CHINESE GEOGRAPHICAL SCIENCE
Volume 9, Number 2, pp. 166– 171, 1999
Science Press, Beijing, China

GENETIC TYPES AND CHARACTERISTICS OF GROUND ICE IN NORTHEAST CHINA

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(Received 13 July 1998)

ABSTRACT: The southern limit of permafrost in northeast China oversteps that in the other regions of Eurasia by a few degrees of latitude. There are 11 types of ground ice found within the studied region, including vein ice, massive bedrock ice, lava caves ice and so on. The water for the formation of the ground ice comes from various sources: precipitation, surface water, soil water, and ground water. The ground ice types coexist with the surrounding environment. The correlation and distribution features of the original types of ground ice, their surrounding environments are analyzed for the theoretical study of ground ice formation, engineering control of hazards in ice-rich areas and the prediction of changing conditions.

KEY WORDS: ground ice, hazard control, northeast China

1 GENETIC TYPES OF GROUND ICE IN CHINA

Ground ice is well developed in the vicinity of the southern permafrost limit in the Eurasian continent, in the northern part of northeast China. Here, the major ice groups are divided according to their sources of water: precipitation, surface water, soil water and ground water. Numerous mechanisms are involved in the ground-ice formation, including water-vapor sublimation, recrystallization of accumulated snow, gravity-water seepage, ice segregation and transfer, in situ freezing, capillary sucking along the gradients of temperature, pressure and solute concentration, and repeated segregation in the 12 media where the ground ice is found. The ground ice in northeast China can be divided into 11 types: cave ice flowers, cave ice, tunnel ice, crevice ice, epigenetic and syngenetic ice, ice formed by gravity-water seepage, cemented ice, segregated ice, repeatedly segregated ice, intrusive ice and massive ice in bedrock (Fig. 1) based on the field investigations during the past 30 years (Cheng, 1992; Tong, 1993; Li *et al.*, 1996; Jia, 1987; Peng, 1990; Wang, 1990; Ye, 1983).

2 CHARACTERISTICS OF GROUND ICE IN NORTHEAST CHINA

The ground ice can be divided into 11 types according to the water supply, moisture migration, formation mechanisms, existing environments and time in northeast China.

2.1 Cave Ice Flowers

The cave ice flowers are formed by the congelation of the moisture as a result of cooling in the atmosphere on the cold surface of the media, or by the sublimation and re-freezing on the surface of the cave area, such as in the crevices and between the stalactites in Shuijinggong Cave and Bailongdong Cave in Wudalianchi Lake area. This type of ice is also found in the top of the pingoes on the southern side of Chaozhong Railway Station along the Ya Lin Railway.

