
Subsidence and Soil Expansion and Contraction
(and Karst!)

Learning Objectives

- Understand subsidence and soil and expansion and contraction and what causes them
- Know the geographic regions at risk from subsidence and soil expansion and contraction
- Understand the hazards associated with subsidence
- Recognize links between subsidence and other hazards, as well as the natural service functions of karst

Learning Objectives

- Understand how people interact with subsidence and soil hazards

- Know what can be done to minimize the risk of subsidence and soil expansion and contraction

Guatemala City, Guatemala

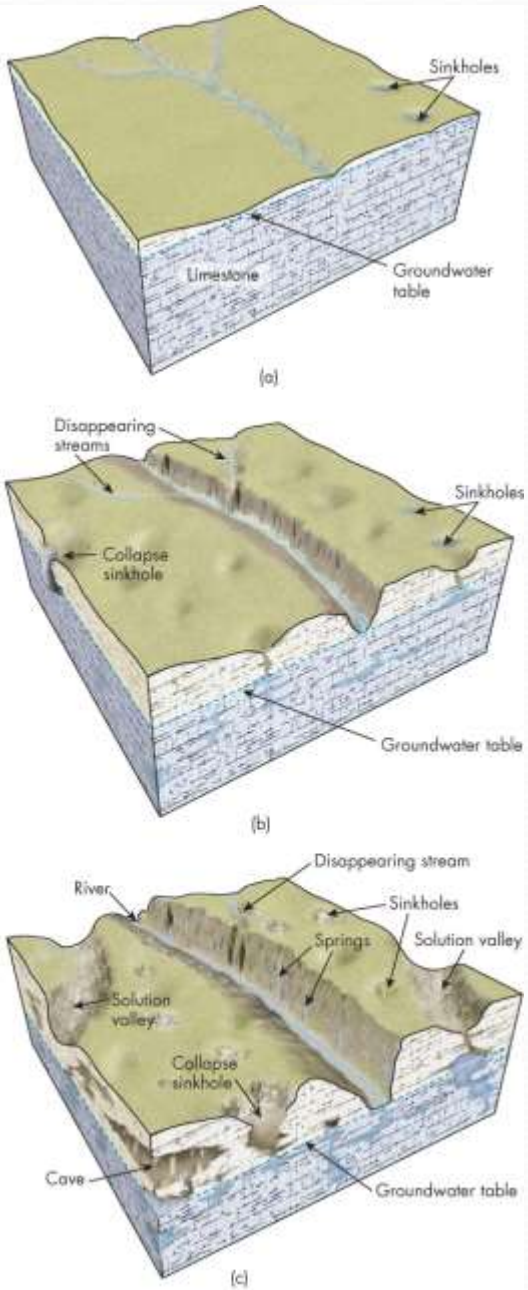
http://www.ordena.com/digg/sinkhole.html

Introduction

- is a slow or rapid, nearly vertical, downward movement of Earth's surface
-
  - Landscape resulting from the dissolution o limestone, dolostone, marble, gypsum or rock salt
- Soil expansion and contraction results from:
  -
  -
- Subsidence is not usually life threatening, but is one of the most widespread and costly natural hazards.

Karst

- Common type of landscape associated with subsidence
- Rocks are dissolved by surface water or groundwater
- Dissolution produces voids which join to form caves and
- A surface pockmarked with a large number of sinkholes is a



► **FIGURE 8.1 DEVELOPMENT OF KARST TOPOGRAPHY** (a) In the early stage of karst formation in a limestone terrain, water from the surface seeps through fractures and along layers in the soluble rock. Weak acid in the water slowly dissolves the rock. (b) The water table falls as a river incises into the rock. Caves start to form and then collapse to become sinkholes. Some surface streams disappear underground. (c) In later stages of karst development, a downward-eroding river continues to lower the water table. Large caverns and sinkholes develop and eventually merge to form solution valleys and plains without surface streams. In humid tropical climates, intense dissolution removes nearly all the rock, leaving behind pillars of limestone referred to as tower karst. *(Based on an illustration by D. Tasa in Tarbuck, E. J., and F. K. Lutgens. 2005. Earth: An Introduction to Physical Geology, 8th ed. Upper Saddle River, NJ: Pearson Prentice Hall)*

