十三、冻土地区活动断裂的灾害效应

青藏铁路横穿处于强构造活动区和高寒环境的青藏高原，断裂活动与冻土融冻相互耦合，产生特有的地质灾害，称为断裂诱发地质灾害，包括断裂蠕滑变形、不均匀融冻变形、夏季线性排列的泉水群、冬季串珠状斜列冰丘、构造裂缝等灾害类型。沿部分断裂破碎带，由于断裂活动、桥梁施工及火车震动，还诱发位置随时间发生变化的移动冰丘。在青藏高原岛状冻土带和常年冻土地区，沿活动断裂发育特殊的热结构和丰富的地下水；断裂活动—地下水运动—不均匀冻胀相互耦合，能够产生显著的灾害效应，导致路基变形、路面破裂、桥梁破坏和涵管拱曲，威胁铁路、公路、输油管道等线路工程安全（吴珍汉等，2003d，2004，2005；Wu et al., 2004）。

PART 13 GEOLOGICAL HAZARDS POSED BY ACTIVE FAULT IN THE PERMAFROST NORTH TIBETAN PLATEAU

The Golmud-Lhasa Railway goes across the Tibetan Plateau characterized by intensely tectonic activity and severe cold climate. The coupling among active faulting, underground water flow and feeezing-thawing may result in variety of geological hazards including seismic fracturing, creep deformation, inhomogeneous freezing and thawing, surface fracture, pingo and migrating pingo. These geological hazards together with earthquake threaten the safety of railway, highway, oil-pipeline and other engineering facilities as bridges, culverts and buildings (Wu et al., 2003d, 2004, 2005).

图 164 两道河兵站南侧沿活动断裂发育的泉水群与泉华台地

（镜头向东，摄于 2001 年 7 月）

Fig.164 View eastward in July of 2001 at hotspring ponds in linear distribution along active fault in south of Liangdaohe Station of the Golmud-Lhasa Highway

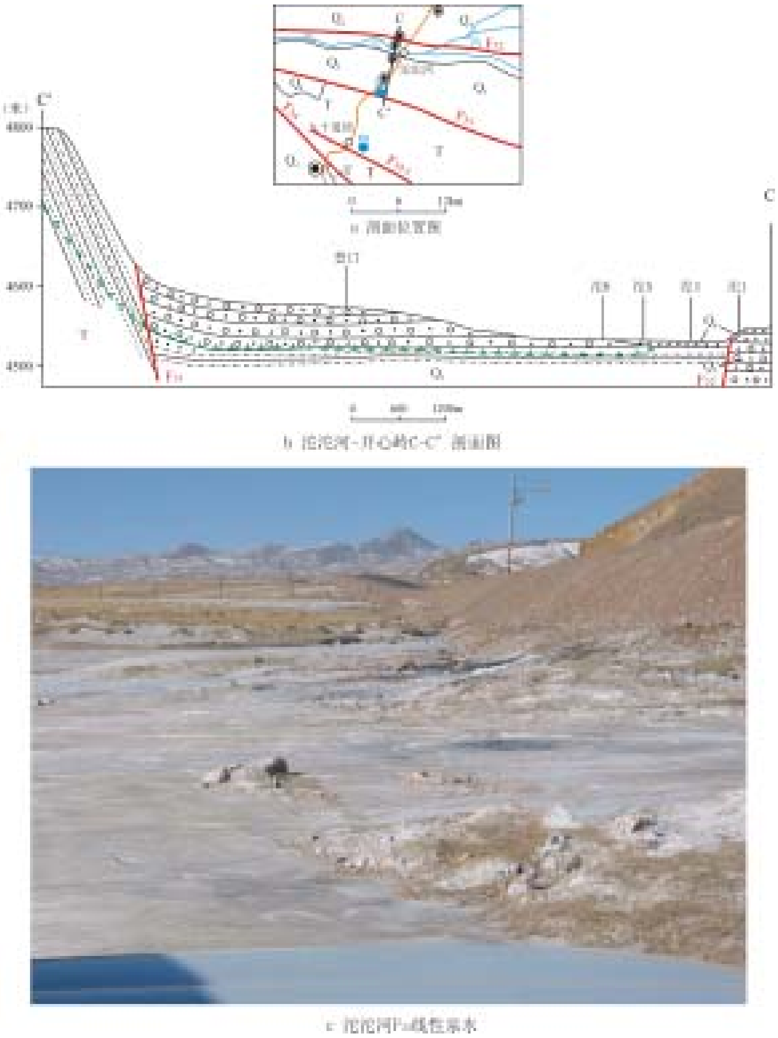

图 165 沱沱河断陷盆地钻探剖面与低温温泉群

Fig.165 Cross section from Tuotuohe to Kaixinling and freezing hotsprings in winter along Tuotuohe active fault

