layer of snow for approximately 3-4 months, usually melting by April. The snowmelt is a major source of water in streams during late winter and early spring. Approximately one-half to two-thirds of the precipitation becomes runoff in a river or stream.

Temperatures vary widely on an annual basis. Temperature data taken from nine weather observatories in the study area, from 1961 to 1990, indicate that the warmest month in the study area is July and the coldest month January. Average temperature for July at these sites was 70.3°F and average temperature for January was 23.5°F (Northeast Regional Climate Center, written commun., 1996). Winter temperatures are more variable across the study area than summer temperatures based on monthly average temperatures. For example, average temperatures in July during 1961-90 ranged from 68.0°F at Rumford, Maine, to 72.7°F at Providence, Rhode Island, whereas the average temperature in January during the same period ranged from 16.5°F at Rumford to 27.9°F at Providence (fig. 3). The growing season ranges from 140-200 days in the Coastal Division to 90-140 days in the Northern Division (U.S. Department of Commerce, 1977, 1982a, 1982b, and 1982c).

Evapotranspiration is most pronounced in the summer and early fall period and results in a reduction of total runoff (Gay and Delaney, 1980). Evapotranspiration has a minor effect on runoff during the late fall and winter because of the loss of deciduous leaves (Likens and Bormann, 1995). On a year-to-year basis, evapotranspiration remains fairly constant (Likens and Bormann, 1995). Approximately 51 percent, or 23.2 in., of the annual inflow in the Charles River Basin at Waltham, Massachusetts, is removed by means of evapotranspiration (Myette and Simcox, 1992).

Geology

Geology has a major influence on the natural quality of surface and ground waters. The geochemistry of the various rocks and sediments is determined by the original chemical composition of the parent material and by previous geologic activity leading to their emplacement or deposition. Geochemistry of the bedrock and surficial materials plays a large role in determining concentrations of naturally-occurring substances that are dissolved in the water. In addition, the stratigraphy of the surficial sediments determines the occurrence of significant ground-water aquifers and influences the interaction between ground and surface waters.

Bedrock

Bedrock geology records a wide variety of complex geologic processes—sedimentation, deformation, metamorphism, igneous activity, and erosion. Several hundred different geologic formations have been identified in the study area, each distinguished by rock type and age. Rocks of similar age and genesis are found throughout the study area. The bedrock is generally layered and complexly deformed. Structures and contacts generally trend northeast to southwest, perpendicular to the direction of collision during the Acadian Orogeny (Marvinney and Thompson, in press). The mineralogy of the bedrock units is highly varied, from pure quartz in quartzite formations to thin layers of calc-silicate rocks, large bodies of shist with various mineral assemblages (often with high iron and manganese concentrations), and metavolcanics with high base-cation concentrations.

The oldest rocks in the study unit are of PreCambrian age. Plutonic, metaplutonic, metavolcanic, and metasedimentary rocks comprise most of the units mapped as “pC” and “pCO” on figure 4. Volcanic and sedimentary rocks of the Boston Basin (unit pCs) are of similar age. Many of these rocks were formed during an arc-margin and volcanic-arc accumulation phase, followed by sediment deposition and mafic volcanism in an extensional regime (Goldsmith, 1991a). Rocks in northwestern Maine (the northwestern most part of unit pCO), known as the Chain Lakes Massif, are highly metamorphosed sedimentary and volcanic rocks that are PreCambrian or Cambrian in age (Marvinney and Thompson, in press).