Sinkholes

- Can range from one to several hundred metres in diameter
- Two basic types:
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    - Pits formed by dissolution of buried bedrock along planes and fractures
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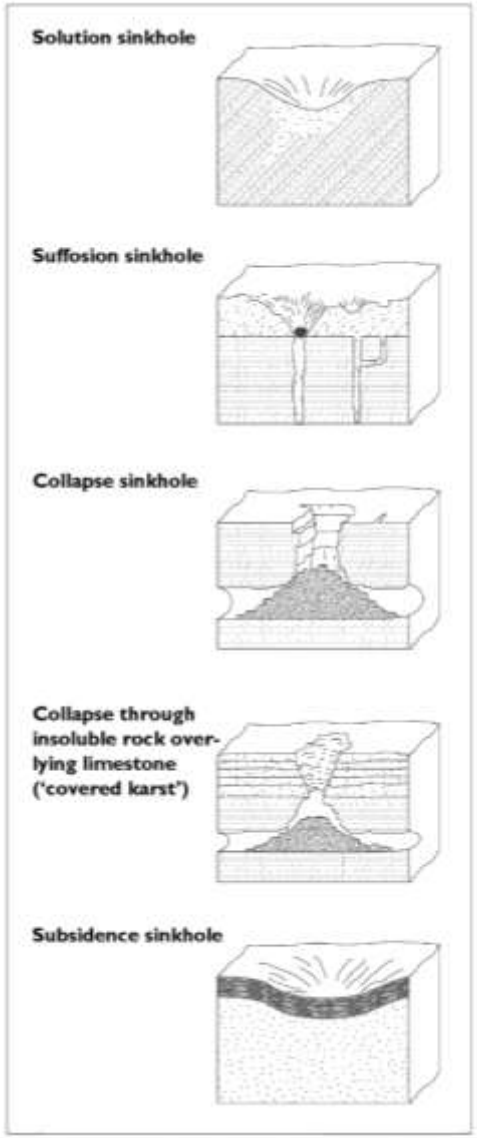
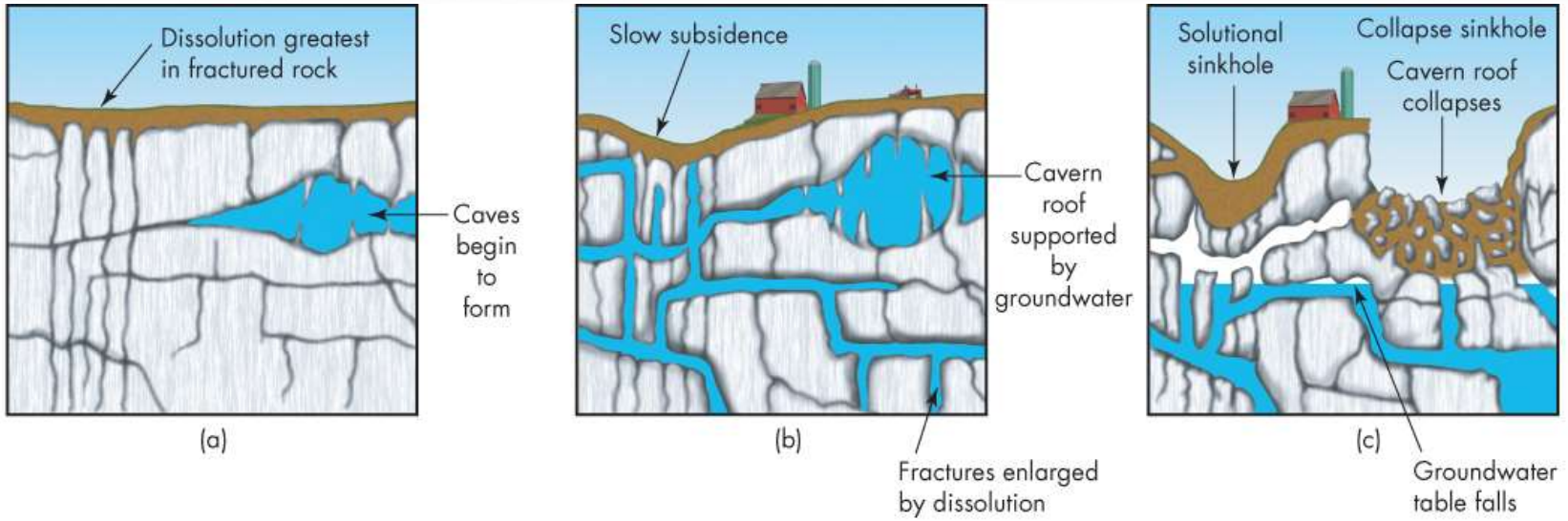
    - Collapse of surface or near-surface rock or sediment

