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CLIMATICALLY SIGNIFICANT FOSSIL PERIGLACIAL PHENOMENA IN NORTHCENTRAL UNITED STATES

INTRODUCTION

Periglacial phenomena include a variety of features derived particularly by intense frost action. Frost action is produced by repeated freeze and thaw or by creation of high pressures during growth of ice in the ground. In most periglacial phenomena, various combinations of the work of wind, water, ice, organisms, and gravity are involved. A vast array of phenomena have been described (e.g., Smith, 1949; Bird, 1967; Hamelin and Cook, 1967).

What features or processes should be called periglacial? This question has been debated at great length (e.g., Dylik, 1964), and those arguments cannot be reopened here. Suffice it to say that most writers agree that the features should be indicative of cold climates in general and of intense frost climates specifically, especially those associated with glaciers. Many writers include the polar regions and high alpine areas where permafrost and cold climates are characteristic, but glaciers are not present. Only a few have attempted to define quantitatively the climatic factors producing or limiting the distribution of periglacial features (e. g., Williams, 1962). Many earlier climatic implications of so-called periglacial phenomena are being questioned (Dylik, 1965).

Hamelin and Cook (1967) have discussed periglacial phenomena under the general headings:

Ground ice
Frost-shattering (congelifraction)
Nivation
Floating ice forms
Fluvial features

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Eolian forms
Patterned ground
Solifluction
Congeliturbation (Frost churning)

Under those headings 51 subheadings were used in their classification. Within the general and rather loose terminology of periglacial processes and phenomena the writer will discuss only the following general categories:

Patterned ground
Solifluction (Gelifluction)
Frost riving and frost heaving
Asymmetrical valleys
Eolian phenomena
Thermokarst
Ice mounds
Icings
Congeliturbation

These topics are all within the major headings or subheadings of the classification of Hamelin and Cook (1967). The change in emphasis is done for convenience in focusing attention on those phenomena or processes that are considered more important for northcentral United States. Space precludes a discussion of all categories or more than a brief introduction to those selected.

Which of the above general groups of periglacial phenomena and processes are truly indicative of local climate at the time of their formation, and which leave diagnostic fossil forms? In other words, which periglacial phenomena or processes are likely to be much use for interpreting paleoclimates? It will not suffice to say that frost action was required, because today in the temperate climate of northcentral United States freezing of water takes place now for part of each year. Frost action is still important (Black, 1969a). However, in the past, northcentral United States was in a periglacial and glacial climate according to our interpretation of various indicators. The former existence of a continental glacier in northcentral United States is indisputable. Gross qualitative changes in climate are recognized, but the amount of change of various climatic factors still needs to be quantified.

These topics are explored briefly, utilizing especially experience gained by the writer from his polar studies and from the State of Wisconsin, northcentral United States. Various grants from the National Science Foundation and the University of Wisconsin which made possible the early studies on which this paper is based are acknowledged gratefully. Talks on this subject were given earlier (Black, 1957, 1965a). It is concluded that we have accomplished relatively little in our application of periglacial phenomena to interpretation of past climates.

PERIGLACIAL PHENOMENA

PATTERNED GROUND

Washburn (1956) subdivides the various forms of patterned ground into sorted and nonsorted circles, nets, polygons, steps, and stripes. Although the various forms occur principally in polar, subpolar, and alpine regions, they are not confined to those climatic types. Many of the forms clearly are not indicative of processes restricted to a particular climate, although often repeated freezing and thawing seems to be a mojor process. Of the 19 hypotheses of their origin reviewed by Washburn (1956), few need be mentioned from the point of view of their specific characterization of the local climate. Those in which freezing and thawing can be demonstrated seem to have analogous forms in which wetting and drying are the cause. Hence, determination of even a freezing environment, let alone a periglacial environment, is only possible for certain forms in certain areas. Few seem diagnostic.

Thus, distinction must be made immediately between those forms not necessarily requiring freezing of water and those forms which do. In those forms which require freezing of water, distinction must be made between those produced by seasonally freezing water and those forms in perennially frozen ground.

It is widely recognized that the presence of permafrost promotes more intensive frost effects in the overlying active layer and, hence, better development of patterned ground (Black, 1954). Other impervious horizons, such as shale or clay, can also concentrate water above them to help promote intensive frost action in areas where permafrost is absent. Thus, the identification of former permafrost or its absence is required. This is not always possible for fossil forms in temperate latitudes today.

