NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY *In cooperation with* LOS ALAMOS NATIONAL LABORATORY, UNIVERSITY OF CALIFORNIA

Geology of White Rock quadrangle, Los Alamos and Santa Fe Counties, New Mexico

by David P. Dethier, 1997

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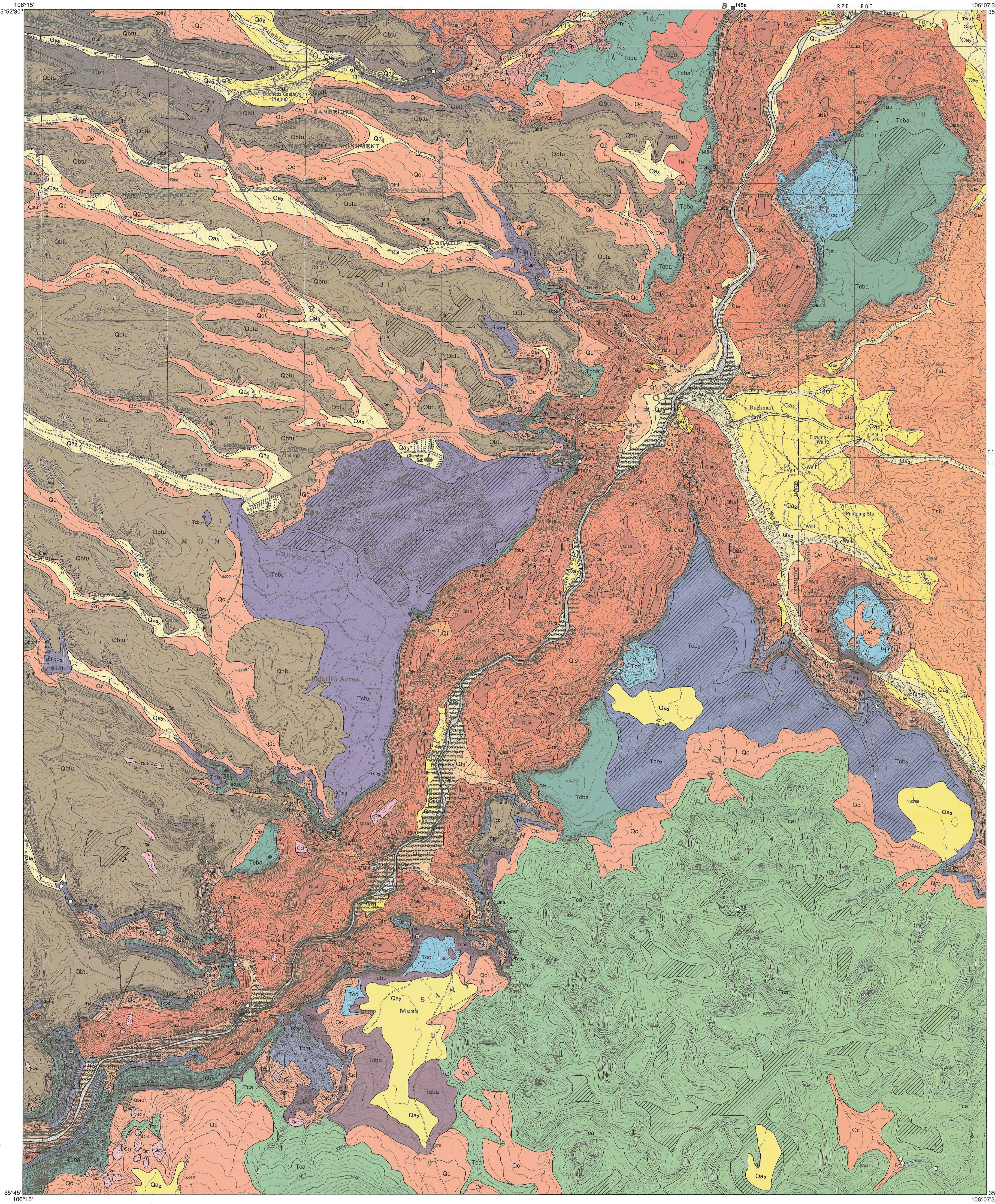

Base from U.S. Geological Survey, 1984
Geology by D. P. Dethier, 1985–86

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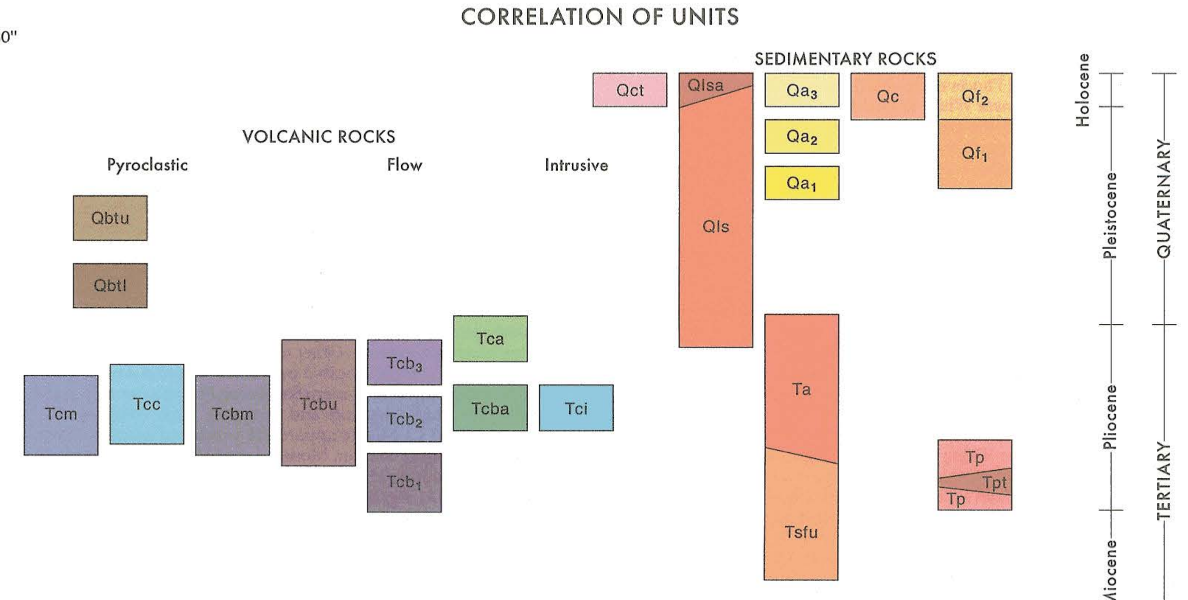
Edited by J. C. Love

CORRELATION OF UNITS



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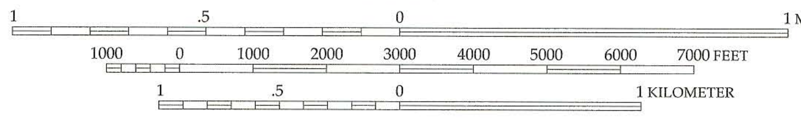
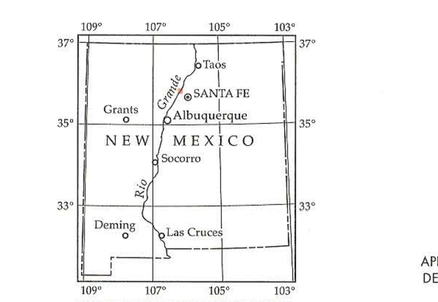
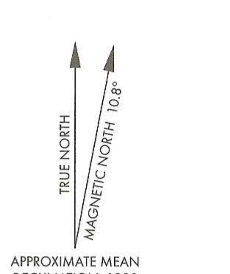