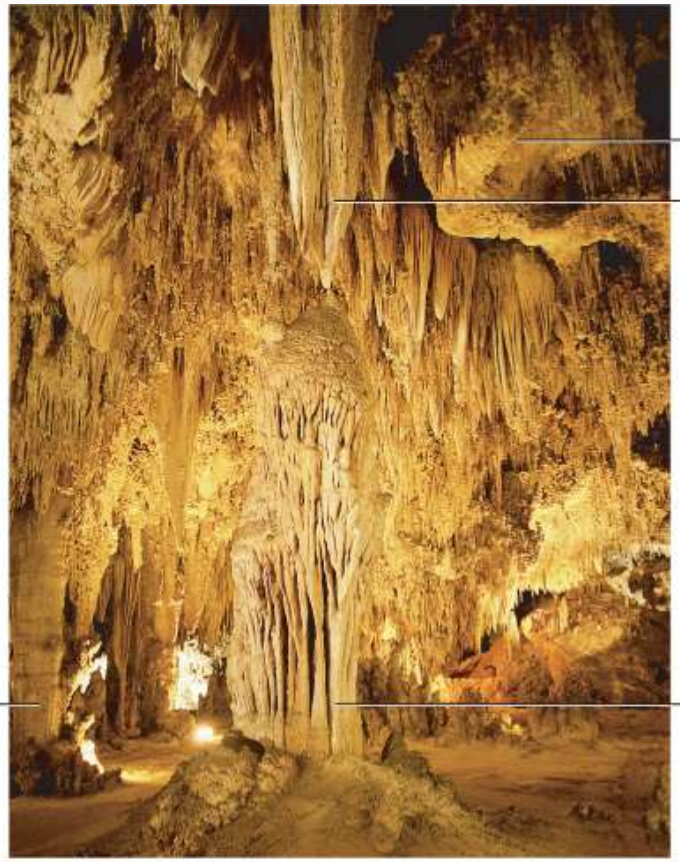




▲ **FIGURE 8.4 FORMATION OF SINKHOLES** (a) Dissolution of soluble bedrock takes place along vertical and horizontal fractures, leading to the formation of small caves. (b) Dissolution continues to enlarge fractures, and some caves become large caverns with roofs partly supported by groundwater. Slow subsidence and enhanced solution in surface depressions initiates a solution sinkhole. (c) A subsequent lowering of the water table leaves cave and cavern roofs unsupported, and a cavern roof collapses to form a collapse sinkhole.

Cave Systems

- **Cave systems** are formed when dissolution produces a series of caves
- Related to a fluctuating groundwater table
- Groundwater seepage will deposit calcium carbonate on the sides, floor, and ceiling of the cave as flowstone, stalagmites, and stalactites



◄ **FIGURE 8.5 CAVE FORMATIONS** Carlsbad Caverns, New Mexico, contains stalactites, which hang from the ceiling, stalagmites, which grow up from the ground, and flowstone, which forms as water flows slowly down the walls or across an inclined surface. These beautiful features form as waters saturated with calcium and bicarbonate slowly precipitate calcium carbonate on the sides, floor, and ceiling of a cave or cavern. *(Bruce Roberts/ Science Source)*

Tower Karst, Disappearing Streams and Springs

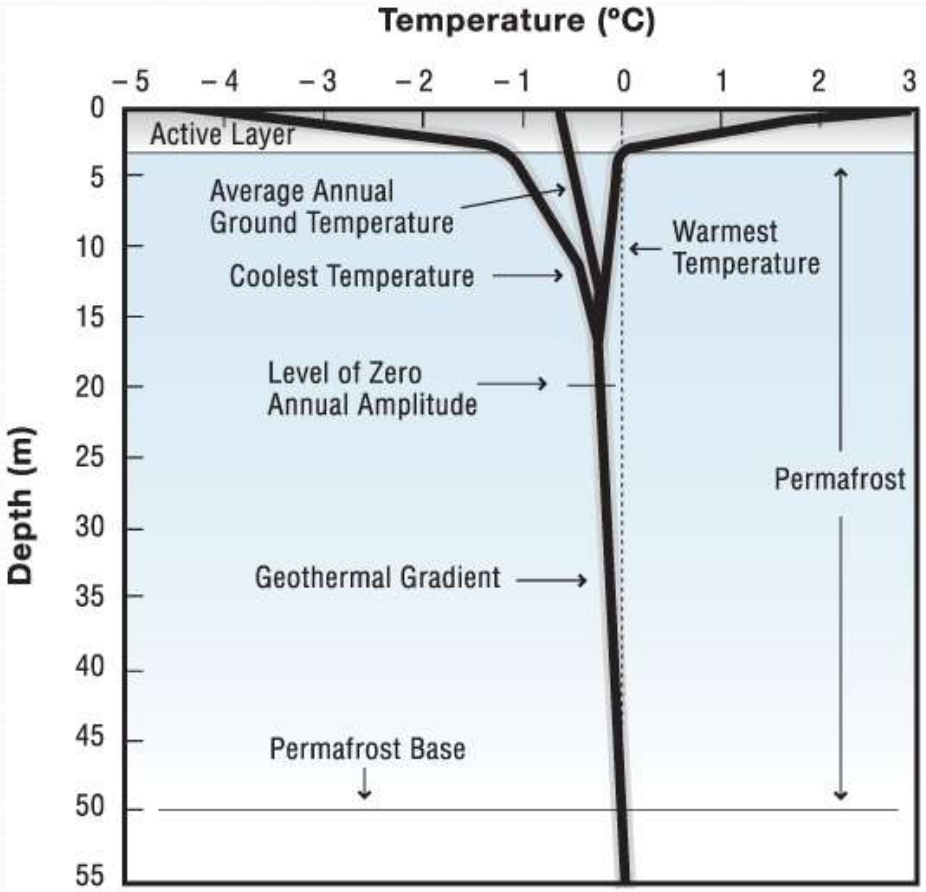
- **Tower karst** is created in highly eroded karst regions
  - Steep limestone pillars common in humid tropical regions

