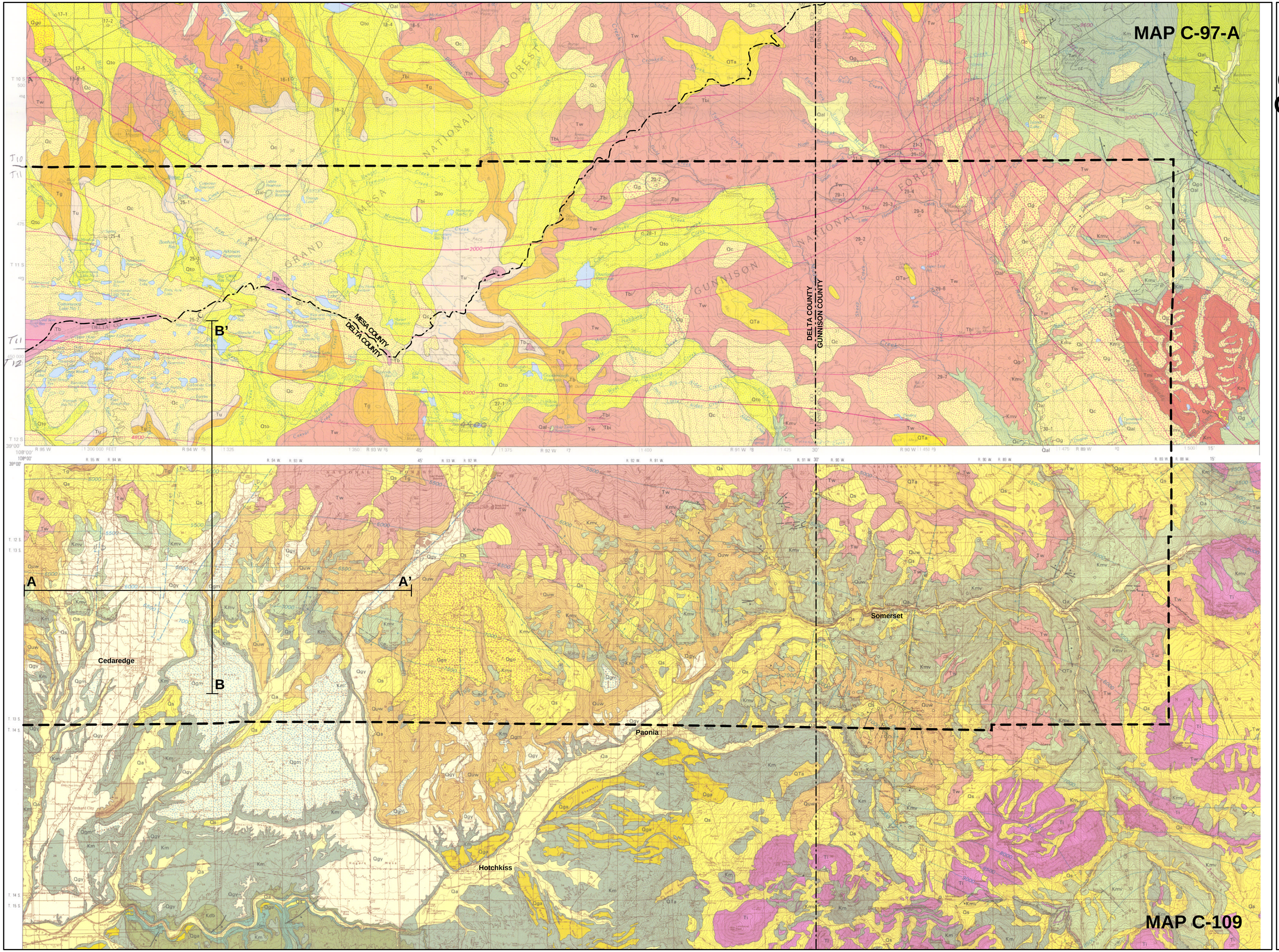

EXHIBIT 4

GEOLOGIC MAP OF STUDY AREA

Lithologic Description for Use with Maps by Ellis and Others, 1987 and Ellis and Freeman, 1984 and Cross-Sections A-A' (Exhibit 5) and B-B' (Exhibit 6)

Qa

Alluvial and colluvial deposits undifferentiated (Holocene and Pleistocene)—Clay, silt, and sand in stream valleys and alluvial fans derived from the Mesaverde Formation to Green River Formations and sand, gravel, and boulders derived from the Grand Mesa Basalts. Estimated thickness ranges from a few inches to 200 ft. Permeability is moderate to high where deposits are well sorted and stratified. This designation is used on Map C-109 and corresponds with **Qal** in Map C-97-A.