INDEX MAP OF NEW MEXICO



APPROXIMATE MEAN DECLINATION, 1993

DESCRIPTION OF UNITS

Sedimentary deposits and rocks

Qa_3 — Alluvial deposit (Holocene)—Crossbedded to planar-bedded sand and pebbly sand and thin beds of silty sand exposed along the Rio Grande, along active channels of tributary arroyos, and on adjacent low (<4m; <13 ft) surfaces. Beds generally <0.5 m (<1.5 ft) thick. Includes areas of late Pleistocene deposits in uplands west of the Rio Grande. Exposed thickness 2–4 m (6.5–13 ft). Actual thickness probably >10 m (>33 ft) along the Rio Grande and Cañada Ancha. Base not exposed. Soils thin (<0.5 m; <1.5 ft) with A/C or Bw horizons on low terraces west of the Rio Grande; stage II carbonate in the eastern part of the area (soil carbonate stages follow Machette, 1985)

Qa_2 — Alluvial and lacustrine deposit (Holocene and late Pleistocene)—Well-sorted cobble to boulder gravel, crossbedded sand, and thin-bedded sand and silty sand beneath terraces along the Rio Grande; cobble gravel along Los Alamos Canyon and other steep tributaries; sand and silty sand near Cañada Ancha; and gravelly sand and eolian silt on upland parts of the Cerros del Rio. Lies beneath surfaces 5–20 m (16–66 ft) above present drainages. Thickness probably 4–15 m (13–50 ft). Overlies and truncates rocks of the Santa Fe Group, landslide deposits, and older alluvium. Soils are 0.5–1.0 m (1.5–3 ft) thick and display stage II or stage III carbonate at dry sites and Bw or Bt horizons at wetter sites

Qa_1 — Alluvial and lacustrine deposit (middle? Pleistocene)—Well-sorted cobble to boulder gravel and rhythmically bedded fine sand, silt, and silty clay exposed beneath terrace remnants 25–45 m (80–150 ft) above the Rio Grande. Contact relations best exposed near the mouth of Cañada Ancha (Section E), where 15 m (50 ft) of gravelly deposits fill channels cut into the Santa Fe Group. Laminated to thin-bedded sediment 15–20 m (50–66 ft) thick lies over the gravel. Thickness mainly 10–30 m (33–100 ft). Overlies and truncates Santa Fe Group and landslide deposits. One surface west of Chino Mesa is overlain by El Cajete tephra (~50–60 ka; Reneau et al., 1996). Soil at that locality is 0.8–1.3 m (2.5–4 ft) thick and contains weak stage IV carbonate; soils on other remnants are thinner, and carbonate development is stage III

Qf_2 — Alluvial-fan deposit (Holocene and late Pleistocene)—Crossbedded, poorly sorted cobble to boulder gravel deposited mainly along White Rock Canyon by high-gradient, ephemeral channels. Includes debris flows along channels that drain Bandelier Tuff. Most small fan deposits west of the Rio Grande are mapped as Qa_3 or Qc. Thickness 4–8 m (13–26 ft). Generally overlies landslide deposits. Interfingers with and merges laterally with alluvial deposits. Soils are thin to absent on active areas of fans and <0.8 m (<2.5 ft) thick with stage II or weak stage III carbonate elsewhere

Qf_1 — Alluvial-fan deposit (late to middle Pleistocene)—Crossbedded, poorly sorted cobble to boulder gravel and poorly sorted, matrix-rich debris-flow deposits that form remnants 5–15 m (16–50 ft) above adjacent Qf_2 deposits. Thickness 4–15 m (13–50 ft), but most contacts obscured by colluvium. Overlies landslide deposits and Santa Fe Group. Overlain by El Cajete tephra (~50–60 ka; Reneau et al., 1996) along Water Canyon. Soils poorly exposed but locally thicker than 1.0 m (3 ft), exposing stage III or weak stage IV carbonate

Qc — Colluvial deposit (Holocene to middle Pleistocene)—Rockfall, debris-flow, and poorly sorted alluvial deposits at the bases of cliffs, particularly along White Rock Canyon. Texture and clast lithology variable. Includes thin (<2 m; <6.5 ft) alluvial deposits west of the Rio Grande and, in places, El Cajete tephra (~50–60 ka; Reneau et al., 1996). Thickness generally 4–10 m (13–33 ft) but locally along White Rock Canyon exceeds 25 m (82 ft). Overlies Bandelier Tuff west of White Rock; elsewhere overlies basaltic flows, phreatomagmatic deposits, and landslides. Soils thin (<0.5 m; <1.5 ft) and weakly developed at most locations, but lenses of El Cajete tephra, strong Bt (west of Rio Grande) or K horizons (White Rock Canyon and east), and buried soils (Birkeland, 1984) demonstrate that deposits are polygenetic and locally older than late Pleistocene

Qlsa, Qls — Landslide deposit (Holocene to late Pliocene)—Massive slumps and debris flows rich in basaltic-boulder gravel mainly exposed along White Rock Canyon, north of Chaquehui Canyon, and along Cañada Ancha. Most slides are inactive. Deposits consist of massive slump blocks with coherent internal stratigraphy near canyon rims and progressively deformed slumps and debris flows closer to the Rio Grande. Upper surfaces of many slumps (near Pajarito Springs and southwest of Otowi Bridge, for example) are sites of active fluvial and colluvial processes and are covered with >4 m (>13 ft) of fluvial, eolian, and colluvial deposits. Such flat to gently sloping areas are mapped as *Qlsa*. Dips in massive slump blocks range from 8° to 70° toward head scarps. Failures occurred along (1) steeply dipping planes rooted in the Santa Fe Group, (2) subhorizontal planes in clayey silt layers found at several levels of Pliocene fluvial and lacustrine deposits (*Ta*), and (3) steep walls of maars. Limited areas of autochthonous rocks are included in areas mapped as *Qls*. Slide material overlies rocks of the Santa Fe Group at most sites. At several locations undisturbed late Pliocene deposits lie stratigraphically above landslide deposits (Section H). Morphology of most failures and inclusion of Bandelier Tuff in some suggest that slides were active in early to middle Pleistocene time but that many became stable in the middle to late Pleistocene. El Cajete tephra (~50–60 ka; Reneau et al., 1996) lies on landslide deposits south of the White Rock area. Soils are generally 0.8–1.4 m (2.5–4.5 ft) thick. Carbonate morphology (Birkeland, 1984) is stage IV at some sites, but stage III carbonate is present in most exposures. Cation ratios in rock varnish (Dethier et al., 1988) at two sites suggest that those landslides stabilized >250 ka

Ta — Fluvial and lacustrine deposit (early Pleistocene? and Pliocene)—Crossbedded sand, gravelly sand rich in lithologies from the Sangre de Cristo Range, thin-bedded silt and silty sand, and beds of phreatomagmatic cinders and debris flows exposed along Cañada Ancha (Sections F and G) and north of Water Canyon, west of the Rio Grande (Sections A and D). Maximum thickness ~30 m (~100 ft). Overlies phreatomagmatic deposits along Cañada Ancha and Puye Formation or basaltic rocks near the Rio Grande. Overlain by and interlayered with phreatomagmatic deposits and flows of basaltic andesite (*Tcba*) or basalt (*Tcb_2*). Paleocurrent directions measured on channels and gravelly crossbeds range from 180° to 270° and average about 220°. Correlates with older alluvium of Griggs (1964) and, in part, with the Ancha Formation of Spiegel and Baldwin (1963). Relationship to Santa Fe Group sediment unknown. Contains lenses of dacitic tephra along Cañada Ancha. Manley (1976) reported an age of about 2.7 Ma (Table 1) for one lens some 8 km (5 mi) east of Caja del Rio Canyon. Age elsewhere not well known