- **Disappearing streams** are streams that flow from the surface into cave openings

- **Springs** are natural discharges of groundwater at the surface
  - Vulnerable to contamination

Permafrost

- Soil or rock must remain _____
- More than half of Canada is underlain by permafrost
- Continuous permafrost
  - Mean annual temperature is less than _____
- Discontinuous permafrost
  - Covers 50-90% of the landscape in an area
  - Mean annual temperature is between _____



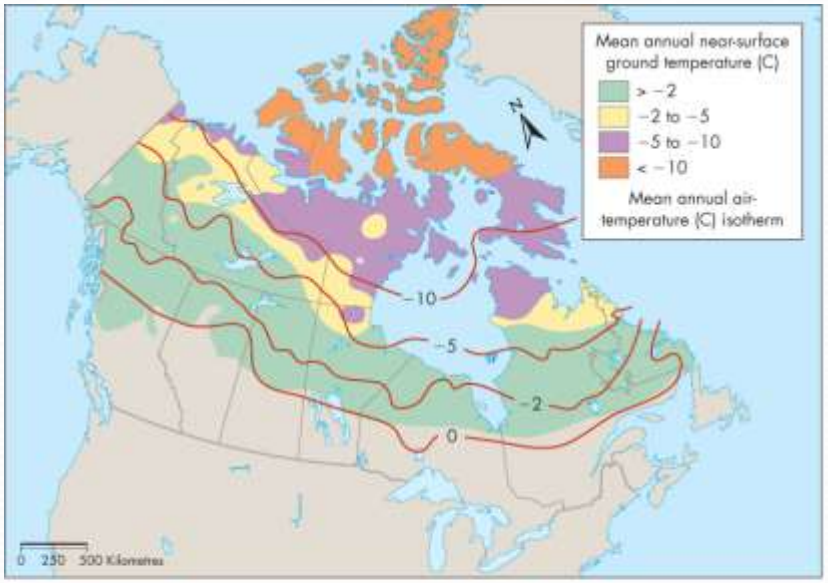
◀ **FIGURE 8.8 GROUND TEMPERATURE AS A FUNCTION OF DEPTH NEAR YELLOWKNIFE** The curves in this diagram show the coolest temperatures of the year (left), the warmest temperatures of the year (right), and the mean annual ground temperature (middle). The seasonal difference in temperature decreases with increasing depth to about 15 m, where there is no discernable change in temperature over the course of a year. Every summer, a portion of the ground just below the surface—the active layer—rises above 0°C and thaws, only to refreeze in the fall. *(Burgess, M. M., and S. L. Smith. 2000. "Shallow ground temperatures." In L. D. Dyke and G. R. Brooks (eds.),* The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change. Geological Survey of Canada Bulletin 547. *Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2013.)*

Permafrost

- Sporadic permafrost
  - Covers less than 50% of the landscape in an area
  - Mean annual temperature is between -2°C and 0°C

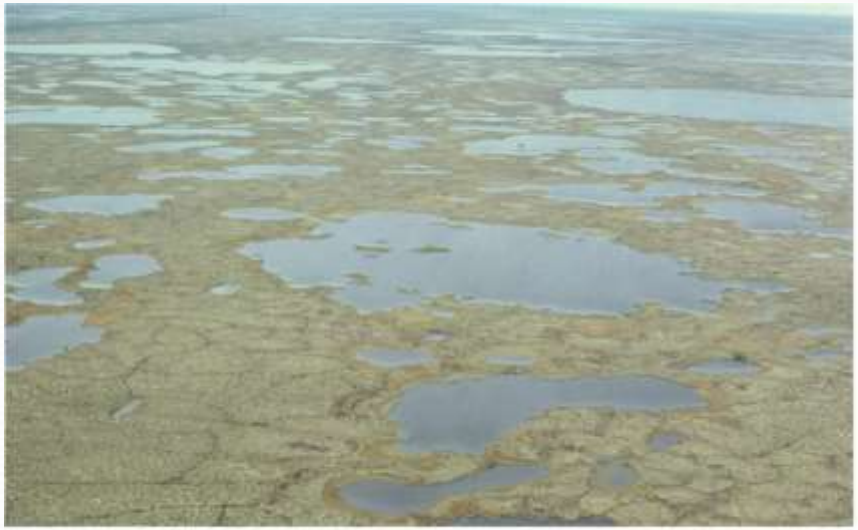
- The _____ thaws in spring and refreezes in fall
  - When permafrost thaws, it can create land subsidence
  - Extensive thawing creates uneven soil called _____

- **Frost-susceptible sediments** expand when they freeze
  - Causes frost heaving