One distinctive form, the ice wedge, is not only diagnostic of permafrost, but also is diagnostic of the range of temperatures which is required for the formation of the wedges. Sand wedges, that is wedges of sand produced directly by contraction and expansion of perennially frozen ground and not subsequent fillings of former ice wedges, are also diagnostic if they can truly be identified as to their genesis. However, sand wedges form also in areas without permafrost by seasonal frost effects and even wetting and drying (Black, 1952). Because of the non-uniform terminology and lack of three-dimensional studies of the phenomena, much confusion still exists in the identification and interpretation of sand wedges in present polar environments. The correct identification and interpretation of fossil forms of former ice and sand wedges in areas far removed from the present periglacial climates is even more subject to debate. However, their distinction is possible in most groups where three-dimensional fabrics of the fillings can be ascertained.

Studies by Black (1954, 1963), Black and Berg (1963a, and b, 1966), Berg and Black (1966), Lachenbruch (1962, 1966), and Péwé (1959, 1962, 1966a) among others, have established a framework for an understanding of the climatic conditions in which sand wedges and ice wedges grow. (See Dylik and Maarleveld, 1967, for a summary of the literature). Where therminal coefficients of expansion of the ground in permafrost approach those of ice, contraction cracking annually occurs when the "cold wave" penetrates some decimeters into the upper part of permafrost. A rapid temperature drop in the ground of 4°C is sufficient to initiate a crack which can be propagated downward with temperature changes on the order of 2°C. The nature of the medium and the rate of temperature change are major factors. Where the thermal coefficients of expansion of permafrost approach those of rock (about 1/5 or 1/6 of that of ice), a commensurately greater range in temperatures is needed to initiate cracking. Field data suggest about 10°C change is needed, and cracks are propagated to depths where temperature changes are on the order of about 4°C.

Sufficient studies have now been done to provide us with a reasonable interpretation of the thermal regime of the permafrost in most periglacial environments. Thus, it is quite possible to predict, as Black (1954) and Péwé (1966b) have done, where actively growing ice wedges may be expected. We know, further, that moderately high humidities are required during the spring to provide moisture for the development of hoar frost or melt water in the still open contraction cracks in permafrost. Where atmospheric humidity is low in the spring, or runoff water is not available, ice wedges do not grow;

only sand wedges can form in such environments. If sand is not available, then the wedges are comprised of whatever rubble might be available to work its way downward in the contracting zone.

Sand wedges grown as such in the dry polar regions contrast markedly in their internal fabrics with those of casts of sand which fill former ice wedges. The mechanism of formation makes this difference clear. As only a narrow crack a few millimeters to 1 to 2 centimeters in width is present in the winter, the size of particles that can work downward is restricted. In the arid areas where abundant sand is available, it runs or drifts into the cracks to become foliated vertically within them. Where snow covers the cracks, hoar frost grows in them and builds ice in vertical dikelets. Contraction cracks in subsequent years may be localized in or between or on the edge of the dikelets of sand or ice, depending on their tensile strength compared with that of the adjacent material. Commonly, in sand wedge development, new loci are occupied between contraction cracks, so that over a period of many decades numerous narrow vertical dikelets of sand traversing any previous structures may be seen (Pl. 1). The ice dikelet, however, commonly is the weakest zone, and continues to crack within or on one of its borders to build up a more massive ice wedge through time.

During fossilization of an ice wedge, collapse of the surface material into the void vacated by the melting ice allows a slow subsidence or an abrupt collapse from the surface downward across the width of the entire wedge. Such subsidence or collapse foliates the descending material in the depression vacated by the ice. Foliation parallels the sides and crosses the wedge in a basin shape (Pl. 2). It is not like the narrow, vertical planes of the original sand wedge. Large masses of till, rock, gravel, or other host material which can stand while wet may be incorporated in the descending material.

Relatively few ice-wedge casts may be seen in materials originally fine grained and likely to be fluid when thawed, because they close as rapidly as the ice melts. Those host materials which can stand with steep faces while wet provide the best and most distinctive ice wedge casts. However, relatively few of the patterned ground phenomena are fossilized in environments where the unconsolidated material in which they are found is not quickly modified or destroyed. Nonetheless, ice-wedge casts representing fillings of former ice wedges are the most widely recognized diagnostic periglacial indicators of paleoclimates we have (B l a c k, 1965b; P é w é, 1966b).