图 166 温泉盆地东侧沿主边界断裂线性分布的泉水群

（镜头向南东，摄于 2002 年 2 月）

Fig.166 View southeastward in February of 2002 at freezing springs in linear distribution along east boundary fault of the Wenquan graben

图 167 头二九断裂线性分布的冰丘群

（镜头向北，摄于 2002 年 2 月）

Fig.167 View northward in February of 2002 at pingos in linear distribution along the Touerjiu fault in south of Tanggula Mts.

图 168 雁石坪断裂（F_{40}）破碎带构造裂缝与斜列冰丘群

（镜头向南东，摄于 2002 年 2 月）

Fig.168 View southeastward in February of 2002 at surface fracture and en-echelon pingos along Yanshiping active fault (F_{40})

图 169 安多盆南边界断裂线性展布的古冻胀丘

（镜头向北东，摄于 2003 年 3 月）

Fig.169 View northeastward in March of 2003 at underground freezing domes in linear distribution along south boundary fault of Amdo basin

图 170 安多盆南活动断裂蠕滑与不均匀冻胀耦合错断全新世砂土并破坏青藏公路

（镜头向北，摄于 2001 年 3 月）

Fig.170 View northward in March of 2001 at active faulting and heterogeneous freezing deformation of the Highway along fault in south of Amdo basin

图 171 安多盆南活动断裂蠕滑与不均匀冻胀耦合错断全新世砂土导致青藏公路的路基变形

（镜头向北，摄于 2001 年 3 月）

Fig.171 View northward in March of 2001 at active fault cutting Holocene deposits and road deformation of the Golmud-Lhasa Highway resulted from coupling among active faulting, underground flow and heterogeneous freezing in south of Amdo basin

图 172 安多盆南活动断裂蠕滑及地下水不均匀冻胀变形相互耦合导致青藏公路变形破坏

（镜头向北西，摄于 2001 年 3 月）

Fig.172 View northwestward in March of 2001 at road deformation of the Golmud-Lhasa Highway caused by coupling among active faulting, underground flow and heterogeneous freezing in south of Amdo basin

图 173 唐古拉山北断裂破碎带的不均匀冻胀导致青藏公路塌陷变形

（镜头向北，摄于 2001 年 3 月）

Fig.173 View northward in March of 2001 at depression of the Golmud-Lhasa Highway along north Tanggula fault

图 174 乌玛塘盆北沿断裂破碎带发育的多级滑动面

（镜头向南，摄于 2002 年 7 月）

Fig.174 View southward in July of 2002 at multi-level slides along north boundary fault of Wumatang depression of east Damxung basin

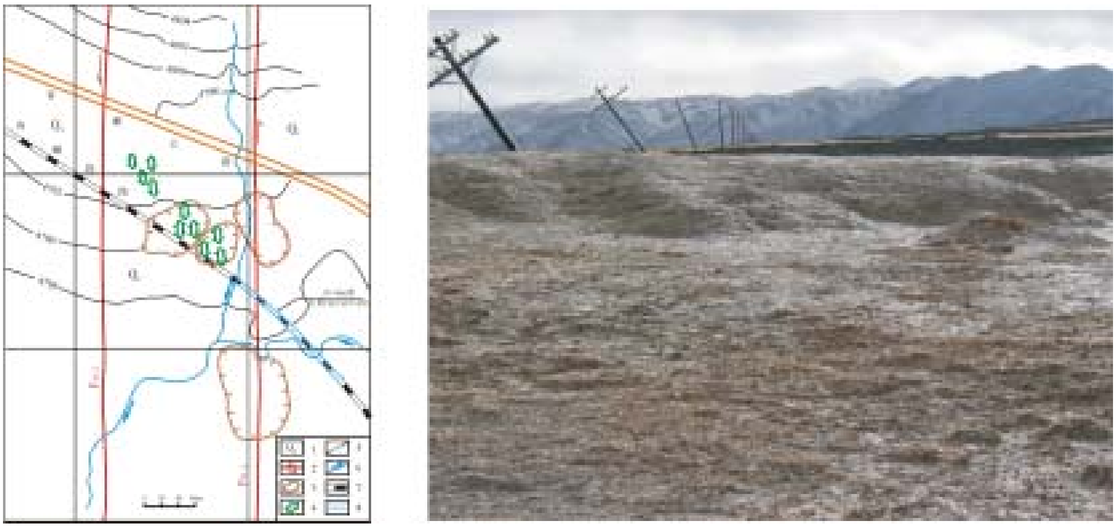

图 175 温泉盆地内部次级断层破碎带冰丘及灾害效应

左图：1-全新世河湖相沉积，2-盆内次级断层，3-热融凹陷，4-冰丘，5-等高线（m），6-布曲河及流向，7-设计铁路线，8-设计铁路大桥。右图表示冰丘不均匀冻胀变形导致电线杆歪斜，摄于 2002 年 3 月，镜头向北。