Tp — Puye Formation fanglomerate (Pliocene; Griggs, 1964)—Weakly lithified pebble to boulder gravel, boulder-rich debris flows, massive to planar-bedded sand, thin (<1 m; <3 ft) beds of dacitic tephra and pumiceous alluvium, and beds of fine sand and silt. Exposed west of the Rio Grande except for an isolated outcrop south of the mouth of Cañada Ancha (Section F). Gravel beds generally 0.5–3.0 m (1.5–10 ft) thick. Debris flows range from 0.3 m (1 ft) to about 5.0 m (16 ft) thick. Clast and matrix lithology mainly dacite derived from the Tschicoma Formation of the Jemez Mountains, but Precambrian material composes >30% of some fluvial units. Thickness 5–30 m (16–100 ft). Fills channels cut in rocks of the undivided Santa Fe Group and, along Los Alamos Canyon (Section A), into cobble gravel of the Puye Formation, Totavi Lentil (Griggs, 1964). Exposed beneath quartzite-rich cobble gravel (Totavi Lentil) or phreatomagmatic deposits at most locations (Sections D and J). Paleocurrent directions measured on channels, gravelly crossbeds, and imbricated cobbles range from about 90° to 200° and average about 150°, slightly south of the trend of present canyons. Faulted locally near the mouth of Ancho Canyon; otherwise undeformed. Pumiceous Puye gravel 8 km (5 mi) north-northwest of Otowi Bridge gave a fission-track age of 2.9 Ma (Table 1). Turbeville et al. (1989) report that the upper part of the Puye Formation may be as young as 1.7±0.1 Ma northwest of the White Rock quadrangle

Tpt — Puye Formation, ancestral Rio Grande facies (Pliocene; Totavi Lentil of Griggs, 1964)—Slightly lithified pebble to cobble gravel rich in clasts of Precambrian rock, sand, and thin beds of silty sand west of the Rio Grande and at one outcrop south of the mouth of Cañada Ancha, east of the Rio Grande (Section F). Coarse units are 0.5–3.0 m (1.5–10 ft) thick, crossbedded, and locally planar bedded. Clasts generally >80% quartzite and other resistant lithologies from northern New Mexico, but clasts from the southern Sangre de Cristo Range are common locally. Thickness 5–45 m (16–150 ft). Maximum thickness and most extensive exposures in Sandia and Mortandad Canyons (Section D). Fills channels in and locally interbedded with Puye fanglomerate except along Los Alamos Canyon, where it overlies Santa Fe Group. Lies beneath landslide deposits, Pliocene alluvium, or phreatomagmatic deposits at most exposures. Paleocurrent directions measured on channels, gravelly crossbeds, and imbricated cobbles range from 160° to 220° and average about 180°. Mainly undeformed. Near the mouth of Ancho Canyon (Section J) lies under a basaltic flow (*Tcb_2*) reported by Bachman and Mehnert (1978) to have an age of about 2.6 Ma (Table 1)

Tsfu — Santa Fe Group, undivided (early? Pliocene to middle Miocene)—Moderately lithified, planar-bedded to massive, silty sandstone, siltstone, and crossbedded pebbly sand in sparse channels. Sandstone beds as much as 4 m (13 ft) thick; channels <1 m (<3 ft) deep. Coarse units cemented with sparry calcite. Clasts mainly (1) intermediate volcanic rocks and quartzite from southern Colorado and the northern Sangre de Cristo Range and (2) Precambrian granite and associated rocks from the southern Sangre de Cristo Range. Matrix arkosic. Thin (<0.3 m; <1 ft), discontinuous beds of altered dacitic (biotite, hornblende) tephra locally abundant. Thickness >185 m (>607 ft) at the southern end of La Mesita, but the base is nowhere exposed, and the well field at Buckman penetrates >600 m (>1,970 ft) of this unit. Lies beneath Puye Formation or phreatomagmatic deposits at most locations, but landslide deposits obscure exposures along White Rock Canyon. Dips gently (<8°) northwest in the northern map area. Paleocurrent directions measured on channels and gravelly crossbeds range from 170° to 270°. Correlates, in part, with the Tesuque Formation of Galusha and Blick (1971) and the Ancha Formation of Spiegel and Baldwin (1963). Age not well defined but pre-mid-Pliocene

Volcanic deposits and rocks

Qct — El Cajete tephra (late? Pleistocene)—Pumiceous lapilli of rhyolitic composition. Forms surface layer in isolated outcrops as thick as 40 cm in southwest part of map area and <5 cm in northeast part of map area. Most exposures have been reworked by slope processes. Derived from the El Cajete vent in the Valles caldera; previously thought to be about 150,000 yrs old (Self et al., 1988) but may be as young as 50 ka (Reneau et al., 1996)

Qbtu — Bandelier Tuff, upper part (early Pleistocene)—Slightly welded pyroclastic flows (Tshirege Member) and a thin (<1 m; <3 ft) pumiceous fall unit (Tsankawi Pumice Bed), both of rhyolitic composition. Dominates surfaces west of the Rio Grande and forms one prominent outcrop east of the Rio Grande (Section H). Two to five pyroclastic flows separated by pumice concentrations or thin, sorted partings are present along deep canyons west of the Rio Grande. Thickness generally <60 m (<200 ft) but about 90 m (300 ft) east of the Rio Grande. As mapped, may include exposures of lower Bandelier Tuff, which it lies above. Paleoflow direction to the east. Derived from the Valles caldera west of the map area. Age 1.2 Ma (Izett and Obradovich, 1994)

Qbtl — Bandelier Tuff, lower part (early Pleistocene)—Slightly welded pyroclastic flows (Otowi Member) of pumiceous rhyolite and a compound pumiceous fall unit (Guaje Member) as thick as 6 m (20 ft), also of rhyolitic composition. Best exposed in deep canyons west of the Rio Grande, particularly in Los Alamos (Section A) and Sandia Canyons. One or two thick flows overlie the Guaje Member, which is absent at many exposures. Maximum thickness about 50 m (165 ft). Lies beneath upper Bandelier Tuff. Fills canyons as deep as 50 m (165 ft) cut into tholeiitic olivine basalt (*Tcb_3*), basaltic andesite (*Tcba*), and phreatomagmatic deposits. Derived from the Valles caldera west of the map area. Age is 1.6 Ma (Izett and Obradovich, 1994)

Tcc — Cinder cone deposit (Pliocene)—Oxidized cinders, agglomerate, and minor areas of phreatomagmatic deposits composed of olivine basaltic andesite and basalt. Contains 2–8% quartz xenocrysts. Exposed mainly along the Rio Grande and at the Caja del Rio Canyon. *Granular surface deposits, dissected cinder cones*, and slightly lithified exposures in canyon walls; best exposed near La Mesita (Section C). Massive to planar bedded, locally rich in lava and accidental bombs <0.2 m (<0.5 ft) in diameter. Maximum thickness about 60 m (197 ft). Lies above phreatomagmatic deposits at many exposures. Age not closely bounded but probably late Pliocene

Tcm — Phreatomagmatic deposit (Pliocene)—Bedded to massive fall, surge, and flow deposits composed of basaltic tuff and cinders and accidental fragments of the Santa Fe Group. Thickest exposures along the Rio Grande and Cañada Ancha (Section G). Fall beds, 0.3–3.0 m (1–10 ft) thick, are composed mainly of ash and lapilli containing sparse bombs of accidental fragments and basaltic fragments. Surge beds are planar and crossbedded, locally rippled, coarse silt to pebbly sand, generally 0.1–0.4 m (0.3–1.3 ft) thick. Flow deposits are mainly matrix-rich pebble to boulder gravel in discontinuous beds 1–4 m (3–13 ft) thick. Near maars the concentration of accidental fragments decreases upsection. Locally sheared, slumped, or brecciated. As much as 60 m (200 ft) thick near maars such as La Mesita (Section C), "Buckman maar" (Section G; Aubele, 1978), and "Montoso maar" (Aubele, 1978). Generally lies above Puye Formation, undivided Santa Fe Group, and interlayered basalt and phreatomagmatic deposits. Lies beneath flows of basaltic andesite, basalt, or cinder and agglomerate deposits. In Ancho Canyon (Section J), lies on *Tcb_2*, which gave an age of 2.6 Ma (Table 1), but stratigraphic relations suggest deposits along Cañada Ancha may be somewhat older. Minimum age not well known