Layered volcanic and sedimentary rocks, later metamorphosed, in the northern and western part of the study unit (narrow band of unit pCO just south of the Chain Lakes Massif) were added onto the North American continent during the Taconic Orogeny of Middle Ordovician time. In Massachusetts, rocks of the same age are also mapped as unit pCO. These rocks consist of gneiss and schist with minor marble and amphibolite and were metamorphosed from sediments derived from volcanic activity interlayered

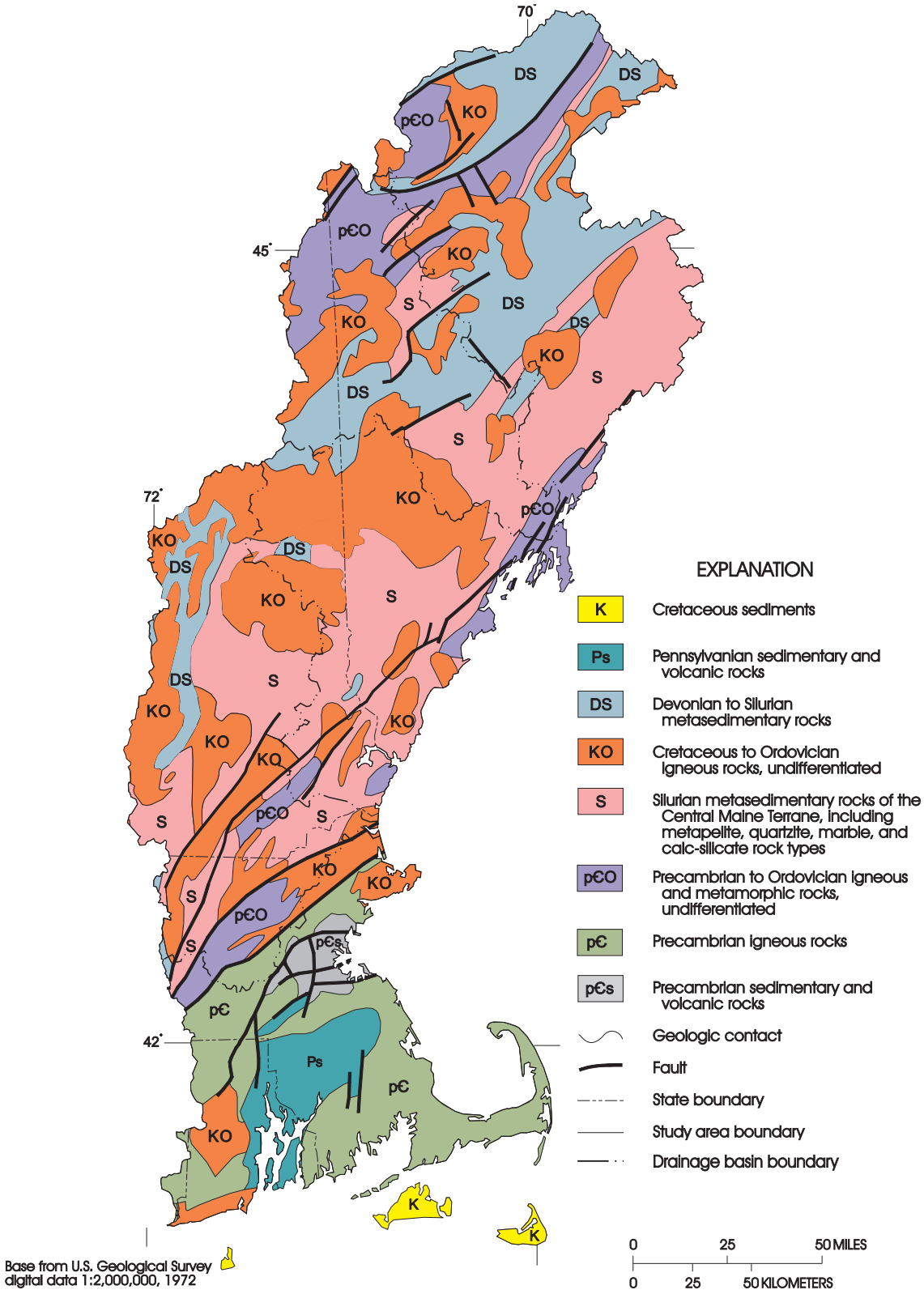

Figure 4. Generalized bedrock geology of the New England Coastal Basins study area. [Modified from King and Beikman, 1974; Lyons and others, 1997; Zen and others, 1983; Osberg and others, 1985; and Hermes and others, 1994.]

with volcanic rocks and limy marine sediments (Goldsmith, 1991b).