▲ **FIGURE 8.7 DISTRIBUTION OF PERMAFROST** Map showing spatial variations in mean annual air temperature and near-surface ground temperature in Canada's permafrost region. Permafrost is sporadic within the zone of air temperatures between 0°C and –2°C, and is extensive or continuous in areas with mean air temperatures less than –2°C. *(Smith, S. L., M. M. Burgess, and J. A. Heginbottom. 2001. "Permafrost in Canada: A challenge to northern development." In G. R. Brooks (ed.), A Synthesis of Geological Hazards in Canada. Geological Survey of Canada Bulletin 548. Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2013.)*

▲ **FIGURE 8.15 INUVIK, A TOWN BUILT ON PERMAFROST** Inuvik is a town of 3500 people in the Northwest Territories, located about 200 km north of the Arctic Circle. A distinctive feature of the town is "utilidors"—above-ground conduits carrying water and sewage. Utilidors are necessary because the ground underlying Inuvik is frozen. An increase in ground temperature from about –3°C to –1°C in the past 35 years has increased permafrost thaw, damaging some buildings. *(© Staffan Widstrand/Corbis)*



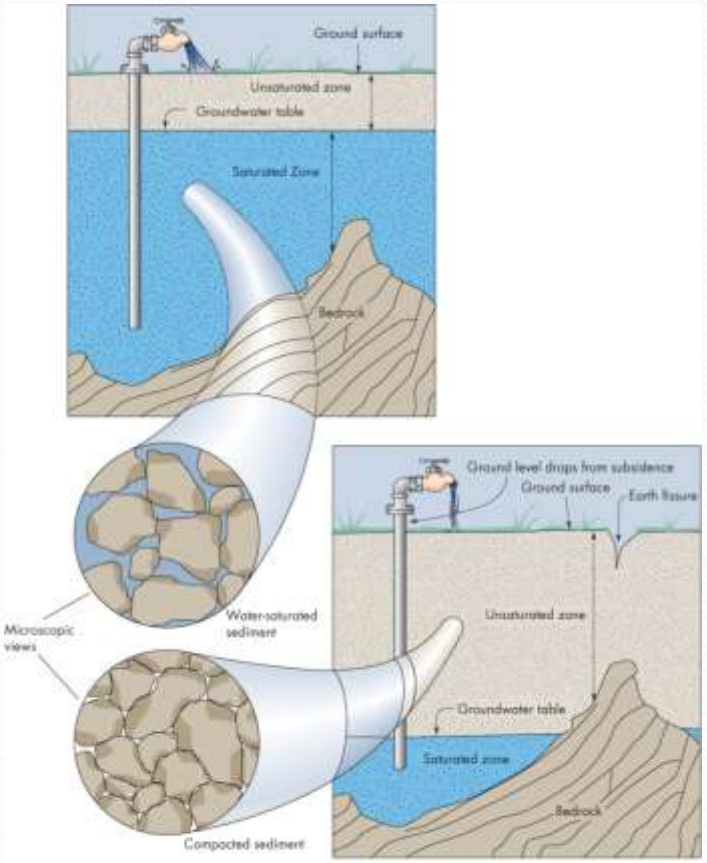
◄ **FIGURE 8.9 THERMOKARST** Thermokarst ponds are common on this lowland bordering Hudson Bay in Manitoba. This scene shows a mosaic of frozen peat and shallow ponds that occupy depressions where permafrost has thawed. The ponds range in width from several metres to several hundred metres. *(Lynda Dredge/Geological Survey of Canada)*

Piping

- Particles of silt and sand in the subsurface slowly carried by groundwater laterally to a spring
- Caused by groundwater creating tunnels as it percolates through loose sediments
- Common in silt and sand sediments
- Over time, shallow subterranean tunnels and cavities may develop to produce surface depressions and ravines