Fig.175 Map and photo showing pingo and its hazard effects. Explanation: 1-Holocene lacustrine deposits; 2-minor fault; 3-thawing depression; 4-pingo; 5-contour of elevation (m); 6-Buqu River and water flow trend; 7-Golmud-Lhasa Railway line; 8-designed railway bridge. Photo was taken northward in March of 2002.

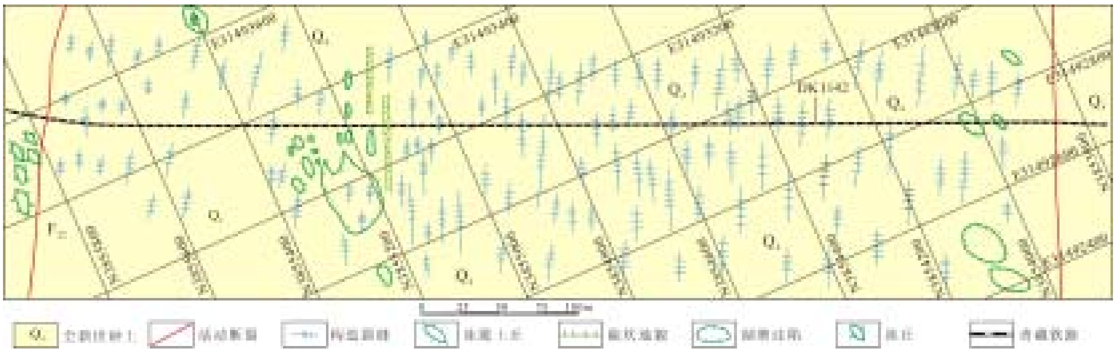

图 176 北麓河断裂 2002 年 2 月构造裂缝分布图

图例说明：1-全新世砂土；2-隐伏断裂边界；3-构造裂缝；4-冻胀土丘；5-线性洼陷边界；6-构造融区；7-冰丘；8-青藏铁路线

Fig.176 Map of surface fractures formed in February of 2002 along Beiluhe fault zone in north of Fenghuoshan Mts. Explanation: 1-Holocene sands; 2-buried boundary fault; 3-surface fracture; 4-underground freezing dome; 5-boundary of linear depression; 6-tectonically thawing region; 7-pingo; 8-Golmud-Lhasa railway line

图 177 风火山北麓构造裂缝及探槽位置

（镜头向西，摄于 2002 年 6 月）

Fig.177 View westward in June of 2002 at trenching perpendicular to surface fracture along Beiluhe fault in north of Fenghuoshan Mts.

图 178 风火山北麓构造裂缝探槽剖面

（构造裂缝切割早更新世棕黄色湖相粘土和晚更新世紫红色砂土；镜头向西，摄于 2002 年 6 月）

Fig.178 View westward in June of 2002 at trench cross-section of surface fracture along Beiluhe fault separating brown lacustrine clay formed in Early Pleistocene and reddish sandy soil of Late Pleistocene in north of Fenghuoshan Mts.

图 179 风火山北麓 2001 年 3 月构造裂缝横切青藏公路

（镜头向东，摄于 2001 年 3 月）

Fig.179 View eastward in March of 2001 at surface fracturing of the Golmud-Lhasa Highway in north of Fenghuoshan Mts.

图 180 风火山北麓构造裂缝

（镜头向东，摄于 2002 年 2 月）

Fig.180 View eastward in February of 2002 at surface fractures cutting the Golmud-Lhsa Highway along buried fault in north piedmont of Fenghuoshan Mts.

图 181 风火山北麓构造裂缝穿切破坏青藏公路

（镜头向东，摄于 2002 年 2 月）

Fig.181 Near view eastward in February of 2002 at fracturing of the Golmud-Lhasa Highway in north piedmont of Fenghuoshan Mts.