Tcbm — Basalt and interlayered phreatomagmatic deposits (Pliocene)—Thin (<10 m; <33 ft) basaltic flows interlayered with basaltic phreatomagmatic rocks, mainly surge and flow deposits, and mapped in the southern part of the map area near the Rio Grande. Multiple baked layers exposed in Chaquehui Canyon (Section K) and along the north margin of Chino Mesa (Section I). Maximum thickness about 50 m (165 ft). Lies on phreatomagmatic deposits and Santa Fe Group. Lies beneath phreatomagmatic deposits and basalt flows. One flow in Chaquehui Canyon gave an age of 2.78±0.04 Ma (Table 1)

Tci — Basaltic intrusion (Pliocene)—Olivine, pyroxene basaltic andesite containing quartz xenocrysts. Forms fine-grained dikes and small, shallow intrusions, with sharp chilled margins, associated with maars and cinder cones along the east margin of White Rock Canyon. Most prominent intrusion is a small plug capped with agglomerate at the west edge of Chino Mesa. Aubele (1978) suggested that a sill lies beneath cinders and agglomerate along the west margin of Sagebrush Flats, and the andesitic exposure in Water Canyon (locality 100) may be intrusive. Dikes generally vertical and <10 m (<33 ft) wide. Unit intrudes phreatomagmatic or cinder-cone deposits. Not dated but probably middle or late Pliocene

Tca — Andesite (early Pleistocene? and late Pliocene)—Massive, steep-sided flows, agglomerate, and domes of hypersthene andesite (Table 2) exposed in the southeast part of the map area. Strongly sheeted near flow surface; brecciated at bases. Thickness of flows >20 m (>66 ft). Total thickness unknown but likely exceeds 150 m (500 ft) in the southeast map area. Lies above basaltic andesite and hawaiite and lies beneath Quaternary Guaje Pumice Bed (*Qbtl*). Manley (1976) reported an age of about 2 Ma (Table 1) from an andesite flow 5 km (3 mi) east of the eastern edge of the map area. Age of youngest domes unknown

Tcb_3 — Basalt (late Pliocene)—Tholeiitic olivine basalt flows (Table 2), pillow basalt, and palagonitic breccia exposed west of the Rio Grande north of Chaquehui Canyon. Flows thin (<10 m; <33 ft) with sharp to rubble-rich contacts. Subaerial thickness <30 m (<100 ft); maximum thickness ~80 m (~260 ft) in Mortandad Canyon (Section D). Overlies lacustrine or sandy fluvial sediment (*Ta*) north of White Rock and older basaltic flows to the south (Section J). Thin (<3 m; <10 ft) fluvial and lacustrine deposits separate the basalt from overlying lower Bandelier Tuff at some sites (Sandia Canyon, for instance). Flow directions measured on foreset deposits of pillow basalt in Los Alamos, Sandia, Mortandad, Buey, and an unnamed canyon range from about 70° to 150° (average about 110°). Topset–foreset contacts in deltas of basaltic debris at 6,200±25-ft elevation suggest that a lake dammed near Chaquehui Canyon persisted in White Rock Canyon during eruption of much of the basalt. Basalt originated from vents buried by Bandelier Tuff west and northwest of the map area. A sample from the basalt exposed near the intersection of Pueblo and Los Alamos Canyons (Section A) in the northwest map area gave an Ar/Ar age of 2.33±0.08 Ma (Table 1), and flows capping Ancho Canyon and underlying White Rock gave ages between 2.5 and 2.4 Ma

Tcba — Basaltic andesite and related flows (Pliocene)—Massive flows of olivine–hypersthene basaltic andesite, andesite, and hawaiite, containing as much as 7% quartz, exposed along the Rio Grande (Table 2). Forms thick (>30 m; >100 ft locally) flows with brecciated bases and cooling joints 4 m (13 ft) in diameter. As much as 170 m (560 ft) thick along the Rio Grande at the south end of the map area. Fills canyons as deep as 40 m (130 ft) southwest of Otowi Bridge (Section B), where flows lie on top of phreatomagmatic deposits (*Tcm*) and the Puye Formation (*Tp* and *Tpt*) and lie beneath fluvial and lacustrine sediment (*Ta*). Overlies basalt (*Tcb_2*), phreatomagmatic deposits and agglomerate, and the Puye Formation south of Water Canyon west of the Rio Grande (Sections J and K) and south of Sagebrush Flats east of the Rio Grande. Outcrop pattern and channel orientation suggest that lava flowed mainly southwest and south from vents near La Mesita, on Sagebrush Flats, between Water and Ancho Canyons, and probably in the vicinity of Chino Mesa (Aubele, 1978). The Otowi flow of Galusha and Blick (1971) gave an age of 2.57±0.02 Ma (locality 145a), and a massive flow probably derived from La Mesita (locality 145c) gave an age of 2.55±0.02 Ma (Table 1). The flow between Water and Ancho Canyons gave an Ar/Ar age of 2.3±0.3 Ma. Age bracketed by the 2.6±0.4 Ma age of stratigraphically lower *Tcb_2* near Ancho Canyon (Table 1) and the 2.33 Ma age of overlying *Tcb_3* along Los Alamos Canyon (Table 1)

Tcb_2 — Basalt flows (Pliocene)—Thin (<10 m; <33 ft) flows of olivine basalt (hawaiite, see Table 2) containing <5% quartz xenocrysts and exposed mainly beneath large areas of Sagebrush Flats (Sections F and G) and along the east boundary of White Rock quadrangle. Brecciated and sparse baked zones between flows. Maximum thickness ~70 m (~230 ft) near Chino Mesa. Overlies phreatomagmatic deposits (*Tcm*) and Pliocene alluvial deposits (*Ta*) along Cañada Ancha, at the White Rock Overlook, and in Pajarito Canyon. A latite–andesite flow (Baldridge, 1979) included with *Tcb_2* lies above the Totavi Lentil (*Tpt*) in Ancho Canyon. Andesite and basaltic-andesite flows (*Tca, Tcba*) and Quaternary alluvium lie above hawaiite in the Sagebrush Flats area, whereas *Tcb_2* flows lie beneath basaltic andesite (*Tcba*) or olivine basalt (*Tcb_3*) at most exposures west of the Rio Grande. Probable vent areas are marked by cinder and agglomerate deposits from Sagebrush Flats south to Chino Mesa; younger basaltic and andesitic flows probably cover other vents. A flow exposed on the south rim of Caja del Rio Canyon (locality 122) gave an age of 2.49±0.03 Ma (Table 1). An age of about 2.6 Ma (Table 1) was obtained by Bachman and Mehnert (1978) in Ancho Canyon

Tcb_1 — Basaltic flows (Pliocene?)—Olivine basalt flows and more evolved rocks exposed within 20 m (66 ft) of the present level of the Rio Grande and Cañada Ancha. Flows are thin to massive and include a lava lake (Caja del Rio Canyon) and a number of poorly exposed outcrops along the Rio Grande from Water Canyon to Chaquehui Canyon. Thickness 20–95 m (66–310 ft). The latter flows lie above deformed phreatomagmatic deposits (*Tcm*) and beneath cinders and agglomerate (*Tcc*). Sources of the flows are buried, probably diverse (Table 2), and may lie in a stratigraphic position similar to subsurface volcanic rocks reported by Griggs (1964), some as old as middle Miocene (WoldeGabriel et al., 1996). A flow near the mouth of Water Canyon gave an age of 2.50±0.04 (Table 1)

