The upper reaches of the Sierra Nevada auriferous gold channels, California and Nevada

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ABSTRACT

The world-famous Eocene "Auriferous Gravels" and overlying Oligocene rhyolitic ash-flow tuffs of northern California and adjacent northwestern Nevada lie unconformably on Mesozoic or Paleozoic basement rocks. These are overlain by volcanic deposits of the Miocene ancestral Cascade volcanic arc. The erosion surface above the pre-Tertiary rocks represents a considerable hiatus, 40–60 Ma, during which time Mesozoic arc volcanics were eroded away. The eroded material was transported west across the future Sierra Nevada to the Great Valley sequence of central and northern California. It is clear that the pre-tuff erosional surface had some relief, with a well-developed system of westward-flowing streams in broad paleovalleys in western Nevada and adjacent California. These streams headed in a central Nevada highland. Locally, in western Nevada, stream deposits are preserved in the central parts of these valleys below the rhyolitic ash-flow tuffs. In adjacent eastern California, the Oligocene ash-flow tuffs lie on the Auriferous Gravels. In some areas farther to the west, only Auriferous Gravels are found in the paleovalleys. The source calderas of the Oligocene outflow tuffs found in the paleovalleys are apparently all located to the east in western or central Nevada; there are no known sources for these Oligocene ash-flow tuffs in the Sierra Nevada. Recognition that ash-flow tuffs of western Nevada and eastern California can be tied to their Nevada source calderas, and that they were deposited mainly in paleovalleys makes it possible to trace the middle Tertiary rivers upstream from where their courses are better known in the western Sierra Nevada.

Most gold in the lower reaches of the Eocene paleovalleys was probably eroded from gold-bearing mesothermal quartz veins, both in the main Mother Lode and in scattered deposits as far east as Lake Tahoe and Quincy. Some of that gold was later reworked in channels contemporaneous with Miocene andesitic volcanism and was also eroded into the present streams that were first worked by the Forty-Niners. Some veins that were eroded to supply gold to Eocene rivers may have been completely eroded or their remnants are concealed beneath Miocene volcanic rocks. Some Eocene placer gold was eroded from polymetallic veins, particularly those associated with granitic intrusions and porphyry-copper-related mineralization. In northern California, Au-Cu-bearing veins in the vicinity of the Lights Creek Porphyry and in the nearby Genesee and Taylorsville Districts (eastern Plumas and Lassen Counties) are potential sources. Similar mineralization in the Meadow Lake District of Nevada County supplied some gold to paleoplacers of the Tertiary Yuba River. In Nevada, gold in the known paleoplacer deposits under Oligocene ash-flow tuffs (Yerington and Little Valley) probably was eroded from similar polymetallic Au-Cu (quartz-tourmaline)

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veins. Speculative upstream continuations of various branches of the Tertiary Yuba and American Rivers enter Nevada near the Fort Sage Mountains, Hallelujah Junction, Reno(?), Little Valley, and Hope Valley (via Echo Pass). One branch of the Little Valley channel can be speculatively traced to the vicinity of Yerington.

Key Words: Paleovalleys, Auriferous Gravels, ash-flow tuffs, calderas, placer gold, Sierra Nevada, Basin and Range, mesothermal gold-quartz veins, quartz-tourmaline-gold veins

INTRODUCTION

Within a few years after the discovery of placer gold at Sutter's Mill on the American River (between Auburn and Placerville), the Gold Rush miners recognized that gold could also be found in consolidated gravels that were located well above the present stream valleys. These gravels, commonly capped by somewhat younger rhyolitic or andesitic rocks, were being exploited by hydraulic mining as early as 1852, four years after gold discovery. As the miners and early geologists like Josiah Whitney (e.g., 1880) and Waldemar Lindgren (U.S. Geological Survey; e.g., 1897, 1911) began to work out the trends of these Tertiary paleochannels, they found them to be somewhat parallel to the present day southwest-flowing streams of the western Sierra Nevada (Fig. 1). These old river channels, such as the Tertiary Yuba River or the Tertiary American River (Fig. 2), are named after the modern streams that reach the Great Valley at the approximate points where the prevolcanic paleovalleys reached the sea (Bateman and Wahrhaftig, 1966, p. 134). The names reflect the thought that these old rivers flowed down a paleotopographic slope similar to the slope we see today. Lindgren and other early workers concluded that the streams that

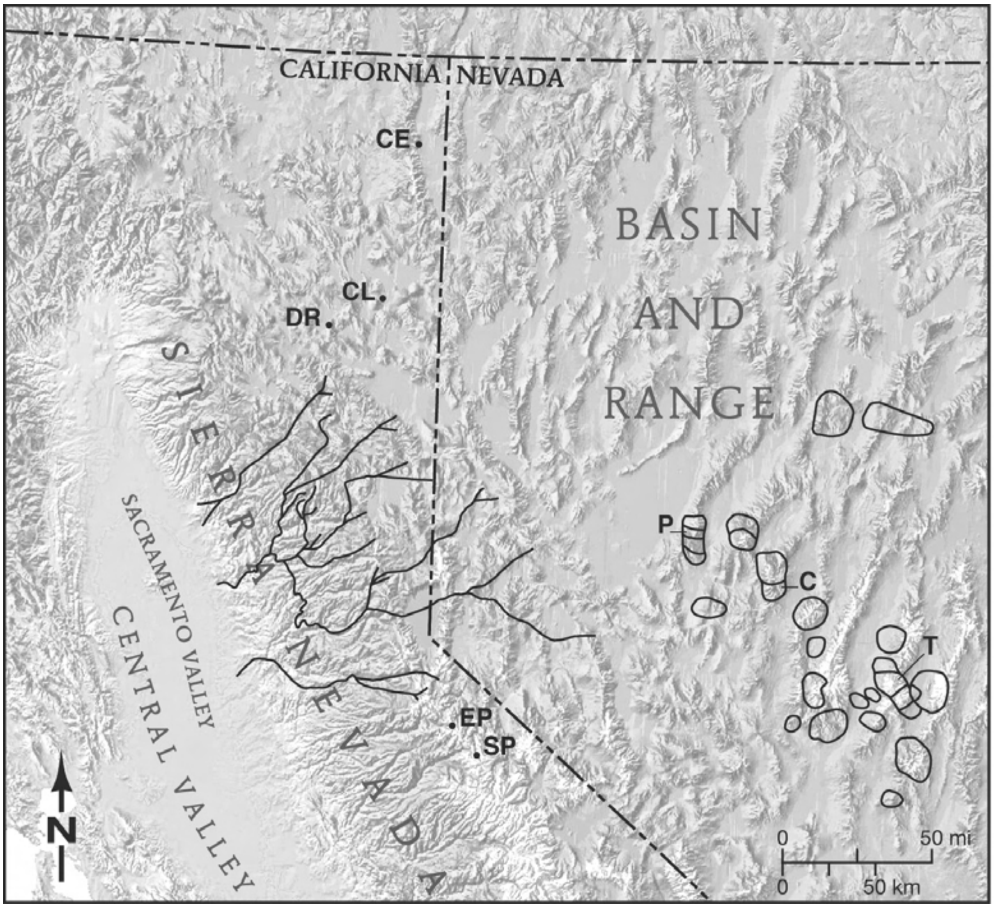

Fig. 1. Shaded relief overview map of northern California and western and central Nevada showing main topographic regions, Tertiary Yuba and American Rivers, and some central Nevada calderas. C, Campbell Creek caldera; CE, Cedarville; CL, Crest Lake Reservoir; DR Deans Ridge; EP, Ebbets Pass; P, Poco Canyon caldera; SP, Sonora Pass; T, Toquima caldera complex.