Qs

Surficial deposits undifferentiated (Holocene and Pleistocene)— Includes various types of glacial deposits as well as debris flow deposits, landslide deposits, talus, rock glaciers, and local colluvial deposits. Includes colluvium shown in Grand Mesa area by Ellis and Freeman (1984). Estimated thickness ranges from a few inches to 200 ft. Permeability is estimated to be low to very low for the mudflow/debris flow deposits and clays of the glacial deposits to moderate to very high for the talus, rock glaciers, and the boulders and gravels of the glacial deposits. Geologic units with **Qc** and **Qto** designation on Map C-97-A correlate with this description.

Quw

Unconsolidated deposits (Pleistocene)—Fans, pediments, and other high-level alluvial deposits derived from the Wasatch Formation and, to a lesser degree, the Green River Formation and from basalts capping Grand Mesa. Includes extensive debris flow deposits and stratified and well-sorted deposits derived from debris flow deposits. Consists of clay, silt, and sand derived from the Wasatch and Green River Formations and sand, gravel, and boulders derived from the Grand Mesa basalts; the deposits are heterogeneous to well sorted and stratified. Debris flow deposits locally form hummocky topography. Stratified, high-level alluvial deposits (pediments and alluvial fans) commonly overlie the debris flow deposits and may be interlayered with the alluvial deposits. Estimated thickness ranges from about 50 ft at the southern end of Section B-B' to as much as 300 ft in the Wilbanks Mesa area. Deposits have been divided into three groups according to age of deposition by Hail (1972) as: **Qgy** (Younger Gravels), **Qgm** (Middle Gravels), **Qgo** (Older Gravels). Unit also includes **QTa** (Pleistocene and/or Pliocene)—High-level alluvial deposits similar to **Qgo**, except these deposits occur at a higher level and may be older. Vertical and horizontal permeability is estimated to be low to very low in the debris flow deposits. Estimated vertical and horizontal permeability is high to very high where stratified material consists of predominantly boulders, gravel, and sand. Horizontal permeability is high to very high, but vertical permeability may be low, where the highly permeable boulders, gravel, and sand layers are separated by clay and silt layers of low permeability. The geologic unit with **Qg** designation on Map C-97-A also correlates with this description.

Tb

Basalt lava flows (Pliocene and Miocene) and talus—Flows occur as dense, black, and massive layers and also vesicular, light reddish brown layers. Although there are likely some small, local outcrops near the northern part of Section B-B', the flows are mostly represented as talus boulders and gravels resting on, or intermixed with, the underlying marlstone and siltstone of the Green River Formation and the clays and other rock units of the intertonguing Uintah Formation. Permeability is likely moderate in the fractured outcrop to very high in the talus deposits. Water in contact with these rocks may leach out significant amounts of calcium, iron, and magnesium, and lesser amounts of sodium and manganese from the calcium plagioclase, hornblende, and pyroxene minerals present.

Tbi

Basalt Dikes and plugs (Pliocene and Miocene)—Probable sources of basalt flows capping Grand Mesa (Tb). They also may intrude overlying flows. Permeability would be very low in the dike material. Water conductivity at the contact zones with Mesaverde and younger rocks is not known.

Ti/Tmi

Intrusive rocks (Miocene and Oligocene)—Granodiorite and quartz monzonite stocks, dikes, sills and laccoliths. Permeability is likely moderate in the fractured outcrop to very high in the talus deposits.

Tu

Uinta Formation (Eocene)—Siltstone, sandstone, and claystone. Vertical permeability through the formation is estimated to be low to very low, because of the siltstone and claystone interlayered among the sandstone. Horizontal permeability of the sandstone may be moderate; however, little permeability information is currently available.

Tg

Green River Formation (Eocene)—Light gray marlstone, oil shale, siltstone and sandstone. May include tongues of siltstone, sandstone, and claystone of the Uinta Formation in the upper part, and tongues of claystone and siltstone of the Wasatch Formation in the lower part. Unit is about 600 to 1,200 ft thick. Permeability is low to very low, based on the numerous lakes present at the top.