SOLIFLUCTION (GELIFLUCTION)

Solifluction (gelifluction) phenomena and processes in Greenland have been separated by Washburn (1967) from creep processes and phenomena. Washburn (1967, p. 14) defines frost creep as "a ratchet-like down slope movement of particles as a result of frost heaving of the ground and subsequent settling on thawing, the heaving being predominantly normal to the slope and the settling more nearly vertical." Black (1969a) finds that rapid creep movements in Wisconsin, a temperate region today, are taking place in winter by freezing and thawing, but movements of almost the same magnitude occur in summer through wetting and drying. Thus, correlation of the creep process quantitatively to periglacial climates seems most difficult, if not impossible.

Separation of the creep movement from solifluction or gelifluction was possible by Washburn (1967) in his detailed field studies in Greenland where the process was going on. However, the morphological features resulting from the combined processes likely would be distinguished only with great difficulty, if at all, in fossilized form. Hence, the recognition of solifluction phenomena in general, which range from freezing to non-freezing environments, and gelifluction, which is confined only to freezing environments, seems most difficult at our present state of knowledge. Hence, those phenomena now fossilized appear to be of very limited use as climatic indicators. This conclusion is enhanced also by the fact that such phenomena were formed on slopes of instability. Generally such slopes continue to be unstable, even after climatic changes from a possible periglacial environment to a temperate environment, such as northcentral United States has experienced.

FROST RIVING AND FROST HEAVING

Frost riving and frost heaving are by definition associated with freezing water. However, splitting of rocks and heaving of stones or tussocks of vegetation also take place in areas where freezing is not the factor. Hence, these processes or the phenomena produced by them can only be used as an indicator of freezing climates under certain circumstances. At least in light of present knowledge, they are not usable for quantification of the temperatures involved, or of other climatic factors.

ASYMMETRICAL VALLEYS

Asymmetrical valleys are found throughout the world and obviously are the result of many processes and factors. Distinguishing processes inherent only to periglacial climates seems most difficult in light of our present state of knowledge. For example, in the permafrost environment of northwest Alaska, Everett (1966) finds that asymmetry of Ogotoruk Creek is probably the result of structure and lithology which produce a homoclinal shift of the stream. The asymmetry of the valley thus formed provides slopes of different character, climatically, botanically, and pedologically. These differences are further manifested in differences in kind and distribution of frost features and in rate of slope movements. However, Currey (1964) concludes that lithology and structure are not the causes of the asymmetry of the same creek, but that processes acting asymmetrically in causally ordered sequence from morphologic activity to development of colluvium, positioning of axial drainage, and lateral corrasion by axial drainage are the causes. Which is cause and which is effect?

In that part of northwestern Alaska north-facing slopes are steeper. Other workers elsewhere concluded that south-facing slopes in permafrost areas were steeper (Smith, 1949). In southwest Wisconsin the north-facing slopes commonly are steeper and were interpreted as having been produced in non-periglacial climates (Judson and Andrews, 1955). However, Wayne (1967) uses asymmetrical valleys in Indiana to infer more frequent freeze-thaw cycles and more active solifluction on the gentler south-facing slopes, but not necessarily the presence of permafrost. Any direct correlation of asymmetrical valleys with climatic indicators obviously must await further study.

EOLIAN PHENOMENA

Eolian phenomena, such as sand dunes, ventifacts, and loess, are widespread especially outside the periglacial zone. Nonetheless, they have been used as evidence of climate change in areas marginal to former ice steets (Smith, 1949). Changes in the intensity of wind work or in available material to be moved by wind are locally commonplace today in most climates. On a regional basis such changes can be indicative of gross changes in climate, but only indirectly. No direct correlation with temperature, effective moisture, etc. has been made.