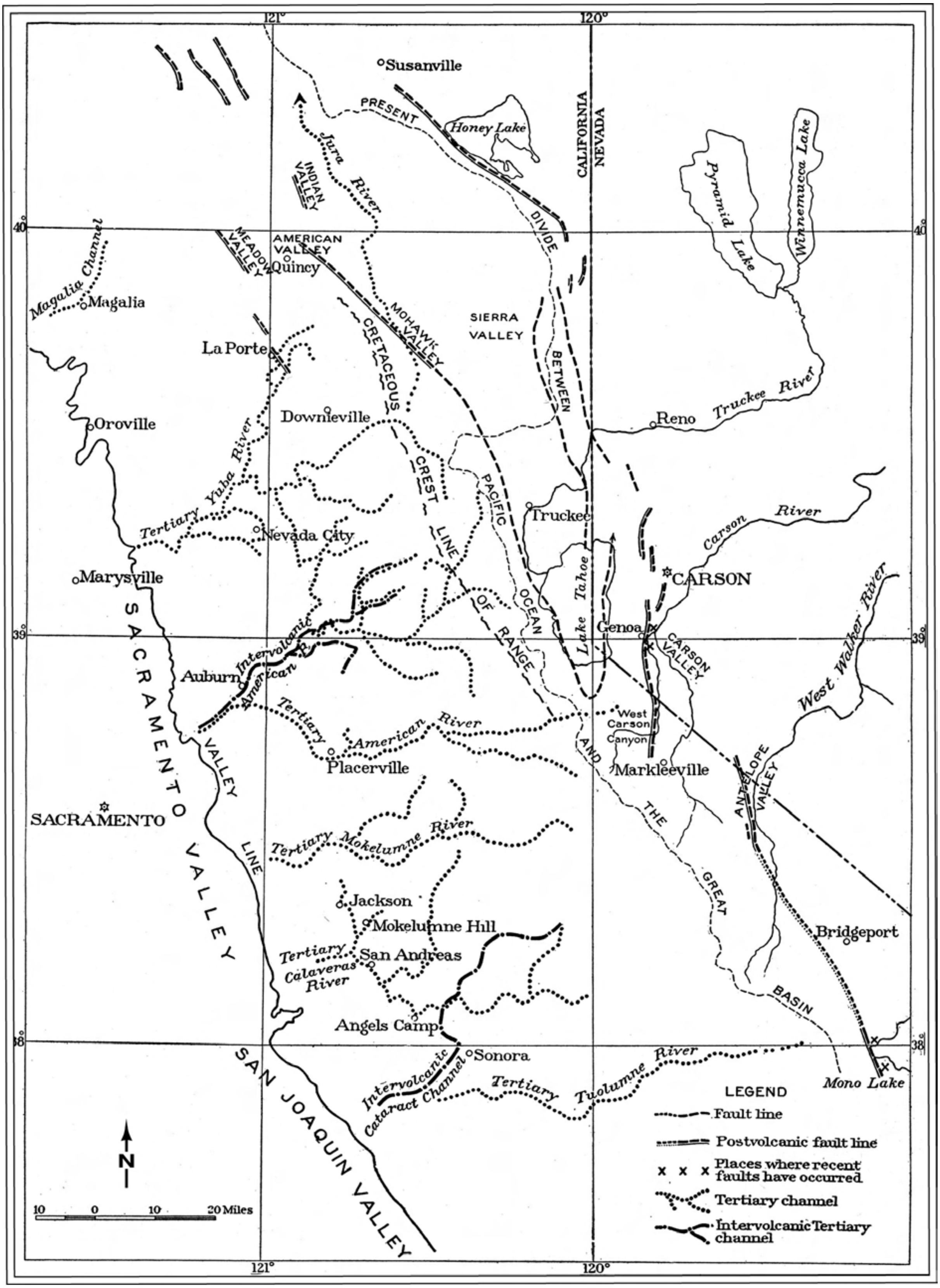

Fig. 2. Lindgren's (1911, Fig. 3) map of courses of Tertiary auriferous channels in the northern Sierra Nevada, illustrating his view that the paleovalleys headed west of the present Sierra crest. Note the postulated Jura River is east of that crest.

deposited the gold-bearing gravels had their headwaters no farther east than the present crest of the Sierra Nevada west of Lake Tahoe (Lindgren, 1911, p. 41; see Fig. 2).

Lindgren (1911, p. 44) recognized that the east margin of the Sierra Nevada was relatively uplifted with respect to the Basin and Range. It was his opinion that in the Cretaceous the site of the present Sierra Nevada was occupied by a low mountain range that had "a symmetrical structure," with an old crest line extending from southwest of Lake Tahoe to near Quincy (Lindgren, 1911, Plate 1; see Fig. 2). To quote Lindgren (1911, p. 37):

> Our knowledge of the Tertiary and pre-Tertiary physiography of the range is mainly confined to its western slope; the eastern slope has been so changed by orogenic movements, principally faulting, that it is difficult to draw a definite conclusion as to its topographic features, but it is probable that before the dislocations along the great fault system began the range had a rather long easterly slope corresponding to that on the west.

The high areas that Lindgren (1911) used to interpret the location of his proposed pre-Tertiary divide (e.g., Sierra Butte, Pyramid Peak) are now known to be high areas between broad, southwest-trending paleovalleys (Figs. 3,4).

Lindgren also concluded that the uplift of the Sierra Nevada and down-dropping of the Basin and Range began in the late Cretaceous. For these reasons, in his reconstruction of Eocene river channels, the stream courses started near this presumed crest line, which is somewhat east of the present divide. East of his presumed pre-Tertiary divide in northeastern California, Lindgren (1911) proposed a northerly flowing early Tertiary river, the Jura (Fig. 2), which headed near Haskell Peak and flowed to a marine or lacustrine delta in the Mountain Meadows area 25 km southwest of Susanville. In part, this reconstruction was based on work by J.S. Diller of the U.S Geological Survey (e.g., Diller, 1906). Later workers (e.g.,

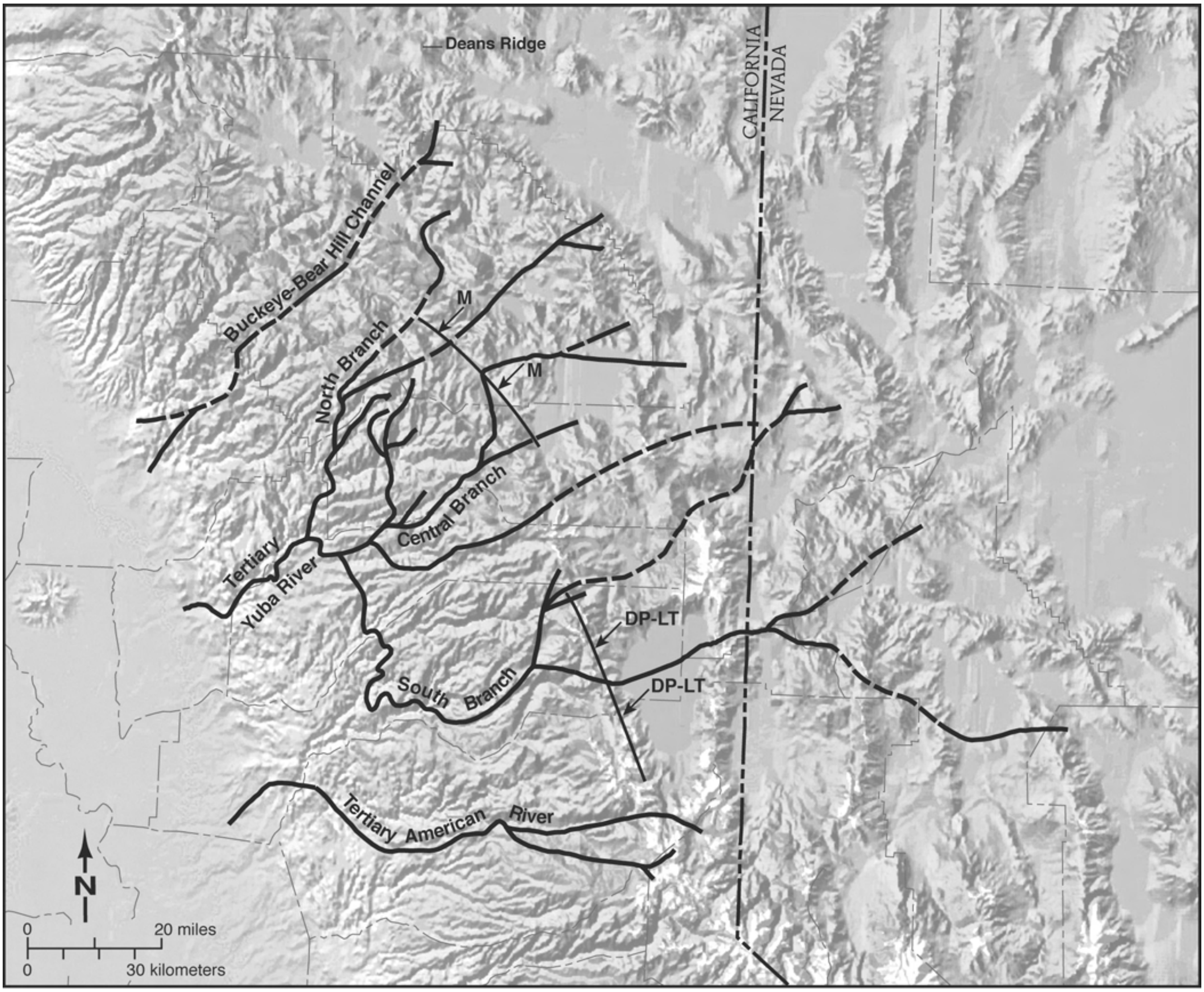

Fig. 3. Map of known and speculative Eocene-Oligocene paleovalleys of northern California and western Nevada on a shaded relief DEM base. Lower parts of channels from Lindgren (1911, Plate 1) and Lawler (1995). DP-LT, Donner Lake-Lake Tahoe fault; M, Mohawk Valley fault.