Tcbu — Basalt, undivided (Pliocene)—Olivine basalt, hawaiite, and basaltic andesite containing 2–8% quartz xenocrysts and exposed in the southern part of the map area (Section I). Thin to massive flows. Thickness from 20 m to >150 m (from 66 ft to >490 ft) in the southern map area. Lies above phreatomagmatic deposits (*Tcm*). Generally lies beneath *Tcba* and may be equivalent, in part, to basalt mapped as *Tcb_2*. Montoso maar (Aubele, 1978) was the probable source for much of this unit. Age unknown but probably middle to late Pliocene

MAP SYMBOLS

Contact

Normal fault—Ball and bar on downthrown block; dashed where approximately located; dotted where buried or concealed

Strike and dip of bed

Thin (<4 m; <13 ft) fluvial and eolian deposit

Paleocurrent direction—Arrow tail at measured site

Top of landslide block in slide complex

Trace of stratigraphic section

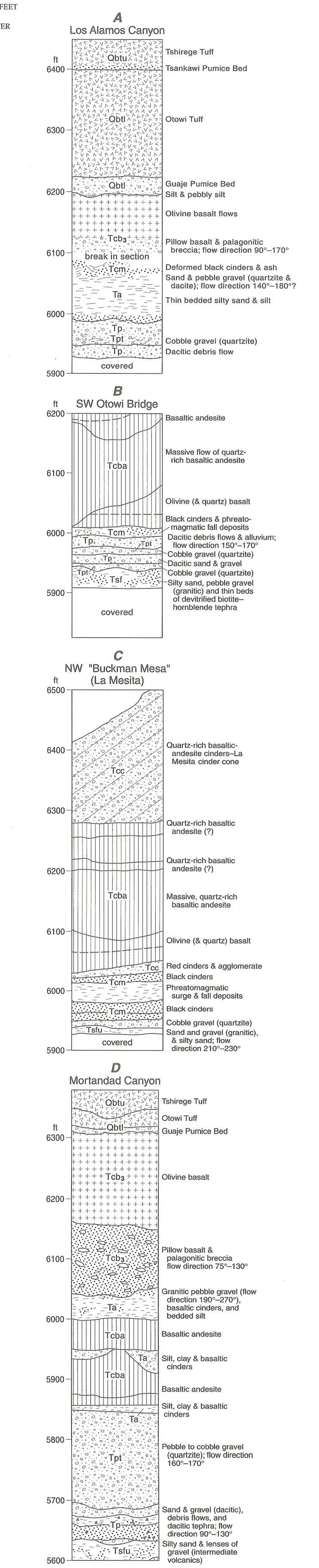
■ 147c **Sample locality**—Number refers to Table 1

● 147b **Sample locality**—Number refers to Table 2

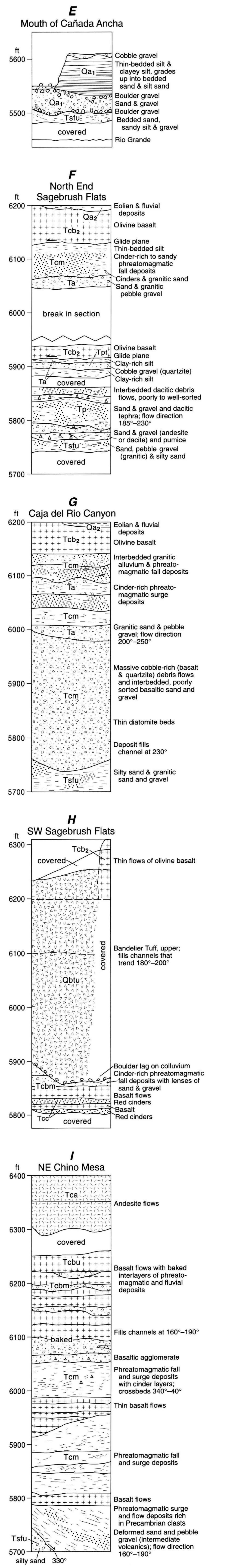
○ 36 **Sample locality of Baldridge (1979)**—Number refers to Table 2

⊙ 4 **Sample locality of Aubele (1978)**—Number refers to Table 2

Unnumbered sample localities are from Baldridge, 1979, and WoldeGabriel et al., 1995



Stratigraphic sections and text continued on back



INTRODUCTION

The White Rock quadrangle (Fig. 1) exposes a diverse suite of Miocene through Holocene rocks that record volcanism, sedimentation, and erosion along the axis of the Rio Grande rift in the southern Española Basin. Rocks were derived from volcanic sources in the Cerros del Rio and the Jemez Mountains and from eroded metamorphic and intrusive rocks exposed in the Sangre de Cristo Range. In Miocene time, before the Rio Grande developed as axial drainage for the Española Basin, the map area was on the west and southwest margin of a large alluvial-fan complex. Sometime before about 3 m.y. ago (Ma), perhaps in early Pliocene time, the Rio Grande began to run through the vicinity of White Rock Canyon (Manley, 1979). Since middle Pliocene time, the river has flowed near its present location, shifting less than 10 km (6.2 mi) laterally in response to volcanic activity along the river and to the construction of a volcaniclastic fan (Puye Formation) from the Jemez Mountains. The symmetry and age of slump complexes along the Rio Grande indicate that the river has not changed course appreciably since before middle Pleistocene time. Middle Pliocene fan construction; location, age, and chemistry of volcanic rocks erupted at maars and other vents along the Rio Grande; and the Quaternary history of White Rock Canyon are discussed below. Miocene sedimentation and tectonics of the Española Basin (Manley, 1979), evolution and petrochemistry of the Cerros del Rio volcanic field (Aubele, 1978; Baldridge, 1979; Duncker et al., 1989), and evolution of the Jemez volcanic field (Gardner et al., 1986; Self et al., 1986, 1988) have been discussed in detail by previous workers and are not examined here.

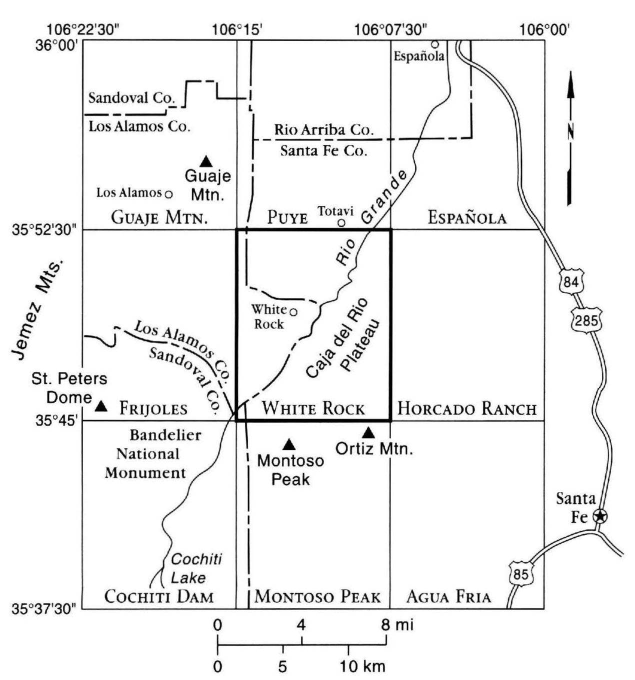
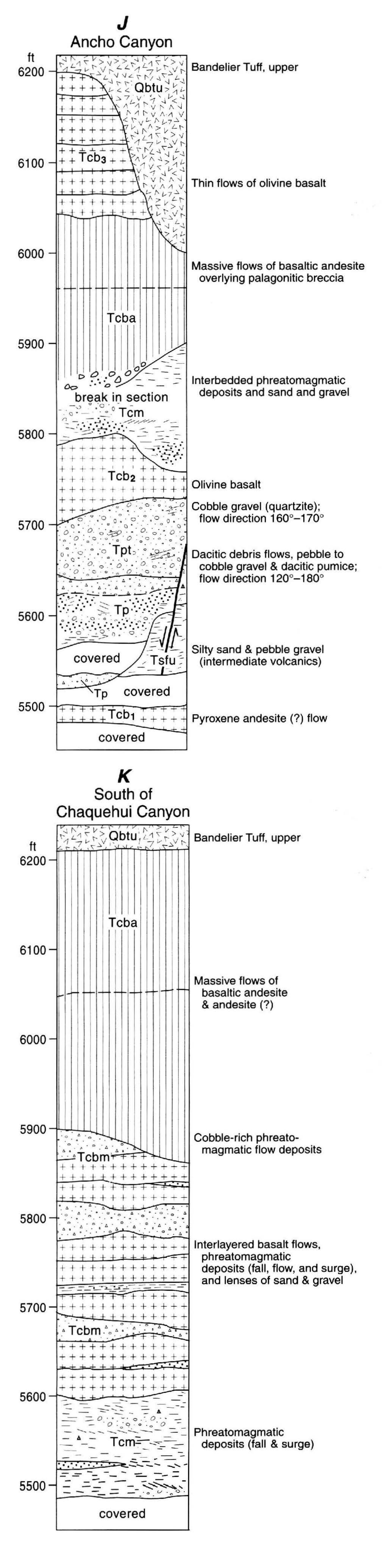