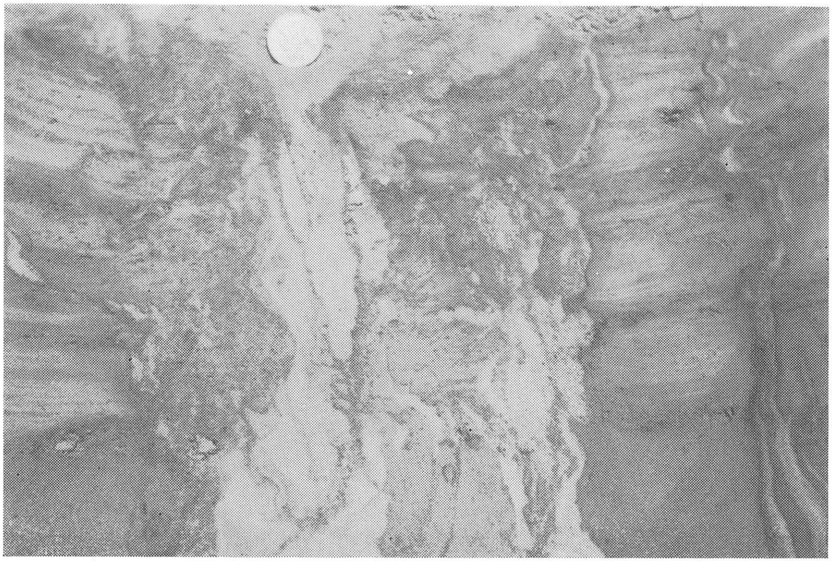
The widespread loess in northcentral United States is derived mostly from proglacial streams, and is intimately related to advance and retreat of continental glaciers (Frye, Willman and Glass, 1968). However, some very fine loess is coming in today from the prairie states. Sand filling former ice wedges is considered eolian and generally was derived fairly locally at a time when forests apparently were absent from Wisconsin (Black, 1965b). Fossil sand dunes and ventifacts are not common in northcentral United States, but both are still forming locally under present climates. Climatic correlations, thus, are most difficult.

THERMOKARST PHENOMENA

Thermokarst phenomena are by definition confined to areas in which melting of frozen ground takes place. The majority of thermokarst phenomena described are those in permafrost environments, and are produced by the thawing of the permafrost. Pits of various sizes, whether dry or occupied by water, are commonplace in certain portions of the permafrost areas (Black, 1969b). Where identifiable as true thaw pits, they are diagnostic of frozen ground. However, the thawing takes place over a wide range of climatic conditions, whether permafrost is growing or decaying. Hence, these features are of only somewhat limited use as indicators of present climate. As fossilized forms seem rare, their value as indicators of former climates is also very limited. At least in much of northcentral United States, separation of thermokarst pits as a permafrost phenomena from the tens of thousands of glacial kettles of all sizes seems almost hopeless.