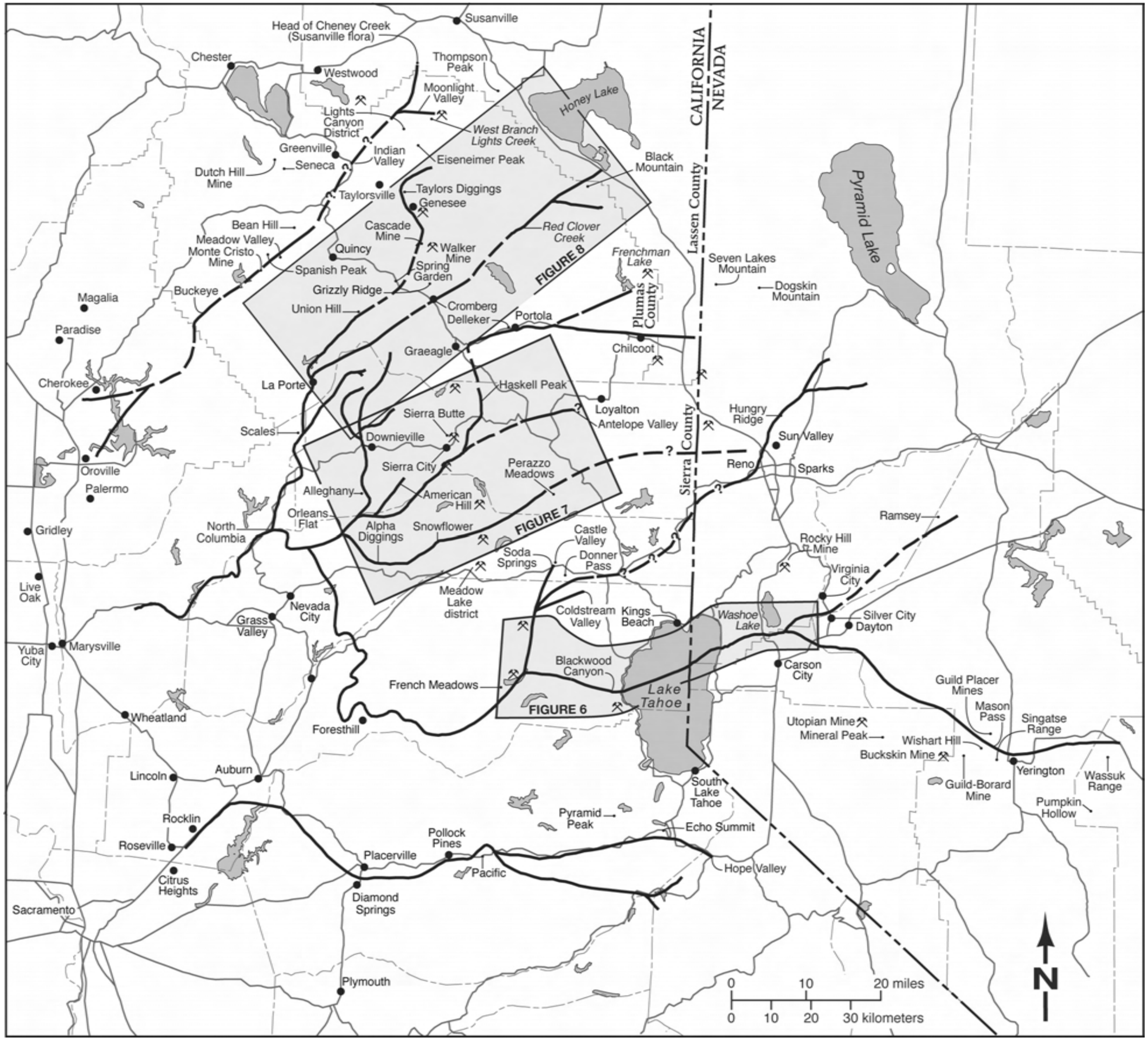

Fig. 4. Map of known and speculative Eocene-Oligocene paleovalleys of northern California and western Nevada, showing some places mentioned in text and the locations of more detailed figures. Lower parts of channels from Lindgren (1911, Plate 1) and Lawler (1995). Lines represent the general midcourse of the valleys and are dashed or queried in areas of uncertain projection. No consideration is given to Basin and Range extension. Mine symbols represent selected eastern California and western Nevada gold mines in pre-Tertiary rocks.

Jenkins, 1932; Clark, 1970) mainly followed Lindgren in their display of the channels. However, Durrell (1957) first reported that Eocene gravels in the Blairsden Quadrangle (the Cromberg area, Fig. 4) were deposited by streams that flowed southwest, and thus debunked the idea of the Jura River. Vernon McMath, a student of Cordell Durrell, also argued against it (McMath, 1958, p. 162–163) based on evidence from his geologic mapping in the Taylorsville area. As described later by Durrell (1966):

> Lindgren (1911) believed that the rivers had their headwaters in the present Sierra Nevada, and he thought that he knew where the divide was between the coastal and the interior drainage as far back as the Cretaceous. His conclusion requires that all of the channel filling, including the gold, originated within the range as we now know it. However, the size of the channels in the present summit region and the occurrence of cobbles of rocks foreign to the Sierra Nevada indicate that the streams headed far to the east. Thus the Jura River that was supposed to flow northwestward across Sierra and Plumas Counties in the summit region could not have existed. Furthermore, its course was drawn by linking occurrences of gravel of different ages and quite different petrologic characteristics.

Durrell also reported (1959a, p. 167) that the Auriferous Gravels at La Porte (30 km south of Quincy; Fig. 3) contained chert pebbles that must have come from Paleozoic rocks of central or northern Nevada; this conclusion would require that the upper part of the Eocene paleovalley at La Porte extended well into Nevada, and across the pre-Tertiary crest postulated by Lindgren. Durrell later speculated (1987) that the upper course of the northern branch of the Tertiary Yuba River continued northeast from La Porte, across the Mohawk Valley fault (Fig. 3), to Eocene gravel deposits to the east and north (Durrell, 1987, Fig. 80). This course was also shown by Bateman and Wahrhaftig (1966, Fig. 5). Durrell (1959 a, b; 1987) was in error, however, regarding the stratigraphic order of the Tertiary units above the Auriferous Gravels. He concluded that the Lovejoy Basalt, now known to be ~16 Ma (Page et al., 1995; Wagner et al., 2000), was the first unit deposited above the Auriferous Gravels; he also concluded, incorrectly, that a unit of andesite lahars was older than his Delleker Formation (now known to consist of Oligocene ash-flow tuffs). These errors were a direct result of the confounding relationships common to the paleovalleys, where younger stratigraphic units may have been deposited topographically below older ones in paleocanyons (see Wagner et al., 2000).

Yeend (1974) compared the Tertiary Yuba River to modern river systems in the Pacific States, and used a logarithmic relationship between drainage areas and stream gradients to estimate that it must have had a maximum drainage area of about 2000 square miles (5180 km^2). The gradient he used, 20–25 ft/mile (3.8–4.7 m/km), was based on his and Lindgren's (1911) work. Using a logarithmic relationship between stream length and drainage area (Leopold et al., 1964, p. 145) Yeend estimated that the maximum attained length of the Tertiary Yuba River (along its watercourse) was 150 miles (240 km), placing the headwaters in western Nevada. However, these graphical calculations are highly sensitive to the gradient selected; for example, a gradient of 9–17 ft/mile (1.70–3.22 m/km; ave. 13 ft/mile or 2.46 m/km; Jones et al., 2004) would yield a maximum stream course length nearly twice that calculated by Yeend (1974). Black chert pebbles at the base of andesites near Ebbetts Pass and a few miles south of Sonora Pass (Fig. 1) were most likely derived from chert-bearing Paleozoic rocks in western Nevada. This indicates that the crest of the Eocene range was farther east than the present Sierra Nevada (Bateman and Wahrhaftig, 1966, p. 139). Black-chert-bearing Paleozoic rocks, such as the Ordovician Palmetto Formation, crop out today over 110 km east of Sonora Pass (e.g., Stewart et al., 1982).

Lindgren recognized that the unit he referred to as rhyolite contained some pyroclastic component, but he interpreted the massive units as lava flows. The pyroclastic nature of most ash-flow tuffs was not recognized by most U.S. geologists until the middle twentieth century. The rhyolites described by Lindgren in his California folios of the Geologic Atlas of the United States overlie the prevolcanic Auriferous Gravels that were originally deposited only in the valleys occupied by the gravels. He reported (1897) that "Rhyolite … flowed down the valleys of the Neocene range but did not cover the whole slope. …Somewhat extensive areas of rhyolite occur on the western slope of the main range, and indicate quite accurately the principal Neocene valleys." However, Lindgren did conclude that the sources of the rhyolites (as well as the heads of the middle Tertiary rivers), were near the present crest of the Sierra Nevada. The presence in the paleovalleys of distinctive ash-flow tuffs from central Nevada calderas (Garside et al., 2002) confirms that the Sierra Nevada was not present as a barrier in the Oligocene and indicates a sloping surface, probably from a central Nevada highland.

The valley-filling nature of the rhyolitic ash-flow tuffs of eastern California (the Valley Springs Formation) was also recognized by Bateman and Wahrhaftig (1966), who reported that "they filled narrow valleys in a landscape whose relief was more than 1000 ft and formed a continuous sheet only in the Great Valley." However, Slemmons (1966, Fig. 2) implied that the ash-flow tuffs were once a relatively continuous sheet, although he stated that "there may have been several areas of nondeposition between some of the southwest-trending channels of maximal thickness." In the northern Sierra Nevada, the correlative tuffs (Delleker Formation) were thought to be younger than some of the andesite flows and lahars (Durrell, 1966). Durrell (1966) also concluded that "the rhyolite tuff was no doubt deposited as a sheet over the region, but is now discontinuous and present often only in very small areas."