FIGURE 1—Index map of White Rock quadrangle, surrounding quadrangles, and major geographic features.



PLIOCENE AGGRADATION AND CANYON CUTTING

Sediment of the Santa Fe Group (Griggs, 1964) and overlying alluvial-fan deposits (Puye Formation and Pliocene alluvium) record alternate aggradation and canyon cutting centered near White Rock during late Tertiary time. Rock types and sparse paleocurrent directions in the Santa Fe demonstrate that it was derived from eastern and northern sources and deposited on low-gradient surfaces, probably as a broad alluvial plain that extended beneath the present Jemez Mountains. This thick basin fill accumulated in and filled the sagging western margin of the Española Basin to a local elevation greater than 6,100 ft (present) from at least middle Miocene until Pliocene time. By middle Pliocene time (~3 Ma), however, a southwest-flowing arroyo complex and east-flowing drainage from the Jemez Mountains deeply eroded the fill to a base level apparently determined by the ancestral Rio Grande. Ensuing volcanic and volcaniclastic activity filled and built broad areas of low slope near what is now White Rock Canyon.

Evidence for the principal southwest drainage is exposed best along Cañada Ancha (Sections F and G), where phreatomagmatic deposits fill a deep channel cut in undivided Santa Fe Group and are interbedded with and overlain by Pliocene fluvial and lacustrine units (*Ta*) deposited by southwest-flowing drainage. Spiegel and Baldwin (1963) mapped the southwest wall of Cañada Ancha east of the White Rock quadrangle as Pliocene Ancha Formation, and it is likely that some undivided deposits in the Caja del Rio area are equivalent to the Ancha. I follow Griggs (1964), however, and include all sediment beneath phreatomagmatic deposits as undivided Santa Fe Group and map overlying nonvolcanic fluvial and lacustrine deposits as Pliocene alluvium. Aggradation recorded near Caja del Rio and in canyons west of the Rio Grande (see Sections D and J) followed middle Pliocene downcutting, and fluvial, volcaniclastic, and volcanic rocks filled the area of White Rock Canyon. Canyon-filling deposits included fluvial deposits and debris flows (Puye Formation) derived from dacitic volcanics (Tschicoma Formation) in the northeastern Jemez Mountains (southeast paleocurrent directions), cobble gravel rich in Precambrian quartzite deposited by the ancestral Rio Grande (Totavi Lentil of the Puye Formation; south paleocurrent directions), and phreatomagmatic deposits and basaltic rocks mainly erupted at maars along the Rio Grande.

Griggs (1964) described the Totavi Lentil as a record of the initiation of the Rio Grande in the White Rock area, but field relations and studies by Waresback (1986) show that the Totavi is time transgressive. Outcrop patterns suggest that the aggrading Rio Grande flowed as far east as Buckman Mesa (La Mesita) and along the north edge of Sagebrush Flats (Section F), yet the thickest deposits of the Totavi Lentil crop out 1–4 km (0.6–2.5 mi) west of the present river. Waresback (1986) demonstrated that the pre-Puye Rio Grande flowed some 10 km (6.2 mi) west of its present position and migrated to the east as the Puye fan expanded and possibly in response to tectonic tilting. Griggs (1964) concluded that the Totavi Lentil was interlayered with flows of the Tschicoma Formation in the subsurface near Los Alamos, near the base of a volcaniclastic sequence in the subsurface of Guaje Canyon. South of Los Alamos Canyon, however, Totavi gravel rests on Puye Formation deposited by east–southeast paleocurrents (Sections D, F, and J). In Water Canyon, for instance, the Totavi forms a thick layer 30 m (98 ft) above the base of the Puye. Puye mudflows and fanglomerate exposed at Sections D, F, and J were deposited when the Rio Grande flowed to the east of these areas. Subsequent aggradation and volcanic activity near Otowi Bridge forced the Rio Grande west over the dacitic deposits. Thick Totavi gravel exposed along Sandia, Mortandad, and Ancho Canyons suggests that the Rio Grande may have aggraded at these locations for an extended period of time. If the subsurface interpretations of Griggs are correct, models for deposition of the Totavi Lentil include: (1) the early Pliocene Rio Grande flowed along the eastern margin of the Jemez Mountains, moved east as Tschicoma volcanics were emplaced and the Puye fan expanded eastward, and shifted west in response to the growth of the Cerros del Rio field; (2) the early Pliocene Rio Grande flowed along its present course, shifted west in response to tectonic activity, and returned east as the Puye fan expanded; and (3) little stratigraphic significance can be attributed to the presence of gravel rich in Precambrian rock because lenses and channels are present at several horizons within the Puye Formation. Extensive radiometric dating of the La Mesita maar–cinder cone complex and subsurface exposures of the Puye Formation would greatly aid choosing between these alternatives, but stratigraphy in the White Rock area favors (1).

The apparent paleogradient of the Pliocene Rio Grande in White Rock Canyon, 0.50%, is more than twice the present gradient and may suggest the influence of tectonics or changes in hydraulic geometry. The basal contact of Puye Formation fluvial deposits near White Rock Canyon closely defines the elevation of the Pliocene Rio Grande and permits calculations of paleogradient. Basal Puye Formation is between 5,800 and 5,900 ft along lower Los Alamos Canyon (0.5 km [0.3 mi] north of the White Rock quadrangle), 5,750 ft in Sandia Canyon and southwest of Cañada Ancha, and about 5,500 ft at Ancho Canyon, the most southerly outcrop in White Rock Canyon. If this contact is isochronous, the average gradient of the Pliocene Rio Grande was more than twice the present grade of 0.20%, and there is an apparent steepening of slope between Ancho and Sandia Canyons. Post-depositional tilting to the southeast may have produced the steep gradient, and local, unmapped faults could be responsible for the slope discontinuity. It is also possible, however, that the slope of White Rock Canyon was determined by different combinations of hydraulic variables in middle Pliocene time, that the age of the basal Puye Formation near White Rock Canyon is time transgressive, or that there was a waterfall or other knickpoint north of Ancho Canyon in middle Pliocene time.