Sediment Compaction

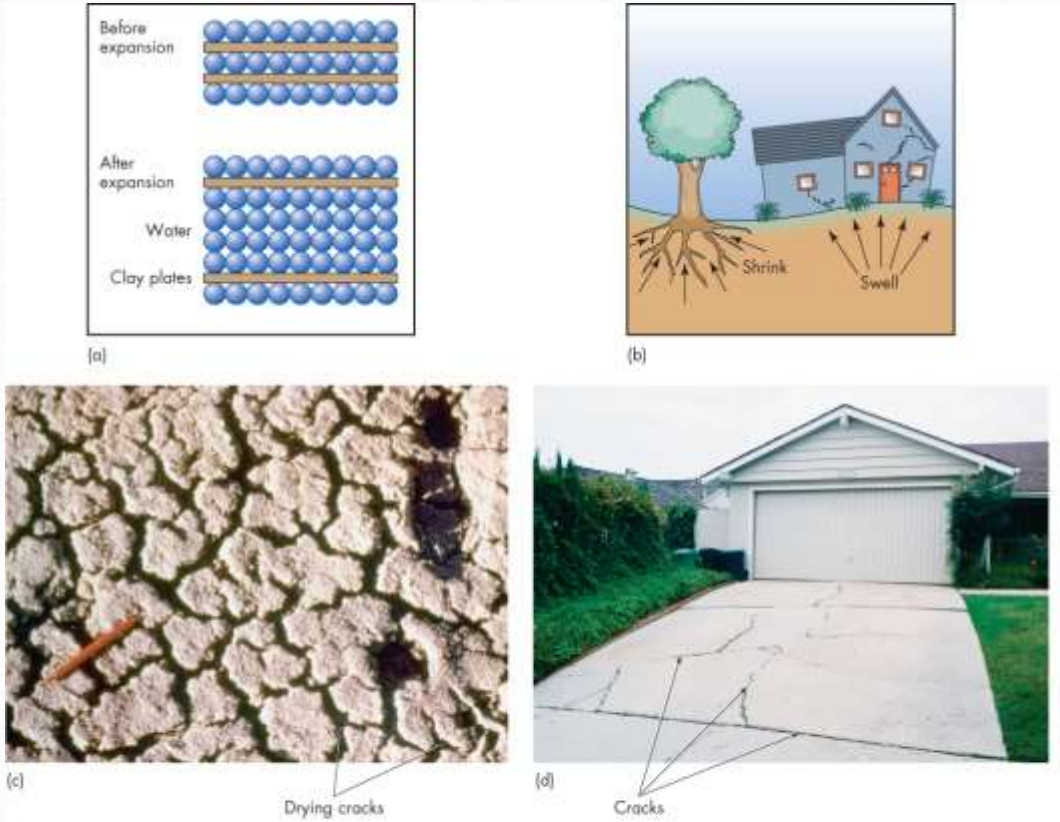
- **Fine sediments**
  - Sediment compacts when **pore water** is removed
  - Common on river deltas
  - Flooding replenishes sediment, thwarting compaction
- **Collapsible sediments**
  - Loess and some stream deposits in arid regions are loosely bound or are water-soluble
  - Infiltrating water weakens bonds, causing sediment to compact
- **Organic sediments**
  - Wetland soils contain large amounts of organic matter and water
  - When water is drained or soil is decomposed, these soils compact



▲ FIGURE 8.22 **SUBSIDENCE FROM PUMPING OF FLUIDS** Idealized diagram showing how groundwater pumping can cause ground subsidence. The unsaturated zone is above the groundwater table where the space between sediment grains contains both air and water. In the saturated zone beneath the groundwater table, the pores are completely filled with water. When groundwater is removed, the pores become smaller as grains become more tightly packed. This compaction causes the land surface to subside. *(Based on Kenny, R. 1992. "Fissures." Earth 2(3):34–41)*

Expansive Soils

- These soils expand during wet periods and shrink during dry periods
- Common in clay, shale, and clay-rich soil containing smectite
- Can produce desiccation cracks
- Tilting and cracking of blocks of concrete and wavy bumps in asphalt can cause structural damage



▲ FIGURE 8.10 **EXPANSIVE SOILS** (a) Smectite is a group of clay minerals that expand as water molecules are added to the clay particles. (b) Effects of the shrinking and swelling of clay at a home site. (c) Drying of an expansive soil produces this popcorn-like surface texture and a network of polygonal desiccation cracks. (d) Shrinking and swelling of expansive soil cracked the concrete in this driveway. *((a&b) Based on Mathewson, C. C., and J. P. Castleberry, II. Expansive Soils: Their Engineering Geology. College Station, TX: Texas A&M University. (c) U.S. Geological Survey. (d) Edward A. Keller))*

Earthquakes and Deflation of Magma Chambers

- Can lower the ground surface over large areas
- Coastal subsidence can cause flooding
- The outer coasts of Vancouver Island, Washington and Oregon have repeatedly been lowered by earthquakes
- Magma uplifts the volcano during an eruption
- The chamber empties after an eruption, surface subsides

Regions at Risk

- Landscapes underlain by soluble rocks, permafrost, or easily compacted sediment
- Soils that contain abundant smectite clay are susceptible to shrinking and swelling soils
- Soils containing silt are susceptible to frost heaving

▲ FIGURE 8.12 **DISTRIBUTION OF KARST** Karst occurs in areas underlain by limestone, dolostone, and gypsum. This map shows the distribution of these rocks in Canada. Large areas of the conterminous United States, Alaska, and Puerto Rico also are underlain by these soluble rocks. *(© 2004, Encyclopedia of Caves and Karst Science, J. Gunn (ed.). Reproduced with permission)*

Effects of Subsidence and Soil Expansion and Contraction

- Sinkhole Formation
  - Can cause considerable damage highways, homes, and sewage lines
  - Triggered by fluctuations in the water table
- Groundwater Use and Contamination
  - Caves provide direct connections between surface water and groundwater
  - Groundwater can be vulnerable to pollution,
  - The water table can significantly lower during droughts