Isotopic age determinations reported in the following are based on the most recent constants; ages based on older constants (used prior to about 1976) have been converted (see Dalrymple, 1979).

GEOLOGY

During the Late Cretaceous and early Tertiary (ca. 80–30 Ma) several kilometers of upper crust were eroded from a large area of western North America. The erosion surface above the pre-Tertiary rocks represents a considerable hiatus, 40–60 million years, during which time Mesozoic volcanic cover, developed along a magmatic arc of that age, as well as older igneous and metamorphic rocks were eroded away. The eroded material was transported west across the area of the later-developed Sierra Nevada to the Great Valley sequence of central and northern California (Miller et al., 1992). Streams that effected this erosion drained from a highland in central or eastern Nevada toward a marine basin in the area of the present Central Valley (Yeend, 1974; Miller et al., 1992; Wolfe et al., 1997). These streams apparently flowed in broad paleovalleys developed on the basement. This highland, which may have developed as a result of Mesozoic compressional tectonics (Coney and Harms, 1984) might have had an early Tertiary elevation of more than 3 km, similar to the modern Tibetan Plateau (Dilek and Moores, 1999).

The Tertiary paleochannels of the Sierra Nevada contain Paleocene(?) and Eocene gravels (commonly referred to as Auriferous Gravels) that are gold rich, particularly in the basal part. A late early Eocene fossil flora is found in clay beds above the oldest auriferous gravels (MacGinitie, 1941; Yeend, 1974), and the gravels are overlain by Oligocene rhyolitic ash-flow tuffs from Nevada calderas that are as old as 30–31 Ma (Deino, 1985; Saucedo and Wagner, 1992; Garside et al., 2002; Brooks et al., 2003; Fig. 1). Biotite from a volcanic tuff that lies just above the gold-bearing gravel section at North Columbia (east-northeast of Grass Valley; Fig. 4) was dated by K-Ar methods at 38.9±1 Ma (late Eocene; Yeend, 1974, p. 15). The source of this tuff is unknown. A decomposed, intermediate-composition tuff (altered to clay) from near the base of the Auriferous Gravels in the San Juan Ridge Mine (in the vicinity of North Columbia, Fig. 4; see Pease and Watters, 1996) was reported to be 45 Ma, "based on absolute age dating" (Pease, 1997). A leaf-bearing waterlaid dacitic tuff that overlies Auriferous Gravels disconformably(?) at LaPorte (Fig. 4) was dated at 33.3 Ma (Dalrymple (1964, p. 14). These Eocene and earliest Oligocene tuffs within and above the Auriferous Gravels may have northern California sources in the Eocene Clarno volcanic arc (Walker and Robinson, 1990; White and Robinson, 1992; Myers, 1998, p. 11). The paucity of modern age determinations on the Auriferous Gravels limits our present understanding of the unit.

The Oligocene ash-flow tuffs stratigraphically above the Auriferous Gravels filled the valleys and locally covered parts of the surrounding higher ground as well. Individual ash-flow tuffs were thicker in the channels and thus became more strongly welded there, producing a surface that was somewhat lower directly above the pre-tuff channels. Thus, subsequent erosion produced streams that commonly followed rather closely the original, pre-tuff drainages (e.g., Davis et al., 2000). The deposition of ash-flow tuffs and inter-tuff gravels continued until about 24 Ma. The inter-tuff channels are commonly considerably lower in gold content, but are enriched in gold where they cut older gold-rich gravels. Where the Oligocene rhyolitic ash-flow tuffs were deposited in paleovalleys, they are overlain by a great thickness of andesitic volcanic rocks of the ancestral Cascades (generated by subduction of the Juan de Fuca plate beneath North America), mainly 14–4 Ma in the northern and central Sierra Nevada (Mehrten Formation) and 22–6 Ma in western Nevada. These andesitic flows and lahars also filled the paleovalleys, eventually choking them completely and requiring a new drainage system, the modern one, to develop. This drainage system cut down through and exposed the early Tertiary Auriferous Gravels for eventual exploitation. This down cutting apparently resulted from uplift of the Sierra Nevada during the last 3–5 million years (Wakabayashi and Sawyer, 2001; Jones et al., 2004).

Locally, in western Nevada, stream deposits are preserved in the central parts of paleovalleys below the rhyolitic ash-flow tuffs (Davis et al., 2000; Henry et al., 2004; Hinz, 2004). In at least one area, hornblende andesite is found below the lowest ash-flow tuff. In adjacent eastern California, Oligocene ash-flow tuffs lie on the Auriferous Gravels; farther west, the distal, less-welded remnants of the tuffs and associated inter-tuff gravels are found in paleovalleys (e.g., the Valley Springs Formation; Piper et al., 1939, Plate 5) on the Auriferous Gravels or their deltaic and lagoonal lowland equivalent, the Ione Formation. There are no known sources for these Oligocene ash-flow tuffs in the Sierra Nevada.

Where the courses of the paleovalleys are well exposed and studied, the gradients of various reaches can be determined (Lindgren, 1911, p. 44, Plate 10). Because the Sierra Nevada has been uplifted, probably by westward tilt of a rigid slab (Wakabayashi and Sawyer, 2001) about an axis roughly parallel to the range, the present gradients of the paleovalleys have increased. The maximum increase is along reaches perpendicular to the tilt axis. Lindgren (1911) used the difference in paleovalley gradients between reaches parallel and perpendicular to the Sierra Nevada to estimate that the 90–100 ft/mile (~17–19 m/km) present gradients have been tilted about 60–80 ft/mile (~11–15 m/km) from an original gradient of about 20 ft/mile (3.8 m/km). A more recent and rigorous calculation (Jones et al., 2004) had a similar finding, indicating that the ancestral Yuba River flowed at a mean grade of 1.7–3.3 m/km (9–17 ft/mile or ~0.1–0.2 degree).

GOLD

Most gold and the milky vein quartz clasts in the lower reaches of the Eocene paleovalleys were probably eroded from gold-bearing mesothermal quartz veins of considerable vertical extent, both in the main Mother Lode (generally south of Placerville), the Grass Valley district, and deposits farther east. Significant pre-Tertiary lode gold deposits in northern California (including the mesothermal veins) are concentrated west of a line from the Meadow Lake district to Genesee (see Clark, 1970, Fig. 3), although scattered deposits are found farther east, into western Nevada (Fig. 4). Diggles et al. (1997, Fig. 18.1) suggested that the area permissible for low-sulfide gold-quartz deposits (mesothermal quartz veins) extends as far east as a line between Susanville and a few kilometers west of Lake Tahoe. It was recognized more than 100 years ago that the gold-quartz veins of the Sierra Nevada were found in the so-called "auriferous slates," associated greenstones, and schists (e.g., Lindgren, 1897). In areas east of metamorphic quartz veins and the auriferous slates (particularly the Shoo Fly Complex), the Auriferous Gravels are poor in milky vein-quartz clasts, whereas such clasts make up a significant part of gravels in areas of Shoo Fly and metamorphic quartz veins. Some of the gold from the Auriferous Gravels was later reworked into Miocene channels and eventually into the present streams. Some veins that were eroded to supply gold to Eocene rivers may have been completely eroded or their remnants are concealed beneath andesitic volcanic rocks of the ancestral Cascade arc.

Some paleoplacer gold was probably derived from porphyry-copper-related mineralization, particularly in areas upstream of significant mesothermal quartz veins. Examples of such mineralization include the gold- and silver-bearing, bornite±chalcopyrite±toumaline veins in the vicinity of the Lights Creek Porphyry (Lights Canyon district; Putman, 1975; McFarlane, 1981; Storey, 1978; Diggles et al., 1997), in the nearby Genesee and Taylorsville districts (eastern Plumas County; California; MacBoyle, 1920a), and at the Meadow Lake mining district (Lindgren, 1893; Doebrich et al., 1996, p. 54; Fig. 4). The vein at the Walker Copper Mine (Fig. 4), for example, is reported to average approximately 0.05 oz Au/ton (1.7 gm/t; (MacBoyle, 1920 a). Trace amounts of gold are associated with narrow quartz veins containing chalcopyrite and bornite in the Lights Creek and Moonlight Valley area, and prospects north of Genesee Valley are reported to contain minor gold with pyrite (Smith, 1970).

