frost ring frequency. Data from all relevant climatic stations that would be necessary to find possible explanations are currently only partly available. Future investigations, however, will take into account data on the seasonal air-mass distribution and the spatial extent of atmospheric circulation systems. On the basis of these data, it will then be possible to find climatological explanations of frost ring distribution in Mongolian mountain areas.

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