Effects of Subsidence and Soil Expansion and Contraction

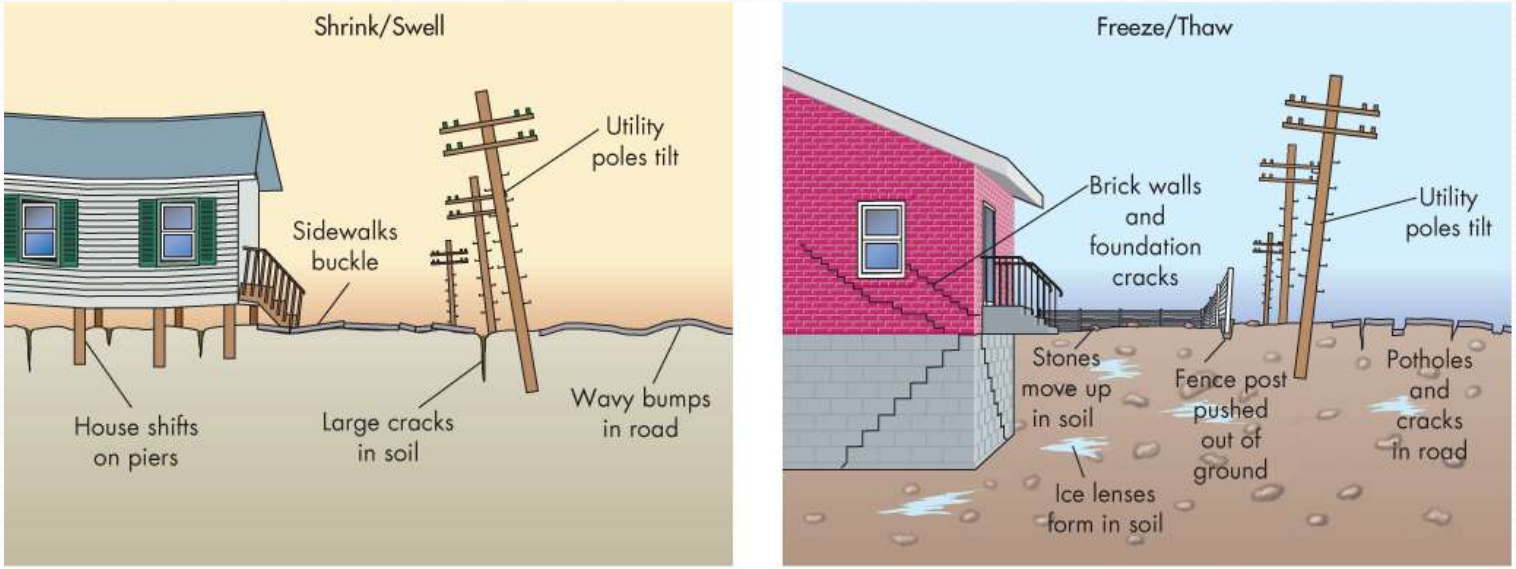
- Permafrost Thaw
  - Melting of permafrost has caused roads to cave in, airport runways to fracture, railroad tracks to buckle, and buildings to crack, tilt, or collapse.

◄ **FIGURE 8.14 THAWING PERMAFROST DESTROYS BUILDING** This apartment building in Cherskii in eastern Siberia partially collapsed because the permafrost on which it was built is thawing. Structural damage from thawing permafrost is becoming common in Canada, Russia, and Alaska. *(Professor V. E. Romanovsky, University of Alaska Fairbanks)*

Effects of Subsidence and Soil Expansion and Contraction

- Coastal Flooding and Loss of Wetlands
  - Along the Mississippi Delta, this has contributed to the sinking of New Orleans
  - Wetlands that protect the city from surges are disappearing
- Soil Volume Changes
  - Swelling of expansive soils and frost heaving
  - Causes billions of dollars in damage annually in North America

▲ FIGURE 8.18 WETLAND LOSS ON THE MISSISSIPPI DELTA Excavation of numerous canals for oil and gas drilling, like these near Leeville, Louisiana, have contributed to wetland loss on the Mississippi Delta. Each canal drains the adjacent wetland and exposes organic soil to decomposition and erosion. Loss of this soil causes the land surface to subside. In many areas, the only land remaining is the piles of sediment that were dredged to make the canals. *(Philip Gould/CORBIS)*



▲ **FIGURE 8.16 SOIL MOVEMENT EFFECTS** (a) Shrinking and swelling of expansive soils and (b) freezing and thawing of frost-susceptible soils have similar effects. They crack and shift foundations and pavement, and tilt utility poles, road signs, and fence posts. Soil contraction can produce deep cracks in the ground, and soil expansion can produce an irregular land surface. Freeze-thaw activity moves large objects such as stones upward in the soil to the surface.