Where placer gold is known from gravels in paleovalleys in western Nevada, the source(s) are speculative. Also, large areas of pre-Oligocene rocks that might contain potential gold sources are covered by later Tertiary rocks or buried in fault-block valleys. At Little Valley, east of Lake Tahoe (Fig. 4), where placer gold deposits are found below 27 Ma ash-flow tuffs (Reid, 1908; Davis et al., 2000), the 1–10(?) mm gold grains must have come from deposits farther to the east that were eroded in the Oligocene or earlier. One type of mineralization that could have produced gold for western Nevada paleoplacer deposits is Cu-Au quartz-tourmaline veins (e.g., Doebrich et al., 1996) and similar mineralization commonly found at the periphery of porphyry copper deposits. Several Mesozoic quartz-tourmaline veins that are probably gold-bearing cut metaigneous rocks near Silver City (Gianella, 1936, p. 39, 88), west of McClellan Peak (Hudson et al., 2003; D.M. Hudson, oral commun., 2004), and at the Rocky Hill Mine (Pleasant Valley) (Overton, 1947, p. 64; Doebrich et al., 1996). Additionally, similar pre-Tertiary gold-bearing mineralization is present in the Mineral Peak area between Carson City and Yerington (e.g., Utopian Mine; Doebrich et al., 1996, p. 102), and in a Mesozoic Cu-Au vein at the Buckskin Mine west of Yerington (Fig. 4). Placer gold deposits are also associated with pre-tuff gravel in the Yerington District (e.g., Penrose, 1937). The source of gold for paleoplacers in the Yerington District is probably Cu-Au-bearing veins peripheral to the Yerington Batholith. Gold is also found in late stage Fe oxide-Cu-Au replacement deposits (e.g., the Lyon deposit in the Pumpkin Hollow area east of Yerington; Dilles et al., 2000)

PALEOCHANNEL ROUTES

This report documents continuations of paleochannels eastward beyond their long established lower parts in the central and western Sierra Nevada. The lower courses of most paleochannels have been known since the early twentieth century; as shown on Figure 3, they were taken from Lindgren (1911, Plate 1) and Lawler (1995). Paleovalleys deduced from this study are above La Porte and Hepsidam on the northern branch of the Tertiary Yuba River, above Graniteville and Diamond Creek on the central branch, and above French Meadows and Donner Pass on the southern branch (Fig. 4). For more information on the lower parts of the channels see Lindgren (1911), Yeend (1974), and Lawler (1995). The detailed descriptions below are an attempt to describe new and previously published evidence for the most probable paleovalley routes from the areas where they are best known into western Nevada. More detailed data on localities examined for this study, including those described below, are available at: ftp://comstock.nbmg.unr.edu/pub/dix/paleochannel/Lead_web_page.htm.

SOUTHERN BRANCH OF THE TERTIARY YUBA RIVER

French Meadow-Blackwood Canyon-Little Valley-Virginia Range-Yerington

Lindgren (1911, Plate 1) showed the Eocene channels west of Lake Tahoe and Truckee as being the upper parts of a southern fork of the Tertiary Yuba River (Fig. 2). He recognized (1897) that the rhyolites (today known to be ash-flow tuffs) commonly marked the upper courses of the paleovalleys. This is certainly true in the upper reaches of the paleovalleys west of Lake Tahoe (Figs. 5a, 6). Auriferous Gravels were found by prospecting shafts under the rhyolites in the vicinity of French Meadows (Lindgren, 1897). These prospects are apparently located near the north end of the present French Meadow Reservoir (Lindgren, 1897, Economic Geology Map; Loyd, 1995). Lindgren (1911, p. 161) described the course of the paleoriver as heading near Barker Pass and passing through Five Lakes Creek on its way to Grayhorse Valley and the head of Long Canyon. Based on the outcrops of Oligocene ash-flow

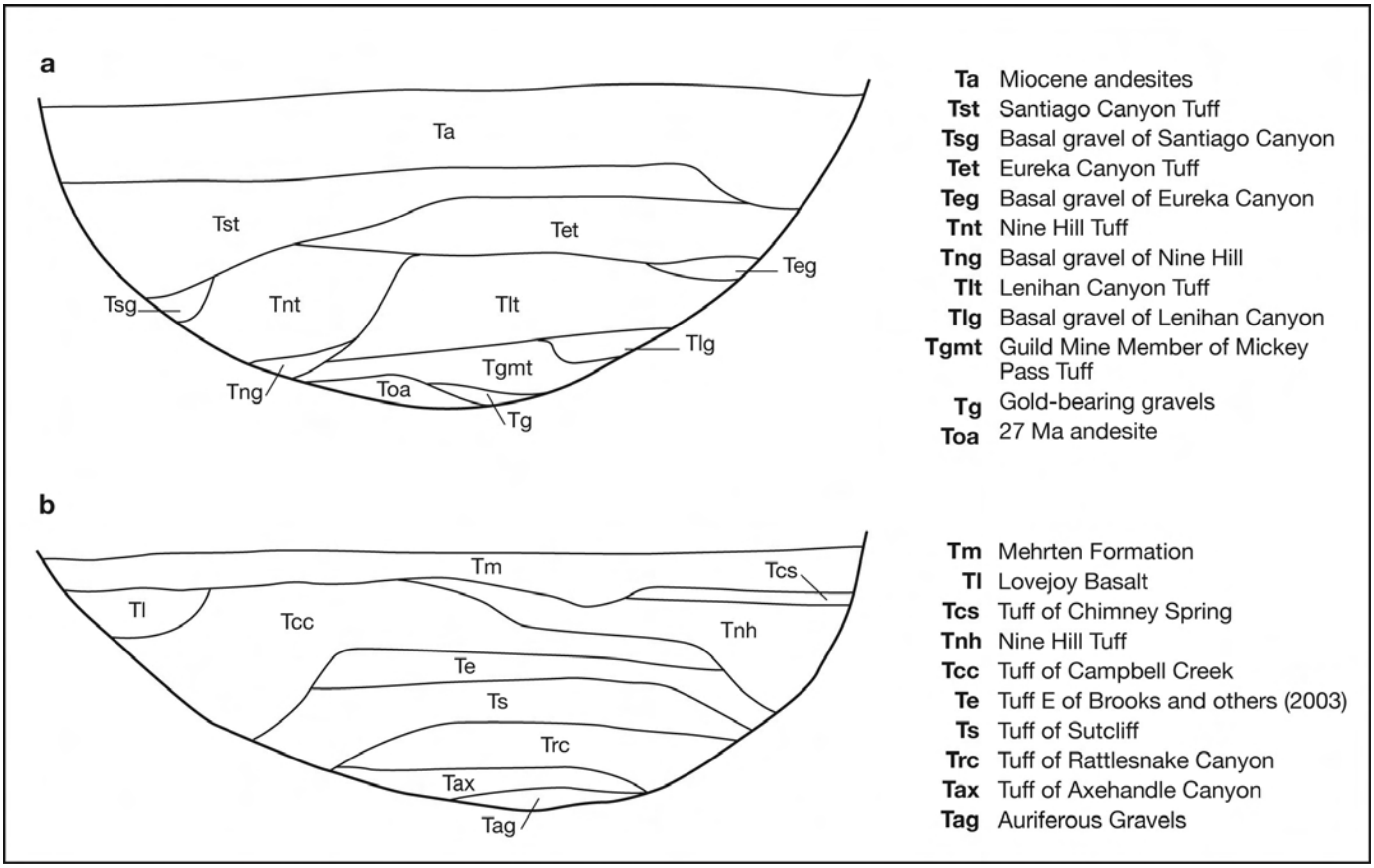

Fig. 5. a. Composite diagrammatic cross section of paleovalley, Virginia City-Lake Tahoe, showing relationships of Oligocene andesite flow breccia, Oligocene-Miocene ash-flow tuffs and underlying gravels, and Miocene andesites. b. Composite diagrammatic cross section of northern California paleovalley, showing relationships of Auriferous Gravel, Oligocene ash-flow tuffs, and Miocene basaltic and andesitic rocks. One or more Tertiary units may be present at a single paleovalley site. At Haskell Peak, gravels underlie most tuffs (Brooks et al., 2003).

tuffs and their elevation with respect to underlying pre-Tertiary rocks, we project the apparent course of a Tertiary channel east of the French Meadow gravels to pass across Grayhorse Valley, where more ash-flow tuffs are exposed (Fig. 6). Farther east, Miocene andesite flows fill a paleovalley that extends still farther east, across one or more strands of the Donner Pass-Lake Tahoe fault (Fig. 3, 6) (Henry and Perkins, 2001), slightly north of Barker Pass, to the Blackwood Canyon area and the west margin of the Lake Tahoe graben. This paleovalley has been extended eastward across Lake Tahoe into Nevada, to the Marlette Peak-Little Valley area where gold-bearing gravels underlie the same ash-flow tuffs seen in Grayhorse Valley (Davis et al., 2000). Farther east, ash-flow tuffs and gravels are found in paleocanyons at the south end of the Virginia Range (Hudson et al., 2003).

Ash-flow tuff distributions demonstrate the continuity of this paleovalley into the Sierra Nevada from at least as far east as Yerington, Nevada (Figs. 3, 7; Table 1). The Guild Mine Member of the Mickey Pass Tuff is the oldest of at least five major tuffs recognized in the southern branch of the ancestral Yuba River (Figs. 3, 5a). From geologic mapping, petrographic studies, and ^{40}Ar/^{39}Ar dating, we correlate the Guild Mine from the Sierra Nevada near French Meadow Reservoir across the Carson Range, eastward through Yerington, and then to a source caldera in the Toquima Range near Round Mountain, Nevada (Garside et al., 2002; Fig. 1). The equivalent intracaldera tuff was called the lower tuff of Mount Jefferson and identified as one of the most voluminous ash-flow eruptions from the Toquima caldera complex (Boden, 1992; Henry et al., 1996). ^{40}Ar/^{39}Ar dates on intracaldera tuff in the Toquima Range and Guild Mine at Yerington and Nine Hill of 27.07, 27.12, and 27.11 Ma (Henry et al., 1996; Garside et al., 2002; Table 2), respectively, illustrate the correlation. Outcrops of the Guild Mine Member near French Meadow Reservoir are ~300 km west of the caldera complex. Even allowing for an unlikely maximum of 100 percent extension in the Basin and Range part of the flow path, the Guild Mine flowed ~200 km from its source. This great flow distance probably reflects the large volume of the tuff and the concentration of flow in the paleovalley.