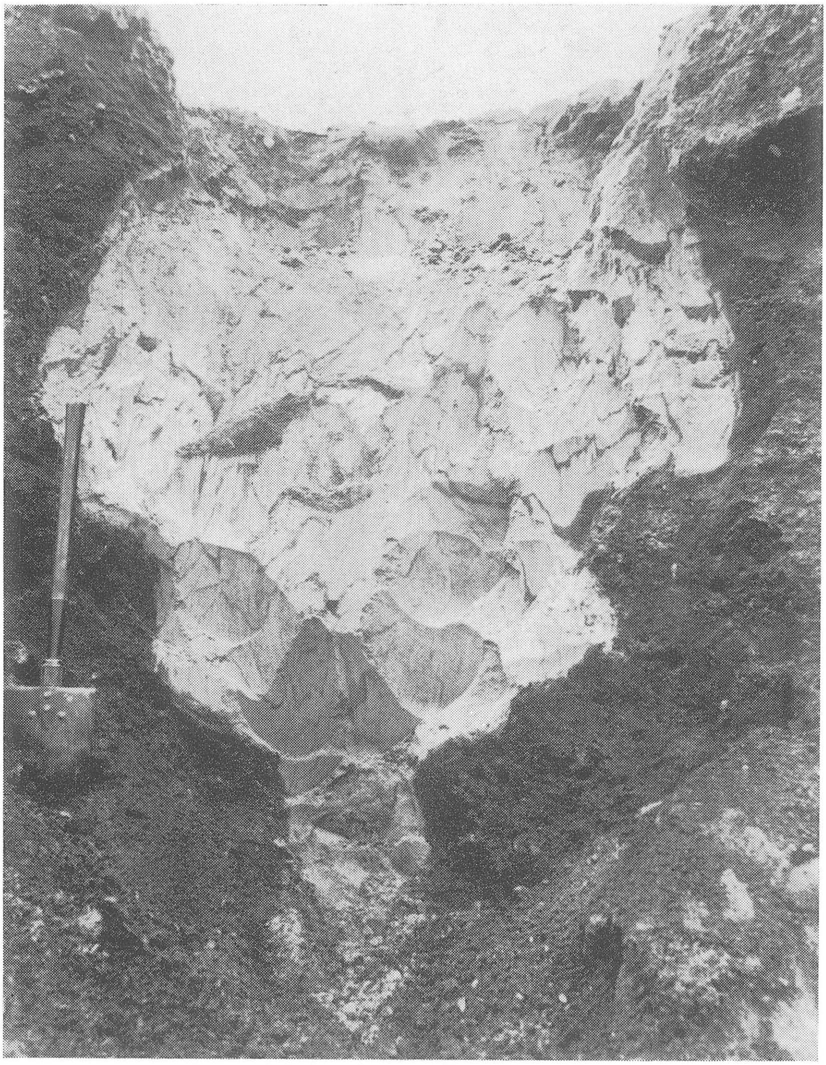
ICE MOUNDS

Mounds of various sizes and shapes are commonplace in permafrost environments, but are also found in other regions of the world. Those with ice cores, or which result from cryostatic processes, are indicative of the periglacial environment. Unfortunately, such mounds do not fossilize except indirectly as pits. Identification of pits which were formerly ice mounds is exceedingly difficult in light of present knowledge. Reference, however, is made in the literature to former "pingos" and other kinds of mounds.



Pl. 1. Vertical section of sand wedge at Nowostawy in the Łódź region, Poland

Horizontally stratified clastic sediments are cut in many places by narrow vertically foliated sand dikes representing fillings of initial contraction cracks. This was not an ice wedge replaced by sand



Pl. 2. Vertical section of an ice-wedge cast at River Falls, Wisconsin, north-central United States

The eolian sand fills the former ice wedge in kame sandy gravel. A large inclusion of the host gravel is about 20 cm to the right of the top of the shovel. The irregular dark lines in the cast are secondary ferric oxide concentrations which post-date the filling of sand

In general, it seems that small mounds in the periglacial environment are related to seasonal or active-layer phenomena, whereas the larger mounds are commonly products of the permafrost itself. Reconstruction of the former environment and time of formation of such mounds would suggest that few will be particularly climatically significant. Recognition of seasonal frost phenomena from permafrost phenomena would provide some indication of temperature, but no direct connection exists. In northcentral United States, where tens of thousands of kettle pits, ponds, and lakes are found, recognition of such depressions as having been derived from the thaw of ice mounds, such as pingos, would be exceedingly tenuous. However, former pingos tentatively are identified in Indiana (Wayne, 1967) and in Illinois (Ronald C. Flemal, written communication).

ICINGS

Icings, whether on cliffs or steep banks, or in river bottoms are commonplace in the periglacial environment. Icings on steep banks, however, are also common in the temperate region wherever ground water reaches the surface during winter. River icings of the magnitude found in the tundra reaches of Alaska are not found in the temperate regions. The river icings have caused drainage diversions of considerable magnitude, and remain as perennial masses of ice for several years. Their fossilization seems to be a phenomenon that could be recognized only indirectly, for the melting of a block of ice on the surface cannot be expected to leave a morphometric form directly. Hence, these phenomena, too, are of exceedingly limited usage. No fossil forms are recognized in northcentral United States.

CONGELITURBATION

Congeliturbation or frost churning are common processes in periglacial climates. Fossil involutions and other contorted structures supposedly derived from those processes long have been used as evidence for permafrost and intense frost action (e.g., Frye and Willman, 1958; Wayne, 1967). No direct relationship to climate other than to frost action usually has been made. Although most investigators have considered permafrost a requirement, various loading phenomena and gravity movements without permafrost are now recognized as having been commonplace. Some fossil involutions in northcentral United States are considered to have formed without permafrost (Fries, Wright, and Rubin, 1951). Thus, these phenomena must also be used with extreme caution rather than automatically as has been done so often.