From White Rock north to Los Alamos Canyon, paleocurrent data and clast types in Pliocene alluvium (*Ta*) demonstrate that a west- and southwest-directed fluvial system (including Griggs' type Totavi Lentil) was active during deposition of the Puye Formation and persisted during and after eruption of basaltic flows (Section D). In the northern map area, fluvial deposits (in part the older alluvium of Griggs, 1964) are exposed near Totavi (Section A) and near the intersection of Buey and Mortandad Canyons, demonstrating that the Rio Grande flowed west of its present course at that time. The Otowi flow (Galusha and Blick, 1971) caps the south rim of Los Alamos Canyon and flowed west to the vicinity of Totavi at about 2.6 Ma (Table 1). Tholeiitic basalt (*Tcb*$_3$) that fills canyons in Pliocene alluvium (*Ta*) flowed east and southeast from vents west of the map area into a lake (elevation 6,200 ft), indicating that the Rio Grande had migrated back to the east by about 2.4 Ma (Table 1) and that a period of canyon cutting occurred between deposition of *Ta* and eruption of the flows. Lacustrine sediment, best exposed near Sections A and D and mapped by Waresback (1986) north of White Rock Canyon, demonstrates that White Rock Canyon was repeatedly dammed by volcanic activity in the Cerros del Rio field. Thin (<4 m; <13 ft) fluvial or lacustrine deposits that cap some *Tcb*$_3$ flows suggest that high-level alluvial deposition persisted briefly after eruption of the basalt. There is no evidence, however, that sediment from the southern Sangre de Cristo Range has been deposited west of the present course of the Rio Grande since *Tcb*$_3$ time.

PLIOCENE VOLCANISM ALONG NORTHERN WHITE ROCK CANYON

The Pliocene volcanic sequence that comprises the Cerros del Rio field (Smith et al., 1970) includes flow and phreatomagmatic rocks erupted from maars and cinder cones near the Rio Grande, a dome complex in the southeastern part of the area, and buried vents on both sides of the river. Sources of basaltic rocks (*Tcb*$_1$ and *Tcbm*) that crop out close to the Rio Grande are not known in detail, but at least some flows originated at maars along the Rio Grande and at buried vents to the west, probably at a stratigraphic level similar to a flow-rich interval noted in the subsurface by Griggs (1964). Many slightly younger flows also originated at maars and from cinder cones near White Rock Canyon. Field evidence indicates a widely variable magma–water interaction at those vents. A number of cinder cones (La Mesita and the cones at Caja del Rio Canyon and north of Chino Mesa) overlie phreatomagmatic deposits erupted at the same vent, apparently as part of the same magmatic episode. Other maars do not display evidence of oxidized deposits. A vent complex located between Water and Ancho Canyons and a probable vent along southwestern Sagebrush Flats expose only minor amounts of phreatomagmatic deposits and relatively large volumes of lava. These vents and one at La Mesita apparently produced massive flows of basalt (*Tcba*) exposed near the river. Montoso maar (Aubele, 1978) may have been an additional source. Hawaiite and related rocks (*Tcb*$_2$) that form gently sloping surfaces at Sagebrush Flats, at eastern La Mesita, and at Chino Mesa (Aubele, 1978) originated, in part, from vents near the Rio Grande. Other vents probably are buried beneath andesitic rocks. The youngest basalts (*Tcb*$_3$) flowed east from vents buried by Bandelier Tuff west and northwest of the map area. Most of the basaltic rocks were erupted between about 2.7 and 2.3 Ma (WoldeGabriel et al., 1996). Andesites (*Tca*) that crop out south and east of Sagebrush Flats erupted from vents and domes in the southeastern map area and in the vicinity of Ortiz Mountain on the Agua Fria and Montoso Peak quadrangles. Stratigraphic relationships demonstrate that the andesites are younger than all the basaltic rocks east of White Rock Canyon and that some andesite flows are younger than the 1.60 Ma lower Bandelier Tuff (D. P. Dethier, unpubl. data 1986).

Chemical analysis of 40 flows from the White Rock quadrangle (WoldeGabriel et al., 1996; Baldridge, 1979; Aubele, 1978) shows that compositions range from basalt to andesite and suggests the influence of at least two parent magmas. With the exception of sample 5 (Table 2), all analyzed rocks from the map area are hypersthene-normative. Rocks mapped as *Tcb*$_1$ include hawaiite (40, 104) and basaltic andesite (137). A flow interlayered with phreatomagmatic deposits (*Tcbm*) in Chaquehui Canyon is an olivine tholeiite (129). Two analyses from *Tcb*$_2$ are of hawaiite composition, as is sample 5 (Aubele, 1978) from the undivided basalt unit (*Tcbu*). The "early northern hawaiite" of Aubele (1978) may be equivalent to *Tcb*$_2$ and, in part, to *Tcbu*. Thick flows of basalt and basaltic andesite, both rich in quartz xenocrysts, are included in *Tcba*, which crops out mainly within 1 km (0.6 mi) of White Rock Canyon. The diversity of basalt compositions at each of several stratigraphic levels suggests that closely spaced vents tapped diverse magmas. Nine flows and palagonitic breccias mapped as *Tcb*$_3$, however, are all tholeiitic (WoldeGabriel et al., 1996; Baldridge, 1979); the isolated basalt outcrop at sample locality 141 is the most evolved of this group. Flows from the southeast map area are andesitic.

The range of composition and stratigraphic context suggest that magma composition changed over the million years of eruptions in the Cerros del Rio field, but radiometric ages do not clearly separate different eruption chemistries (Table 1). The relatively young tholeiites of *Tcb*$_3$ are not related simply to the older, more alkalic rocks of *Tcb*$_2$ or to the basaltic andesites that the tholeiites cover in the White Rock area. Hawaiites and more alkalic flows exposed south and west of the map area (Baldridge, 1979; Aubele, 1978) suggest early and probably extensive eruptions of alkaline basalt east of the Rio Grande; however, large areas of alkaline rocks are not exposed in the map area. Andesites in southeastern White Rock quadrangle could have formed from crystallization of tholeiitic magmas. The andesitic flows, however, rest on a platform of hawaiite, from which they could not have evolved. If the average thickness of andesite is at least 60 m (200 ft), the minimum volume of andesitic rock exposed in the White Rock quadrangle is 2 km^3(0.5 mi^3), and larger volumes are present elsewhere in the Cerros del Rio field (Aubele, 1978). Stratigraphic and radiometric evidence suggests that in less than 500,000 yrs basalt, hawaiite, and basaltic andesite erupted along and east of the Rio Grande, followed by eruption of tholeiites from upland areas west of the canyon, building a flow sequence >200 m (>700 ft) thick. Finally andesitic flows emerged from centers east of the Rio Grande, probably in latest Pliocene time. More detailed dating and chemical analysis may help establish the tectonic and petrologic significance of the temporal changes in the locus of volcanism.

FAULTING

The near absence of faults in the White Rock quadrangle is striking, considering its location along the axis of the Rio Grande rift, extensive volcanism, and the proximity to structures such as the Pajarito fault (Smith et al., 1970). Poor exposure and lack of Quaternary activity are probable explanations. If faults are present near the Rio Grande, they could be buried by landslide or colluvial debris, and faults without post-middle Pliocene motion would be covered by basalt, andesite, or the Bandelier Tuff in most of the quadrangle. It seems probable that Pliocene volcanic activity was localized along fault zones, but I mapped evidence of latest Pliocene or Quaternary faulting only in the area south of Ancho Canyon. Dips in the Santa Fe Group are relatively constant in well-exposed areas near Buckman, which suggests that major local faulting has not occurred there since Miocene time. In addition, lithologic units can be broadly correlated across White Rock Canyon in most of the quadrangle. Field evidence thus indicates that faulting has not produced major offset in the White Rock area since before middle Pliocene time. Buried faults, however, are probably present.