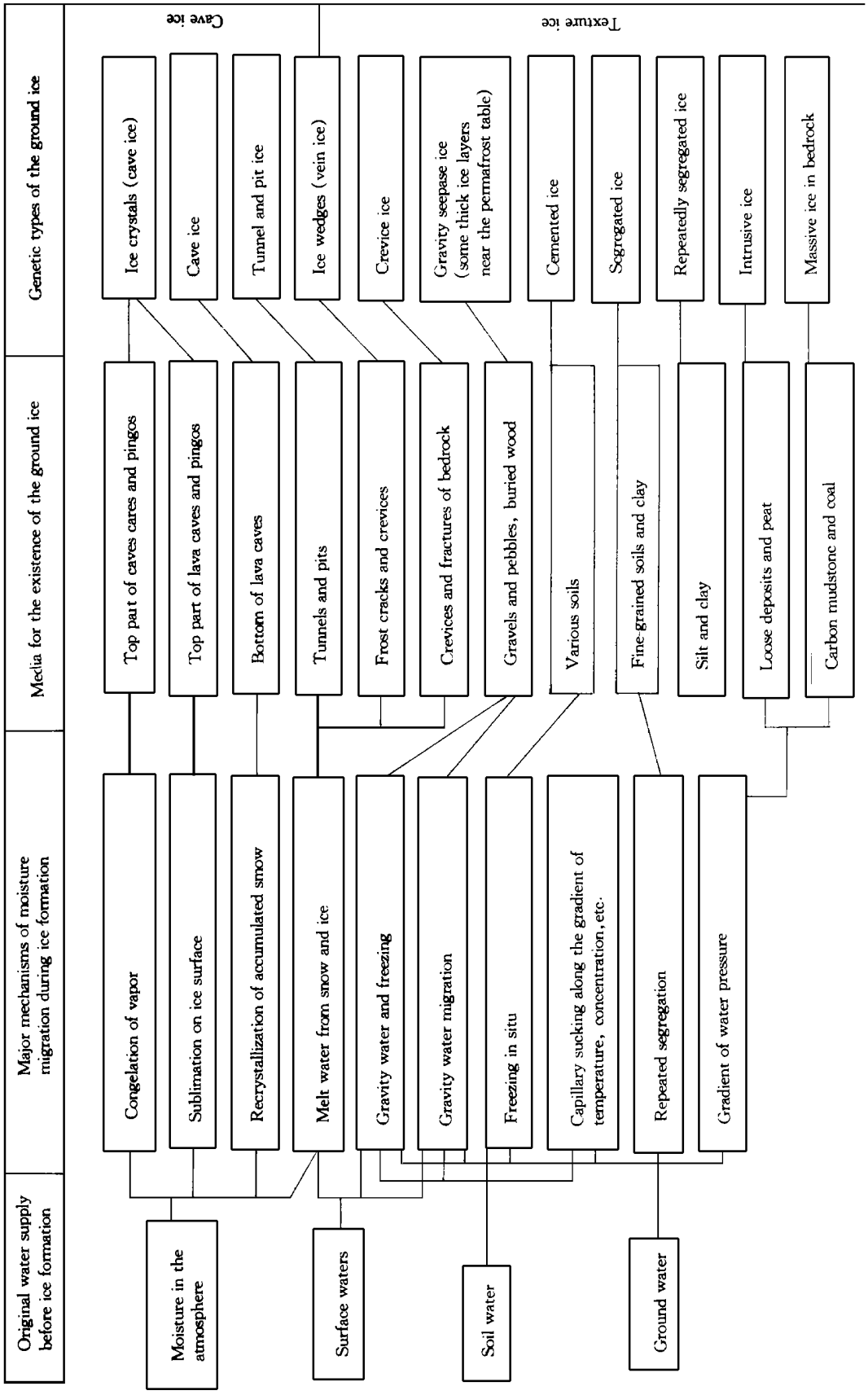

Fig. 1 Genetic types of ground ice in Northeast China

2.2 Cave Ice

Various water sources, such as blown snow, ground water, surface water and migration of soil moisture can supply moisture for ice formation in caves. The cave ice is formed under a cold environment. The ice in the two lava caves in Wudalianchi Lake area was formed by the sink of cold air during winters. It was estimated that the ice accumulation started to form at least 275 years ago (Li *et al.*, 1996) and now is still growing.

2.3 Tunnel and Pit Ice

The tunnel and pit ice is artificial cave ice in the excavations for tunnels, mining and cold storehouses. Most of the tunnel ice in northeast China was formed after the excavation of the railway tunnels. The water for the ice comes from the seepage of surface water, soil moisture and gravity-water, congelation of the moisture in the atmosphere, or runoff in the permafrost sections of the tunnels. This kind of ice significantly endangers the safety of traffic(Table 1).

Table 1 Frost hazards and countermeasures in railway tunnels in the Da Hinggan Mountains

Railway name	Tunnel name	Frost environment	Tunnel hazards	Countermeasures and effects
Ya Lin Line*	Linding Tunnel	Permafrost MAGT** = - 1℃	Water drainage tunnel freezes annually for 0.8 m	Ditches for seepage and warming of water and removal of ice by labor
Huzhong Branch Line*	Cuilin No.2	Permafrost. Drainage tunnel was closed	About 0.7-m ice covers railway and causes traffic jams	Ice melt by steam locomotive and removal of ice by labor
Nen Lin Line*	Xiluoqi No.2	MAAT*** = - 6.45℃ 8 months with subzero air temperature	Ice formation in winter lasts until next August	Removal of ice by labor
Bin- Zhou Line*	Hinggan Tunnel	7-month seasonal frost - 26℃ in January Lowest record: - 50℃	Air temperature below - 15℃ at the gate without insulation curtain	Hanging insulation curtain

* Ya Lin Line: Yakeshi- Mangui forest railway; Huzhong Branch Line: A short branch line near Huzhong; Nen Lin Line: Nenjiang- Mohe forest railway; Bin- Zhou Line: Harbin- Manzhouli railway.