SUMMARY OF CLIMATICALLY SIGNIFICANT PERIGLACIAL PHENOMENA

Of all the various phenomena produced in the periglacial regions, perhaps the only truly diagnostic form indicative of the temperature of its formation is the ice wedge. Thermal coefficients of expansion of the ground and the annual temperature cycle in the upper few meters of the ground determine the general location and growth rates of ice wedges. The length of time such wedges grow is reflected in the amount of ice that is put into the ground. Thus, evidences of ice wedges provide us with our most specific direct climatic relationship. All other periglacial features are less temperature dependent, such as pingos, or have no direct relationship with climate. Some are restricted to areas where freezing takes place, but others also exist in climates without frost. Moreover, few of these features are readily fossilized because of their existence within the active layer or soil profile, or their location on unstable slopes.

In northcentral United States fossil ice-wedge casts are present in numerous locations (Black, 1964, 1965b; Frye and Willman, 1958; Wayne, 1967). They provide us with our best indication of the former periglacial climates, even though the dating of the wedge formation and wedge destruction is vague and unsatisfactory. Other patterned ground, solifluction phenomena, frost riving, asymmetrical valleys, eolian phenomena, and involutions are present but provide at best only qualitative information on the climate. The identification of thermokarst and ice mounds, including former pingos, must await confirmation. No fossil icings have been recognized.

CLIMATIC SIGNIFICANCE OF THE PERIGLACIAL PHENOMENA IN WISCONSIN

According to the size and distribution of ice-wedge casts in Wisconsin, as correlated with the thermal coefficients of expansion of the host materials, it is possible to infer discontinuous to continuous permafrost in the State (Black, 1965b). Mean annual air temperature was $-5°$ to $-10°C$ for 1,000 to 3,000 years. Mean annual air temperature today is about 5°C. Thus, a change from the Late Wisconsinan Stage to the present involved a change in mean annual air temperature of 10° to 15°C. Unfortunately, the precise time of the formation of the wedges is not known. Nor is that of their destruction and filling with eolian sand.

The difference in climate during growth of the wedges from that during their destruction was great. Aridity must have characterized their destruction according to the widespread eolian sand and lack of evidence that trees grew in the State. Unfortunately, the other periglacial indicators have been of little value in helping to quantify either the climate at the time of the wedge formation or at their destruction. Sorted patterned ground, solifluction or gelifluction (?), lobes, and other typical periglacial phenomena are present (Black, 1964). Of these, only some solifluction or gelifluction (?) have been dated and these only relatively. They suggest rapid movement during the interval from about 30,000 years ago to perhaps 13,000 years ago. Such rapid movements may not have occupied the entire interval, and correlation with ice-wedge growth or destruction has not been possible. Some of the sorted patterns are thought to date from the same interval, but little control is available. Frost riving may date in part from that interval, and some from still earlier intervals.

The formation of the wedges calls for moderately wet or humid climates in the spring, but not necessarily any significant vegetal cover. The destruction of the ice wedges calls for drier climates to provide the abundant sand and lack of vegetation to control its movement. No trace of trees has been found for the interval when the wedges likely grew, nor when they were destroyed.

A possible reconstruction of the situation follows. We know that Wisconsin was in a unique position between two major ice lobes — Lake Michigan and Des Moines. During that interval of time from 30,000 years ago to about 13,000 years ago, the zonal westerlies and storm tracks presumably were diverted south of the State. A massive continental ice sheet would have existed to the north, rising several thousands of meters above the land. Most precipitation was confined to the south border of the ice margin, leaving the indentation of Wisconsin to the north relatively dry. Clear skies with little precipitation in winter and probably cloudy skies in summer as Gulf air worked northward, should have ensued. Katabatic, down-gradient winds descending from the continental ice sheet to the north should have funnelled through the State as such winds today funnel off the Antarctic Plateau through the dry valley regions of Victoria Land. Those strong drying winds should have had the velocity to move the sand, and they should also have precluded the formation of forests.

How long the periglacial climate existed is not known (Black, 1965b; 1969a). Only 1,000 to 3,000 years are required for the formation of the former ice wedges, yet 17,000 years was available. The length of time involved in the destruction of the wedges is also not known. Hence, the climatically significant periglacial phenomena in northcentral United States show vast changes took place, but only a sketchy reconstruction is yet possible.

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