Lake Tahoe Graben—The route of the paleovalley across Lake Tahoe is entirely in the subsurface. However, based on the presence of the same ash-flow tuffs in a paleovalley at Marlette Peak to the east and Grayhorse Valley to the west, the connection can be made with some confidence.

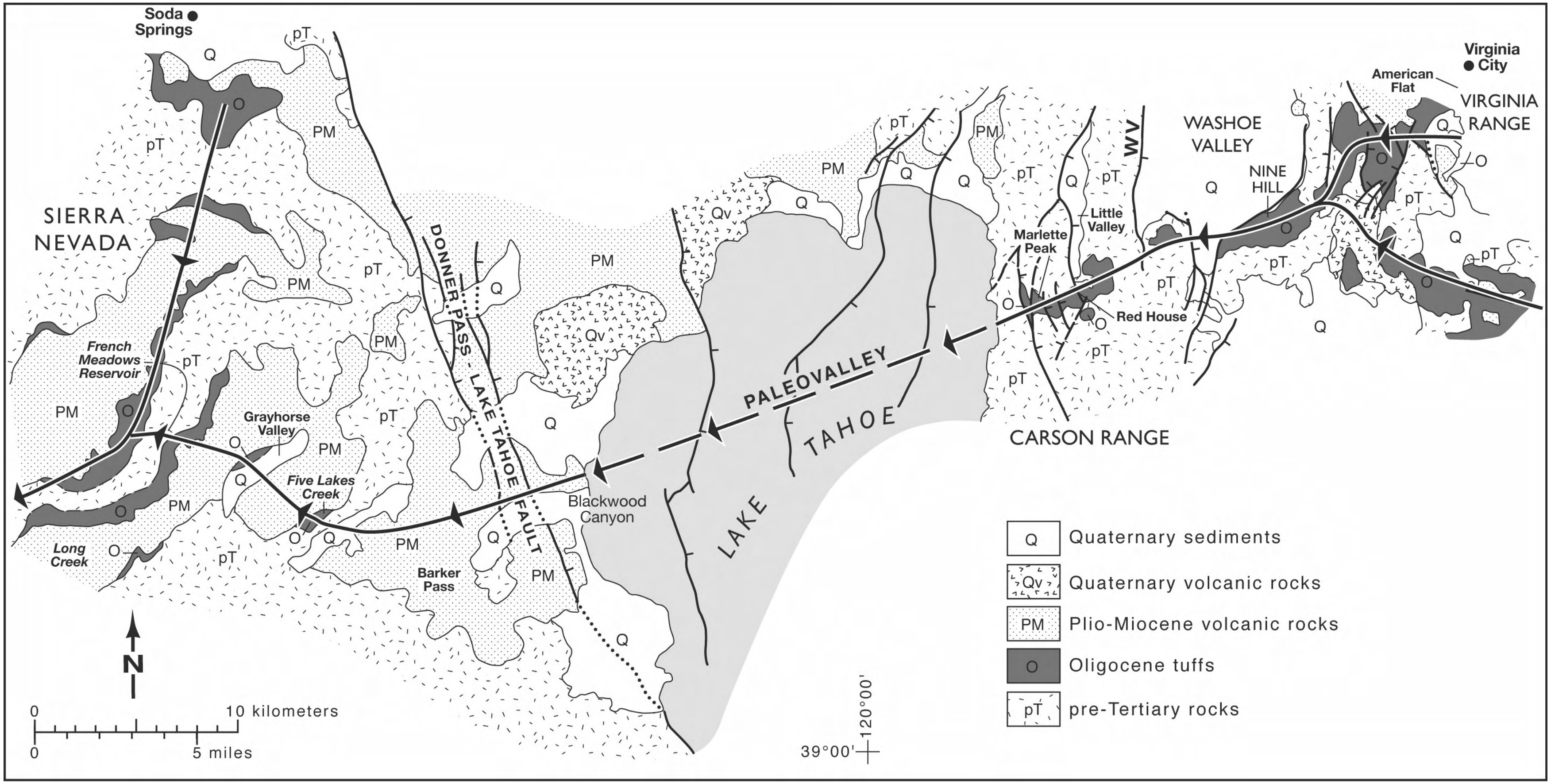

Fig. 6. Geologic map of a part of the middle Tertiary paleovalley between French Meadows, California, and the Virginia Range, Nevada. Contacts generalized and slightly modified from Saucedo and Wagner (1992) and Stewart (1999). Map location shown on Figure 4.

TABLE 1. ROCK UNITS PRESENT AT CALIFORNIA AND NEVADA PALEOVALLEY SITES.

Locality	Older andesite/ basalt	Pre-tuff gravel	Oligocene ash-flow tuffs	Lovejoy Basalt	Miocene andesite	Interandesite gravel	References
French Meadows		X	X		X		this study; Davis et al., 2000
Little Valley	X	X	X				this study; Davis et al., 2000
Virginia Range		X	X		X		this study; Hudson et al., 2003
Yerington	X	X	X				this study
Soda Springs/Donner Pass			X		X		this study
Reno area			X		X		this study; Garside et al., 2004
Hungry Ridge/Warm Springs Valley		X	X		X		this study; Garside et al., 2004
Alpha/Omega		X	X		X		this study
Snowflower Mine		X					Loyd and Clinkenbeard, 1990
Perazzo Meadows/Weber Lake			X		X		this study
Graniteville			X		X		Saucedo and Wagner, 1992
Hilda/1001/Pride Mines		X	X		X		this study; Saucedo and Wagner, 1992
Haskell Peak		X	X		X		Brooks et al., 2003; this study
NE of Graeagle			X		X		this study
Delleker			X		X	X	this study
Seven Lakes/Dogskin Mts		X	X		X		Henry et al., 2004; this study
Satley			X		X		this study
Antelope Valley			X		X		this study; Young and Cluer, 1992
American Hill		X			X		Saucedo and Wagner, 1992
Craycroft/Wide Awake		X			X		Bergquist et al., 1986
Fir Cap		X			X		Bergquist et al., 1986
Tenessee/Gibralter Mines		X			X		Bergquist et al., 1986
California Mine		X			X		Bergquist et al., 1986
LaPorte		X	?	X	X		this study; MacGintie, 1941
Bunker Hill Mine		X			X		this study
Cromberg area		X			X		this study
Red Clover Creek			X	X	X		this study; Wagner et al., 2000
Black Mountain			X		X		Hinz et al., 2003; this study
Feather Fork Mine		X		X	X		this study
Richmond Hill		X		X	X		this study; Turner, 1897
Sawpit		?		X	X		this study
Union Hill		X			X		this study
Spring Garden		?		X	X	X	this study; Sheeks, 1977
Cascade Mine		X		X	X		this study; Durrell, 1987
Wards/Peale Diggings		X					this study; McMath, 1958
Taylor Diggings		X			X		this study
Hull Diggings		?			X	X	this study
Cherokee/Oroville		X		X			Creely, 1965
Buckeye		X		X			this study; Durrell, 1959
Monte Cristo Mine					X	X	this study
Bean Hill		X			X		this study; Hietanen, 1973
Moonlight Valley		X					this study; McFarlane, 1981
Head of Cheney Cr		X			X	X	this study; Diller, 1908
Deans Ridge		?			X	X	this study; Grose et al., 1992
Crest Lake Reservoir						?	this study; Grose, pers. commun.

TABLE 2. PALEOSTREAM GRADIENTS ALONG SOME PALEOVALLEY REACHES.