Tw

Wasatch Formation (Eocene and Paleocene)—Varicolored claystone and siltstone with local lenticular sandstones and limestones. Large landslide deposits are common. Formation is 1,000 to more than 2,500 ft thick. Permeability of the clay and silt is estimated to be very low, but may be low to moderate for the lenticular sandstones.

Kmv

Mesaverde Formation (Late Cretaceous)—Sandstone, fine to coarse grained; interbedded with shale and mudstone; lowest portion of unit contains numerous coal seams.

Further subdivision of this formation with accompanying descriptions is provided below. These subdivided units appear only on Exhibits 5 and 6.

Kmvo Ohio Creek Member of the Mesaverde Formation (Late Cretaceous)—Lenticular sandstones, fine to coarse grained; locally conglomeratic in the upper part, light gray to tan; interbedded with shale and mudstone. Thickness ranges from about 500 ft to 1,100 ft. Horizontal permeability is low to moderate; vertical permeability low to very low because of the interlayered shale and mudstone.

Kmvb Barren Member of the Mesaverde Formation (Late Cretaceous)—Lenticular sandstones, fine to very fine grained to silty, interbedded with shale and mudstone. Thickness ranges from about 750 ft to 1,200 ft. Vertical and horizontal permeability is low to very low because the shale, mudstone, and sandstone have no open pore space—the matrix is filled primarily with clay.

Kmvc Coal-Bearing Member of the Mesaverde Formation (Late Cretaceous)—Sandstone, fine to very fine grained to silty; interbedded with shale, mudstone, and siltstone. Contains the mineable coal seams of the Mesaverde Formation. Thickness of the Coal-Bearing Member ranges from about 300 ft near the outcrop northeast of Cedaredge (along Section A-A') to as much as 700 ft beneath Grand Mesa (near the northern end of Section B-B'). The coal seams range in thickness from one foot to 25 ft in Section A-A'; they range from one foot to 40 ft beneath Grand Mesa (near the northern end of Section B-B'). The coal seams are extensively burned, altered, and slumped within an estimated 500 ft (plus or minus 200-300 ft) of the outcrop. Vertical and horizontal permeability is estimated to be low to very low, except in the burn areas, where fractures—associated with thermal stresses and slumping from the burning coal seams—have occurred. In these areas, vertical and horizontal permeability may locally be moderate to high.

Kmvr Rollins Sandstone Member of the Mesaverde Formation (Late Cretaceous)—Sandstone, fine to very fine grained; tan to very light gray. Siliceous and calcareous cement is common, but may be uncemented near the top. Locally becomes coarser grained and contains more quartz and less cement in the upper part. Thickness ranges from 80 to 200 ft. Permeability is estimated to be low, but may have local zones of moderate permeability in the upper part.

Kcz Cozzette Member of the Mesaverde Formation (Late Cretaceous)—Sandstone, fine to very fine grained to silty and siltstone, light tan to gray. Member becomes coarser grained upward in unit; it also may become coarser grained westward and northward. Unit ranges in thickness from a few feet beneath Oak Mesa to as much as 145 ft beneath Grand Mesa (at the north end of Section B-B'). Permeability is estimated to be low to very low, based on lithology (very fine grained to silty sandstone and siltstone).

Km

Mancos Shale (Late Cretaceous)—Shale and mudstone, gray with yellowish gray bentonitic clay zones and thin limestone beds near the top. A tongue of Mancos Shale is present between the Cozzette and Rollins Members. Thickness ranges between 4,000 and 5,000 ft. Permeability is low to very low in the shale, mudstone, and bentonitic clay zones. Permeability may be locally low to moderate in the top few ft, where weathered and/or fractured.

MAP SOURCE

GEOLOGIC MAP AND CROSS SECTIONS OF THE CARBONDALE 30' x 60' QUADRANGLE, WEST CENTRAL COLORADO, by Margaret S. Ellis and Val L. Freeman, MAP C-97-A, published by the U.S. Geological Survey, 1984.

GEOLOGIC MAP OF THE PAONIA AND GUNNISON AREA, DELTA AND GUNNISON COUNTIES, COLORADO, by Margaret S. Ellis, David L. Gaskill, and C. Richard Dunrud, MAP C-109, published by the U.S. Geological Survey, 1987.

SCALE 1: 60,000 (1" = 5,000')

WRIGHT WATER ENGINEERS, INC
2490 W. 26TH AVENUE SUITE 100A
DENVER, COLORADO 80211