Mudstones, sandstones, limestones, and some volcanic rocks formed during the Silurian (with some occurring later, in the Early Devonian) originally were deposited at the margins of the North American and combined European/African continents (Marvinney and Thompson, in press; Boudette, 1990). Metamorphic grade of these rocks ranges from chlorite-biotite slate to feldspar-quartz-mica migmatite. Later in the Silurian, deposition continued to occur within an oceanic basin, which separated North America from what is thought to be the combined European/African plate. The resultant rocks, mapped as unit S, consist of metamorphic rocks whose protoliths were sediments deposited during Silurian to Early Devonian time in a continental margin basin. The rocks in central New Hampshire through central Maine represent a depositional trough that was filled during Silurian time with several kilometers of carbonates, volcanic rocks, and clastic sediments derived from the North American continent to the west. These sediments were subsequently overlain by turbidite deposits and volcanics derived form the European continent to the east during early Devonian time (unit DS in Maine and New Hampshire, Marvinney and Thompson, in press). They were then repeatedly deformed and metamorphosed during the Acadian Orogeny.

Rocks mapped as unit KO are intrusive igneous rocks, many of which were repositioned during each phase of tectonic activity from the Ordovician to the Devonian. Most of these rocks in Maine and Rhode Island are granitic (Marvinney and Thompson, in press; Hermes and others, 1994). In New Hampshire and Massachusetts, the intrusive rocks consist of granites, gabbros, syenites, and granodiorites (Boudette, 1990; Zen and others, 1983).

Undeformed clastic sedimentary and minor volcanic rocks in southeastern Massachusetts and Rhode Island (unit Ps) were deposited during Pennsylvanian time in a continental basin, before rifting opened up the Atlantic Ocean during Triassic and Jurassic time (Goldsmith, 1991a). This rifting, which occurred outside the study area, is associated with extensive faulting and the formation of many igneous plutons of Jurassic, Triassic, and Cretaceous age in New Hampshire and Maine (also mapped as unit KO).

Surficial Deposits

Glaciation has shaped the landscape of eastern North America during several major glacial periods. As glaciers flowed across the landscape, they scraped and smoothed down the land surface. As glaciers retreated from the landscape during deglaciation, they created lakes and altered the course of rivers. Debris scraped off the land surface was carried by the ice and deposited as sand, gravel, and other unconsolidated sediments across the landscape. Some of the sediments were deposited by the ice directly, and the rest were carried by meltwater streams and deposited in the sea or elsewhere on land. Most of the surficial sediments found across New England are a result of glaciation.

The most recent glacial period, called the Late Wisconsin, began approximately 25,000 years ago (Stone and Borns, 1986). During this glaciation, the ice sheet advanced from Canada southward and southeastward across New England. As a result, the glacial deposits and landforms generally have northwest-southeast orientations, in contrast to the northeast-southwest grain of the underlying bedrock (Smith and Hunter, 1989). During the Late Wisconsin glaciation, the maximum extent of the ice front was at the continental shelf offshore of Maine, New Hampshire, Massachusetts, and Rhode Island. As the climate warmed, retreat of the ice margin began between 15,000 and 17,000 years ago (Smith and Hunter, 1989). By approximately 12,000 years ago, the land was exposed across New England (Borns, 1989; Smith and Hunter, 1989). The total loss of relief during the last glaciation was less than 200 ft according to Boudette (1990).

Glacial erosion of the land surface continued throughout the glacial period, but it is primarily during deglaciation that great quantities of glacial sediments were deposited on the land surface. The deposits found across the New England landscape record the timing and mode of deglaciation in each location, as well as depositional processes associated with deglaciation, such as the formation and filling of glacial-meltwater lakes (Koteff and Pessl, 1981). Many of these deposits form the stratified-drift aquifers that are important water sources for communities and industries throughout the study area.

Along coastal New England north of Boston, Mass., isostatic depression of the crust of the Earth (due to the weight of the glaciers) allowed the sea to