Downstream	Elev. (ft)	Upstream	Elev. (ft)	Distance (mi)	Gradient (ft/mi)	Direction	References
Southern Branch of Tertiary Yuba River							
French Meadows	5100	Marlette Peak	8060	28.5	104	WSW	this study
Below French	5050	Marlette Peak	8060	30.5	99	WSW	this study
Below French	5050	Blackwood Creek	6400	15	90	W, NW	this study
Russian Ravine	4450	French Meadow	5050	6	100	WSW?	Lindgren, 1911, Plate 10
Central Branch							
Alpha	3852	Omega	4028	1.3	135	W	Lindgren, 1911, p. 147
Omega	4028	Diamond Cr	4206	2	89	W	Lindgren, 1911, p. 147
Alpha	3852	Diamond Cr	4206	3.3	107	W	Lindgren, 1911, p. 147
Alpha	3940	Diamond Cr	4190	3.3	75	W	this study
Omega	3980	Diamond Cr	4190	2	105	W	this study
Alpha	3940	Snowflower	5600?	8.1	204	SW	this study, Loyd and Clinkenbeard, 1990
Clinkenbeard, 1990							
Diamond Cr	4190	Snowflower	5600?	5.2	271	SW	this study, Loyd and Clinkenbeard, 1990
Clinkenbeard, 1990							
Snowflower	5600?	Weber L	6600	15	66	SW	this study, Loyd and Clinkenbeard, 1990
Clinkenbeard, 1990							
Diamond Cr	4190	Weber L	6600	20.2	119	SW	this study
Northern Branch	5850						
Gibsonville	5420	Hepsidam	6000	3	193	SW	Lindgren, 1911, Plate 10
Feather Fork	5130	Richmond Hill	5800	2.7	268	SW	this study
Feather Fork	5130	Union Hill	6400	3.9	325	SW	this study
Oroville/Buckeye							
Oroville	600	Buckeye	4800	24	175	SW	this study

Lindgren (1911, p. 160) reported that a 400-foot (122 m) inclined shaft sunk 4 miles (6.4 km) north of French Meadows bottomed in gravel below the Tertiary rhyolite (ash-flow tuff). The gravel was not exposed. An estimate of the subsurface elevation along the profile of the Tertiary channel in the vicinity of the inclined shaft is approximately 5100 ft (1554 m). Lindgren (1911, Plate 10) showed the elevation along a profile of the Tertiary channel at French Meadows (apparently 4 miles downstream from the shaft) to be 5050 ft (see Table 3). A branch of this Tertiary channel is found east of French Meadows, through Grayhorse Valley, to cross Lake Tahoe from the Blackwood Canyon area on the west side, to just north of Marlette Lake, on the east side (Fig. 6), where gravel lies on granitic bedrock at an elevation of about 8060 ft (2457 m) west of the Marlette Lake fault (Grose, 1986; Fig. 6). The course of the Tertiary River from the north end of French Meadows Reservoir to Marlette Lake rises from 5100 to 8060 ft (1554 to 2457 m), a change in elevation of 2960 ft (902 m) in about 28.5 miles (45.9 km). This is a gradient of ~104 ft/mile (19.7 m/km). If the 5050 ft (1539 m) elevation of the channel bottom is used for the French Meadows locality, the course of the paleovalley is about 30.5 miles (49.1 km) and the change in elevation is 3010 ft (917 m), for a gradient of ~99 ft/mile (18.8 m/km). The projected paleovalley crosses the Donner Lake fault in the vicinity of Blackwood Creek (Fig. 6), where the elevation of the base of the channel has been estimated to be about 6400 ft (1950 m; Davis et al., 2000). The gradient along the 15-mile (24.1 km) paleochannel segment from the French Meadows paleoelevation of 5050 ft (1539 m) to the Blackwood Creek site at 6400 ft (1951 m) is 90 ft/mile (17 m/km). Lindgren (1911, Plate 10) reported similar gradients of approximately 100 ft/mile (18.9 m/km) for the channel downstream from French Meadows and other Tertiary paleovalleys in the higher parts of the Sierra Nevada. Thus, the calculated gradient across Lake Tahoe is similar to that of a section west of Basin and Range faulting, and to other calculated gradients of the Tertiary paleovalleys.

These stream gradients are not original, as the Sierra Nevada crest has been uplifted by westward tilting, possibly 1700–1900 m in the past 3–5 million years (e.g., Wakabayashi and Sawyer, 2001). However, the gradients can be used to estimate fault offsets. The course of the paleovalley in the Marlette Lake area appears to be subhorizontal, and certainly not tilted more than about 10°W (Grose, 1986). The immediate inference that can be made from the French Meadows-Marlette Peak channel gradient is that the Carson Range east of Lake Tahoe has not been displaced vertically relative to the unfaulted Sierra Nevada west of Lake Tahoe. Thus, Lake Tahoe must occupy a graben, with the blocks on either side not displaced with respect

TABLE 3. ^{40}Ar/^{39}Ar AGE DATA, PALEOVALLEY FROM CARSON RANGE TO YERINGTON, NEVADA PALEOVALLEY.

Sample	Rock	W Long	N Lat	Mineral method	Age	%^{39}Ar (Ma)	Age	±1σ	Location	isochron	±1σ	40/36	±1σ	mswd	total gas	±1σ
H00-156	hornblende andesite	119° 51.82'	39° 12.36'	hornblende	plateau	92.3	27.18	0.09	near Red House, Little Valley	27.39	0.19	290	12	1.9	27.52	0.22
H00-154	pyroxene andesite lava	119° 51.62'	39° 12.52'	plagioclase	plateau	88.6	27.98	0.20	near Red House, Little Valley	27.74	0.21	307	11	7.1	28.46	0.20
GM, Toquima Range										27.07						
	GM, Yerington									27.12						
	GM, Nine Hill									27.11						
	old shaft, E of Yerington									34.02						

H00-156: hornblende andesite clast in conglomerate that overlies Mickey Pass Tuff.
H00-154: pyroxene andesite lava breccia that underlies Mickey Pass Tuff.
Analyses at the Nevada Isotope Geochronology Laboratory, University of Nevada Las Vegas using methods described in Justet and Spell (2001).
Monitor: Fish Canyon sanidine with an assigned age of 28.02 Ma (Renne et al., 1998).
Decay constants and isotopic abundances after Steiger and Jäger (1977); lb = 4.963 x 10-10 yr^{-1}; le+e′ = 0.581 x 10-10 yr^{-1}; 40K/K = 1.167 x 10^{-4}

to one another. A half-graben model (e.g., Schweickert et al., 2000) would appear to require considerable rotation of the Carson Range paleovalley or reverse motion on faults along the east side of the lake. A scenario that fits the paleovalley data is that a fault on the east side of the Lake Tahoe graben dips west, rather than east.

Little Valley-Virginia Range—Placer gold was found in modern streams west of Washoe Valley, probably within a few years of settlement in the area (Stretch, 1867, p. 23). This area, referred to as the Wisconsin District, probably included modern streams that drained upper Little Valley (Fig. 6). Placer gold was eventually determined to be associated with paleochannels that underlay rhyolitic volcanic rocks (Reid, 1908, 1911), now known to be Oligocene (see Bingler, 1978). These paleochannels were traced west, across several north-striking normal faults, to Marlette Peak overlooking Lake Tahoe (Reid, 1908; Grose, 1986). Geologic mapping in the area of the paleochannel and to the east (Bingler, 1977; Trexler, 1977; Henry, in prep.) demonstrated that late Oligocene and early Miocene silicic ash-flow tuffs were commonly underlain by gravels that contained clasts of pre-Tertiary rocks and older ash-flow tuffs. The oldest tuff filled valleys in the underlying basement (Bingler, 1978) and the complex relationships among tuffs and with the underlying pre-Tertiary basement indicated that channels continued to develop between tuff eruptions, in many cases cutting completely through the previously erupted tuff (Fig. 5a).

Early workers were either uncertain about the direction of the Little Valley paleochannel drainage or thought it drained to the east (Reid, 1908; Gianella, 1936, p. 49). Reid (1911) reported that clasts were more likely to have been derived from the west. Clasts from the paleochannel near Red House (Fig. 6) include pyroxene-phyric gabbro that most likely was derived from the east, in the southern Virginia Range. Near Red House, a pyroxene andesite flow breccia (27.74 Ma; Table 2) is found as remnants on Cretaceous granodiorite, and is overlain by gravel and ash-flow tuffs. Apparently, the oldest tuff, the Guild Mine Member of the Mickey Pass Tuff (Fig. 5a) was deposited first in a channel on granodiorite which contained the erosional remnants of pre-tuff andesitic rocks. As subsequent drainage developed, the Guild Mine was almost completely removed, remaining as only remnants along valley walls. A later deep channel (having gravel 45 m or more thick; Reid, 1908; Gianella, 1935) developed on top of the older ones, and was subsequently preserved under the Lenihan Canyon Tuff (26.6 Ma). Clasts of 27.39 Ma hornblende andesite are found in this gravel (Table 2).

We interpret the eastward continuation of the Little Valley paleochannel (Fig. 6) to pass across a graben at the southernmost end of Washoe Valley (Stewart, 1999; Henry, in prep.) with little or no horizontal displacement, and continue northeasterly through Nine Hill and eventually easterly to the vicinity of American Flat south of Virginia City (Hudson et al., 2003). As in the Carson Range to the west, the channel is complex; it apparently reestablished itself after each ash flow in nearly the same position by down cutting into and through the new tuff, leaving remnants along the channel margins. At least five ash-flow tuffs, 27 to 23 Ma, are found as paleovalley fill or canyon-wall remnants in this area (Hudson et al., 2003; see Fig. 5a).

The Virginia Range paleovalley may divide in this area into a northern branch, which we project to continue northeast along the southeast side of the Virginia Range for at least 25 km to near Ramsey (Fig. 4), and a southern branch through ash-flow tuff exposures in a probable paleovalley south of Dayton to Yerington and the northern Wassuk Range, about 60 km to the east (Fig. 4).

Yerington Area—Penrose (1937) first described the Tertiary gold-bearing gravels that underlie rhyolite (ash-flow tuffs) in the Singatse Range west of Yerington. Penrose concluded that Quaternary placer gold deposits in the Singatse Range (Smith and Vanderburg, 1932; Johnson, 1973) were derived from erosion of these Tertiary gravels.