QUATERNARY EVOLUTION OF WHITE ROCK CANYON

Field data from White Rock Canyon suggest that a deep canyon was cut by the ancestral Rio Grande south of White Rock between middle Pliocene and early Pleistocene time and that the river cut the modern canyon sometime after eruption of the Bandelier Tuff (~1 Ma), perhaps during the middle Pleistocene (Reneau et al., 1995). The Rio Grande has cut canyons near its present location since at least late Pliocene time. Paleocanyons filled with palagonitic breccia demonstrate that the Rio Grande flowed at an elevation of less than 6,020 ft before tholeiitic flows entered a lake dammed in the canyon at about 2.4 Ma (Table 1). Field relations show that this ancestral canyon was at least 250 ft deep at White Rock but do not provide close estimates for the maximum depth of incision at this time. Exposures of the Bandelier Tuff in Chaquehui, Ancho, and Water Canyons fill a paleocanyon cut >120 m (>400 ft) through *Tcb*$_3$ flows (Reneau et al., 1995). The only outcrops of upper Bandelier Tuff east of the Rio Grande suggest that the ancestral White Rock Canyon was probably cut in colluvial debris to slightly less than 5,800 ft, when tuff flowed from the Valles caldera to the Rio Grande. If the canyon had been as deep as at present, significant amounts of tuff would not have reached southwestern Sagebrush Flats.

White Rock Canyon has been deepened by approximately 120 m (400 ft) since Bandelier time, but only sparse geologic evidence about the timing of canyon cutting is preserved locally. Patches of gravel rest on Bandelier Tuff in the White Rock area, suggesting that fluvial systems were active on the canyon rim before renewed downcutting. Elsewhere in the Española Basin (Dethier et al., 1988), rapid incision along the Rio Grande took place after about 620 ka, probably in response to climate change or regional uplift. Exposures and soil development in White Rock Canyon are consistent with cutting of the modern canyon in middle Pleistocene time, but terrace remnants are small and scattered. The highest fluvial terraces (*Qa*$_3$) preserved in the map area are approximately 46 m (150 ft) above the Rio Grande, are older than 50–60 ka (approximate age of the El Cajete tephra; Reneau et al., 1996), and are probably younger than about 300 ka, as suggested by cation ratios in rock varnish. Slumps stable since before ~60 ka have obliterated evidence about the timing of incision between about 1.1 Ma and middle Pleistocene time. Net incision during the past 60–300 ka has been approximately 46 m (150 ft), but downcutting was interrupted briefly by several separate episodes when slumps dammed the Rio Grande downstream from Water Canyon, and lacustrine sediment accumulated at least as far north as Otowi Bridge. The clearest evidence for the oldest of these episodes is exposed at the mouth of Cañada Ancha (Section E). Damming probably resulted from landslide activity after periods of rapid incision, perhaps during climatic episodes wetter than at present. Lacustrine sediment also records landslide activity and damming of the Rio Grande during several periods between 20 and 10 ka (Reneau et al., 1995).

TABLE 1—Ages of Pliocene stratigraphic units, White Rock quadrangle and adjacent areas. Samples 21 and 14 are from Dethier's DN–93 series, and samples 147c, 145c, 145a, 122, and 129 are from Dethier's D–85 series.

Rock unit (this report)	Age (Ma)	Method	Sample no.	Location	Reference
Tca	2.0±0.1	K–Ar	—	Cañada Ancha, Horcado Ranch quadrangle; 35°46.63'N 106°7.31'W	Manley (1976)
Tcb$_3$	2.33±0.08	$^{40}Ar/^{39}Ar$	21	Intersection of Los Alamos and Pueblo Canyons; 35°52.12'N 106°11.83'W	WoldeGabriel et al. (1996)
Tcb$_3$	2.46±0.03	$^{40}Ar/^{39}Ar$	147c	White Rock south of Buey Canyon; 35°49.61'N 106°10.99'W	WoldeGabriel et al. (1996)
Tcba	2.55±0.02	$^{40}Ar/^{39}Ar$	145c	Massive flow from La Mesita; 35°51.65'N 106°9.61'W	WoldeGabriel et al. (1996)
Tcba	2.57±0.02	$^{40}Ar/^{39}Ar$	145a	Otowi flow southwest of Otowi Bridge; 35°52.56'N 106°9.33'W (Puye quadrangle)	WoldeGabriel et al. (1996)
Tcb$_2$	2.49±0.03	$^{40}Ar/^{39}Ar$	122	South rim of Caja del Rio 35°48.13'N 106°8.33'W	WoldeGabriel et al. (1996)
Tcb$_2$	2.6±0.4	K–Ar	—	Ancho Canyon, 1 km (0.6 mi) upstream from Rio Grande; 35°46.50'N 106°13.48'W	Bachman and Mehnert (1978)
Tcbm	2.78±0.04	$^{40}Ar/^{39}Ar$	129	Chaquehui Canyon; 35°41.91'N 104°14.63'W	WoldeGabriel et al. (1996)
Tcb$_1$	2.50±0.04	$^{40}Ar/^{39}Ar$	14	Mouth of Water Canyon; 35°47.08'N 106°12.30'W	WoldeGabriel et al. (1996)
Ta	2.7±0.4	fission track	—	Cañada Ancha, Horcado Ranch quadrangle; 35°46.42'N 106°7.10'W	Manley (1976)
Tpt/Tp	2.9±0.5	fission track	—	Southeast corner of Santa Clara Reservation; 35°57.02'N 106°8.04'W	Manley (1976)

TABLE 2—Selected major-element analyses from the Cerros del Rio volcanic field, White Rock quadrangle. Total Fe is reported as Fe_2O_3; **and.** = andesite, **thol.** = tholeiite, **bas.** = basalt, **bas. and.** = basaltic andesite, **haw.** = hawaiite, **oli. thol.** = olivine tholeiite, and **na** = not analyzed. Analyses of samples 4 and 5 are from Aubele (1978), and analysis of sample 36 is from Baldridge (1979). Sample 1a is from Dethier's D–86 series; all other samples are from the author's D–85 series.

Sample no.	Tca and. 4	Tca and. 36	Tcb$_3$ thol. 131	Tcb$_3$ thol. 141	Tcba bas. 72d	Tcba bas. and. 147b	Tcba bas. and. 145c	Tcba bas. and. 139b	Tcb$_2$ haw. 1a	Tcb$_2$ haw. 122	Tcbm oli. thol. 129	Tcb$_1$ haw. 40	Tcb$_1$ haw. 104	Tcb$_1$ bas. and. 137	Tcbu haw. 5
SiO_2	60.09	64.12	50.03	52.04	52.85	52.65	53.23	58.78	51.57	50.48	49.29	49.79	50.34	55.06	50.18
TiO_2	0.78	0.75	1.49	1.51	1.72	1.53	1.53	0.95	1.49	1.52	1.44	1.61	1.67	1.46	0.93
Al_2O_3	16.92	16.20	16.38	16.42	15.12	17.39	15.52	16.43	16.73	16.21	16.12	16.59	16.87	18.08	15.61
Fe_2O_3	6.02	5.07	11.89	11.27	9.40	8.87	8.83	6.64	9.27	9.43	11.14	9.63	9.63	8.36	10.06
MnO	0.09	na	0.18	0.16	0.15	0.14	0.14	0.11	0.15	0.15	0.16	0.14	0.15	0.08	0.14
MgO	2.80	2.74	6.75	6.02	6.06	4.66	6.00	4.28	6.47	6.93	7.33	6.30	5.43	2.31	6.58
CaO	5.21	4.78	9.34	9.01	7.69	7.54	7.80	6.52	8.54	8.70	9.94	8.59	7.98	6.72	8.67
Na_2O	4.22	4.17	3.42	3.29	4.10	4.75	4.17	4.30	4.49	4.32	3.26	3.70	4.79	4.47	4.10
K_2O	2.60	2.83	0.88	1.14	2.64	2.10	2.44	2.10	1.92	1.78	0.88	1.75	1.76	2.15	1.72
P_2O_5	0.45	0.37	0.34	0.32	0.74	0.84	0.73	0.51	0.94	0.92	0.48	0.76	0.78	0.62	0.74
Total	99.18	101.03	100.70	101.18	100.47	100.47	100.39	100.62	101.57	100.44	100.04	98.86	99.40	99.31	98.73

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