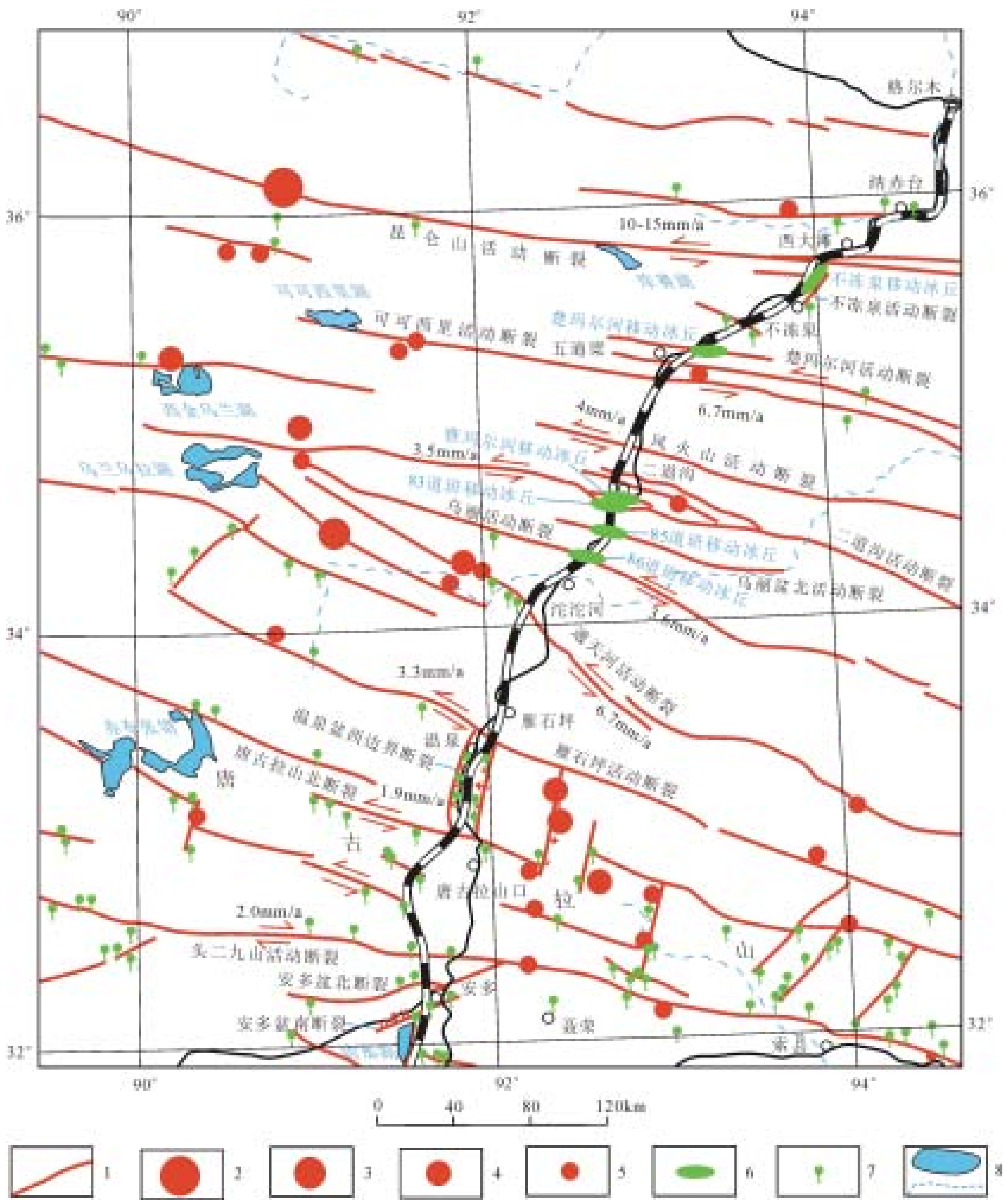

图 182 青藏铁路沿线活动断裂移动冰丘分布图

图例说明：1-活动断裂；2-8 级以上地震；3-7~7.9 级地震；4-6~6.9 级地震；5-5~5.9 级地震；6-移动冰丘；7-温泉；8-重要湖泊与主要河流

Fig.182 Map showing major active faults and migrating pingos along the Golmud-Lhasa Railway across permafrost north Tibetan Plateau. Explanation: 1-active fault; 2-Ms≥8.0 earthquake; 3-Ms 7.0-7.9 earthquake; 4-Ms 6.0-6.9 earthquake; 5-Ms 5.0-5.9 earthquake; 6-migrating pingo; 7-hotspring; 8-major lake and river