Links to Other Natural Hazards

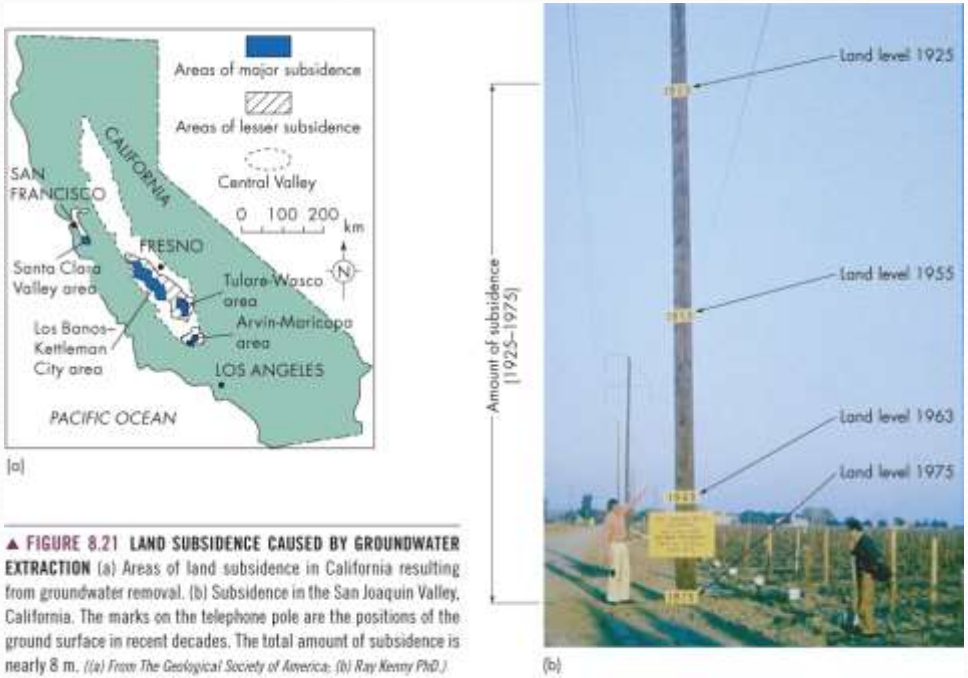
- Subsidence can be an effect of earthquakes, volcanic activity, and climate change
  - Climate change can add to the drying of soils and the altering of the groundwater table
- Subsidence may cause flooding
  - Over-pumping of groundwater

Natural Service Functions

- Water Supply
  - Karst regions contain the world's most abundant water supply
- Aesthetic and Scientific Resources
  - Caves and karst landscapes are scenic areas that attract tourists and provide research for scientists
- Unique Ecosystems
  - Some animal species can live only in caves
  - Caves also provide shelter for other animals

Human Interaction with Subsidence

- Withdrawal of Fluids
  - Pumping oil, natural gas, or groundwater decreases fluid pressure, causing rocks and sediments to subside



▲ FIGURE 8.21 LAND SUBSIDENCE CAUSED BY GROUNDWATER EXTRACTION (a) Areas of land subsidence in California resulting from groundwater removal. (b) Subsidence in the San Joaquin Valley, California. The marks on the telephone pole are the positions of the ground surface in recent decades. The total amount of subsidence is nearly 8 m. *((a) From The Geological Society of America; (b) Ray Kenny PhD.)*

Human Interaction with Subsidence, cont.

- Underground Mining
  - Coal mine structures have collapsed
  - Water is used to dissolve and pump out salt, leaving behind cavities
  - Flooding in salt mines can also cause sinkholes
- Permafrost Thaw
  - Poorly insulated buildings directly on frozen ground
  - Burial of warm utility lines
- Restricting Deltaic Sedimentation
  - Construction of dams, levees, or canals.

Human Interaction with Subsidence, cont.

- Draining Wetlands
  - Soil is drained for agriculture and settlement
  - Extraction of peat for horticulture

- Landscaping on Expansive Soils
  - Poor landscaping practices
  - Adding or removing plants changes water levels, contributing to shrinking and swelling soils

Minimizing Subsidence Hazards

- Restricting Fluid Withdrawal
  - Preventing oil and groundwater extraction
  - Injection wells add water when oil is pumped
- Regulating Mining
  - Prohibit mining in settled areas
- Preventing Damage from Thawing Permafrost
  - New engineering for buildings and pipelines on permafrost
- Reducing Damage from Deltaic Subsidence
  - Removing or breaching levees could reestablish marshes

Minimizing Subsidence Hazards, cont.

- Stopping the Draining of Wetlands
  - Proper water management of existing marshes and swamps
- Preventing Damage from Expansive Soils
  - Design of subsurface drains, rain gutters, and foundations
  - Construct buildings on a layer of compacted fill

Perception of and Adjustments to Subsidence

Soil Hazards

- Perception of Subsidence and Soil Hazards
  - Few people are aware of the extent of these natural hazards
  - People who live in dramatically affected areas are more aware than others

- Adjustments to Subsidence and Soil Hazards
  - Geologic and soil mapping
    - Helps in predicting and avoiding areas where subsidence might occur
  - Surface features
    - Cracks, hummocky grounds, and closed depressions are signs of subsidence
  - Geophysical surveys
    - Knowledge of the subsurface environment is essential