** MAGT: mean annual ground temperature.

*** MAAT: mean annual air temperature.

2.4 Ice Wedges (Repeated Vein Ice)

Massive ground ice wedges can be also called repeated ice veins. Frost cracking in cold permafrost causes ice veins to form by horizontal ice crystals in the cracks in winter and the remaining voids filling with water during spring runoff and then freezing. Fourteen ice wedges were found in the first terrace of the Yitulihe River (Jia, 1987; Peng, 1984; Cheng, 1987), and seven ice wedges were found at Huma in the Da Hinggan Mountains(Tong, 1993). The characteristics and environments are shown in Table 2. The presence of the 21 ice wedges in northeast China is unique in the middle latitudes.

2.5 Crevice Ice (Vein-like)

Vein-like crevice ice is formed by water freezing in the cracks, crevices and other wider spaces in bedrock. The crevice ice may be 15- 20 cm wide and can extend as deep as 54 m at Galaya in the Da Hinggan Mountains. On the tilt wells in a coal mine in the Huola Basin, crevice ice of 1- 3 cm in width was found extending to several tens of meters in depth. Some crevice can also form patterned ground in heavily weathered bedrock.

Table 2 The existing environments and characteristics of ice wedges in the Da Hinggan Mountains, northeast China*

Location	Discovery date	Environments of ice wedges							Sites	Characteristics of ice wedges				
		Geomorphology	Vegetation	Hydrology	Overlying soil layers	Depth (m)	Permafrost table	Lithology of wall rock		Width of the top (m)	Height (m)	Veins form	Formation	Estimated MAAT for formation
Yitulihe, Da Hinggan Mt. (50°32′N, 121°29′E)	Jan. 1983	First terrace on right bank of the Yitulihe River	Hummocks	Accumulated water in summer	Litter, peat		Minimum temperature −8℃	Litter, peat silt	7				Late Pleistocene 2.7−2.3 ka B.P.	
40 m from the first location	Nov. 20 to Dec. 30 1984	First terrace	Turf *Carex*	Accumulated water in summer	Litter, peat	0.9−1.4	FI**: −3600℃·d PT**: 0.8 m	0.0−0.3 m root; 0.3−0.8 m peat	4	1.1−1.3	>1.5	Striped veins	Late Pleistocene 2.7−2.3 ka B.P.	−2℃ −−4℃
730 m a.s.l. in the valley	Late Oct., 1987	First terrace	Turf *Carex*	Local accumulated water	0.35−0.40 m peat, 3−4 layers of segregated ice	0.85−0.92	PT=0.7 m	Peat, sandy clay, deformed wall rock	3	0.2−0.4> 0.73−1.00	>0.73 −1.0	Layered lenses and veins	Late Pleistocene 2.7−2.3 ka B.P.	−5℃ −−7℃
Wuma in Da Hinggan Mt. (52° 45′ N, 120°45′E)	Summer 1990	First terrace on the right bank of Yilijiqi River	Secondary *Betula* moss forest	Mires	Meadow silt, peat humic soil with silt	1.6−2.0	MAAT***=−4.4℃ FI=−3394℃·d MAGT***=−1−1.5℃	Gravels with layered silt	7	0.1−5.0	>2.0	Vertical layers with bubbles	Late Pleistocene synthetic ice 14−10 ka B.P.	−5℃ −−7℃

* According to the data of Jia *et al.*, 1987; Pent *et al.*, 1990; Tong, 1993.

** FI: freezing index; PT: permafrost table.

*** MAAT and MAGT are the same as those in Table 1.

2.6 Gravity Seepage Ice

The gravity seepage ice was first proposed as early as 1963 by Wang chunhe (1982). It has been discovered widely just below the permafrost table in Northeast China and on the Qinghai-Xizang Plateau. It is thick, uncontaminated, widespread and at shallow depths. Consequently, it is very harmful to construction projects and of great concern. It is formed by the combination of the freezing of the gravity infiltrated water, and moisture migration in the thawed layer caused by gradients in soil temperature, water pressure and solute concentration to the freezing front in the vicinity of permafrost table in early autumn (Fig. 1 and Table 3).

Table 3 Genetic types and characteristics of ground ice in northeast China

No.	Genetic Types	Water supply	Formation mechanism	Environments	Lasting Periods	Hazard potential	Examples
1	Cave ice, crystals and hoarfrost	Atmospheric moisture	Ground water seepage, snow recrystallization, frozen dams	Top part and walls of lava caves, tunnels and cracks	Seasonal or year round	Slight	Top part of caves in Wudalianchi and Chaozhong, pingo
2	Cave ice	Surface water, soil moisture and ground water	Infiltration and freezing of ground water	Lava caves	Yearly	Slight	Caves in Wudalianchi
3	Tunnel ice	Surface water, soil moisture and ground water	Infiltration, flowing and freezing of ground water	Artificial tunnels and pits	Seasonal	Sometimes serious	Linding tunnel, Hinggan Cuilin No. 2
4	Ice wedges	Rainfall, snow and ice melt water, surface water	Infiltration flowing and freezing of ground water	Frost cracks	Yearly	Moderate	Yitulihe River and Wuma
5	Crevice ice	Surface and ground water, crevice water in bed rock	Infiltration, flowing and freezing of ground water	Crevice and joints in bedrock	Yearly	Slight	Galaya, Huola Basin
6	Gravity ice	Surface water, soil moisture and ground water	Gravity migration	Permafrost table	Yearly	Very serious	Ya Lin Line
7	Cemented ice	Soil moisture, crevice water in rock	Freezing in situ	Pores in soils	Seasonal or yearly	Minor	Shallow soils
8	Segregated ice	Soil and ground water	Segregation	Wet fine-grained soils	Yearly	Serious	Fine-grained soils
9	Repeatedly segregated ice	Soil moisture and ground water	Repeated segregation	Clay and silt	Yearly	Very serious	Ya Lin Line
10	Intrusive ice	Artesian ground water	Gradient of water pressure	Loose deposits	Seasonal or yearly	Moderate	Chaozhong
11	Massive ice	Deep artesian ground water	Gradient of water pressure	Carbon mudstone, coal	Perennial	Minor	Huola Coal Mine

2.7 Cemented Ice (or Ice Cement)

Cemented ice is formed by the in situ freezing of the moisture in soils. Generally, the ice content in permafrost, with this type of ice, is low and the ice crystals are small. The cemented ice can be divided into 4 subtypes: contace, film, pore and basal cement ice.

2.8 Segregated Ice

Segregated ice is formed by the freezing of the moisture migrating to the freezing fronts along the gradients of soil temperature and solute concentration in loose, fine-grained soils. The segregated ice is often layered or vein-shaped, forming layered or webbed structures in the frozen ground. Generally, the ice content is greater than the pore volumes, sometimes much greater. The excessive ice can form thick ice layers or belts in permafrost or in soil containing ice layers, causing pronounced frost heaving and thermokarst settling.

2.9 Repeatedly Segregated Ice

The repeated ice segregation was proposed by Cheng Guodong(1992) in 1981. The repeatedly segregated ice is formed in syngenetic permafrost containing sufficient fine soils by the following mechanisms: 1) moisture migration and ice formation during upward freezing in the active layer; 2) the unequal migration of unfrozen water; 3) purification of ice; and 4) syngenetic growth of ground ice during deposition. This is he major ice type found just below the permafrost table in loose, fine-grained soils, in the form of ice lenses, 0.3– 0.6 m in thickness and more than 50% in volumetric ice content.

2.10 Intrusive Ice

Artesian ground water can intrude into loose soils, freeze and form intrusive ice. This type of ice is often found in pingoes, seasonal frost mounds and palsas, causing uneven frost heaving (Table 3).

2.11 Massive Ice in Bedrock

Massive ice in Jurassic conglomerate was found in the Huola Basin in northeast China in 1985 (Wang, 1990). A massive ice layer 20.70 m in thickness at the depth from 46.15 m to 66.5 m was found in the borehole H_6; two layers, one 1.8 m in thickness, from 40.0 m to 41.8 m, and the other 16.45 in thickness, from 49.16 m to 65.30 m were found in another instance. The two layers were interrupted by a carbon mudstone 7.35 m in thickness. The ice was slightly silty containing $HCO_3 \cdot Cl - Ca \cdot Na$ type water with a mineral content of 0.5 g/L.

Besides of the 11 types of ice discussed above, combined and transition types of ice also can be found extensively in northeast China.

In summary, the genetic types and characteristics of the ground ice in northeast China are controlled by many factors and are therefore very complicated, and vary according to their environments, the geological conditions and other factors in the different region.

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