Proffett and Proffett (1976) described a west-northwest flowing paleochannel, about 4–5 km wide, that was developed on the pre-Tertiary surface. They estimated that the local relief exceeded 4000 ft (1200 m). The oldest rhyolitic ash-flow tuff in this paleovalley, exposed about 13 km east of Yerington, has been dated at 34.02 Ma (Table 2). Clasts in the gravels at the base of the Tertiary section in the channel west of Yerington consist of about one-fourth pre-Tertiary rocks and three-fourths Tertiary volcanic rocks (Proffett and Proffett, 1976)). The pre-Tertiary clasts consist of locally derived metavolcanic rocks as well as chert, conglomerate, and quartzite thought to have been derived from east of Yerington. The most common Tertiary volcanic clast type is fresh or nearly fresh hornblende or pyroxene andesite (Proffett and Proffett, 1976) having unknown age and source. Pre-ash-flow tuff andesitic volcanic rocks are known from the Slate Mountain area of southern Churchill County about 90 km to the east (Willden and Speed, 1974), and similar volcanic rocks are probably exposed in closer proximity to Yerington. Clasts of basalt were also reported from the conglomerate; these could be locally derived, as basalt flows lie above and interfinger with the conglomerate in the Singatse Range (Proffett and Dilles, 1984). These basalts have not been dated, but they underlie the ~27 Ma Guild Mine Member of the Mickey Pass Tuff (Proffett and Dilles, 1984). Biotite from a boulder of ash-flow tuff from the conglomerate (location unknown?) was dated at 29.6 Ma. Proffett and Proffett (1976) described a brick-red soil and deep, red-weathering zone that may be developed on the pre-Tertiary rocks or conglomerate below the ash-flow tuffs. The variable stratigraphic position of this soil suggests that some gravels on the basement may be older than those that contain Tertiary volcanic-rock clasts. The ash-flow tuffs in the Yerington paleovalley were erupted from caldera sources to the east in the Toquima Range (Garside et al., 2002). The Guild Mine Member of the Mickey Pass Tuff is correlated with tuffs erupted from the Toquima caldera complex (Garside et al., 2002; see Fig. 1).

Gravel below the Guild Mine Member about 3 km northeast of Mason Pass (Fig. 4) contains clasts of both Tertiary and pre-Tertiary rocks, similar to those described in Proffett and Proffett (1976) and Proffett and Dilles (1984). This location is apparently Stop 1 of a field trip by Hardyman et al. (1990). Three-fourths of the rounded and sub-rounded clasts are hornblende and hornblende-pyroxene andesite. Hornblende phenocrysts are unaltered to slightly altered in these clasts, and plagioclase phenocrysts are cloudy. The andesite clasts appear to have been derived from Tertiary rocks. The remainder of the clasts is mainly granodiorite or pink-orthoclase-bearing granodiorite or porphyry. The clasts range from less than 2 cm to 35 cm. The underlying Jurassic granodiorite is yellowish to locally red stained.

About 5 km northwest of Mason Pass (Fig. 4), a shaft penetrated about 30 m of basal Tertiary gravel that lies below the Guild Mine Member. This locality fits the description of the Penrose Placer (Penrose, 1937; Johnson, 1973). The gravel clasts at this site, both on the dump of the shaft and as float in the nearby hills, consist of meta-andesite, granodiorite(?) porphyry, and fine-grained granodiorite. The clasts contain epidote and appear to be pre-Tertiary. About 100 m to the north, the gravel is overlain by pyroxene basalt, which is overlain by the Guild Mine Member.

Basal Tertiary gravel exposed about 2 km southwest of Wishart Hill (Fig. 4) contains clasts that are also entirely or almost entirely of pre-Tertiary rocks. Also, the gold-bearing placers at the nearby Guild Placer Mines and Guild-Bovard Mine (Fig. 4) are developed in Quaternary alluvial deposits which contain many clasts of the Oligocene ash-flow tuffs. It is possible that some of the gold in these placer deposits was derived from the basal Tertiary conglomerate (Penrose, 1937; Johnson, 1973, p. 45, 47).

East of Yerington, Proffett and Proffett (1976) continue the paleovalley to outcrops of ash-flow tuff at the northern end of the Wassuk Range (Fig. 4).

French Meadows-Soda Springs-Donner Pass-Reno?

A prevolcanic paleovalley extended northward from the area of French Meadows approximately along the present course of the Middle Fork of the American River toward Soda Springs), having its head near Castle Valley(Lindgren (1911, p. 153, 161; see Fig. 4). The area south of Soda Springs (Fig. 6) has a thick section of Oligocene ash-flow tuffs in a paleo-canyon. Lindgren (1897) reported that the valley is filled with 1000 ft (300 m) of rhyolite. These ash-flow tuffs also crop out near Donner Pass, in Castle Valley to the north, and in Coldstream Valley to the east of Donner Pass and the present crest of the Sierra Nevada (Fig. 4). Lindgren (1897) thought that outcrops of the rhyolitic rocks in Coldstream Valley indicated "an overflow from the Soda Springs rhyolite basin across the old divide," and proposed that the head of the paleovalley was near Castle Valley; however, with the knowledge that the rhyolitic rocks are ash-flow tuffs having caldera sources in central Nevada, we propose that the Coldstream Canyon outcrops are in a side canyon or along the side of a main canyon that continues to the east of Donner Summit, possibly along the present canyon through Donner Lake and Truckee, California to the Reno, Nevada area. No remnants of pre-Miocene Tertiary rocks are known to be exposed under the Miocene lahars in this area to support this supposition.

In the vicinity of Reno, Oligocene ash-flow tuffs crop out intermittently from Reno northeast to Hungry Ridge (Figs. 3, 4). These tuffs certainly occupy one or more paleovalleys in this area, although the details remain to be worked out; many of the same tuffs found south of Soda Springs are also found in the Reno area. A highly speculative northeast continuation of this paleovalley would be along the present Truckee River course west of Reno, and then along a discontinuous belt of ash-flow tuff outcrop through and beyond Hungry Ridge (Garside et al., 2003, Figs. 2, 4).

An alternative westward connection for the Reno area tuffs is the Alpha Diggings-Weber Lake paleovalley, described in the following section on the central branch of the Tertiary Yuba River.

CENTRAL BRANCH OF THE TERTIARY YUBA RIVER

Alpha and Omega Diggings-Snowflower-Meadow Lake-Weber Lake-Reno(?)

A well defined channel can be continued eastward from Alpha Diggings to Omega Diggings and the Diamond Creek Workings (Lawler, 1995; Fig. 7). From Diamond Creek, the channel apparently connected farther northeast to Auriferous Gravel outcrops in the Snowflower Mine area (Loyd and Clinkenbeard, 1990). We project this channel farther northeast through outcrops of Oligocene ash-flow tuffs near the Meadow Lake mining district to the vicinity of Weber Lake (Fig. 7). Auriferous Gravel and Oligocene ash-flow tuffs are unknown northeast of the Snowflower Mine and Weber Lake, respectively. Continuation of the paleovalley to the north or northeast from Weber Lake is uncertain because of cover of younger andesitic rocks. The presence of clasts of quartz-tourmaline vein material at Alpha Diggings and the Diamond Creek area, probably derived from the Meadow Lake mining district (Doebrich et al., 1996) 20 km to the northeast (Fig. 7), indicates the northeast channel continuation to this area is appropriate.

Lindgren (1897) mentioned the “especially fine” rhyolite outcrops in the vicinity of Weber Lake. He suggested the rhyolite outcrops in this area and extending northwest toward Jackson Meadow Reservoir (Fig. 7) outlined a paleovalley; this description was probably the basis for a northwest flowing channel in this area shown by Jenkins (1932). We suggest that it is more likely the ash-flow tuffs filled two parallel southwest-flowing drainages and a low area between them; this outcrop is nearly 20 km long, from Meadow Lake to southeast of Sierra City.

Plio-Miocene volcanic rocks cover any eastward continuation of a paleovalley from Weber Lake. A speculative continuation is east to Reno and through Hungry Ridge, an alternative to the Soda Springs-Reno paleovalley discussed above.

Graniteville-Hilda Mine-Haskell Peak

Lawler (1995) showed the Tertiary Yuba River branching near Orleans Flat (Fig. 7), with an eastern branch passing through the Eureka hydraulic workings near Graniteville. If this channel is projected northeast to extensive areas of Oligocene ash-flow tuff outcrops (Saucedo and Wagner, 1992; see Fig. 7) it would appear to connect to a northerly trending section of paleovalley that is fairly well defined by drift and hydraulic mines southeast of Sierra City (the Hilda, 1001, and Pride Mines). Gravels mined at these properties underlie Oligocene ash-flow tuffs (this study; Saucedo and Wagner, 1992). Northeast of the Pride Mine, it is about 6 km to Haskell Peak (Brooks et al., 2003), where a section of nine Oligocene tuffs and interbedded gravels is exposed (see Figs. 5b, 7). The lower part of the basal gravel (gravel of Locke Mine) at Haskell Peak appears to have preceded deposition of ~31 Ma ash-flow tuffs (Brooks et al., 2003), and thus be Eocene or earliest Oligocene. Paleoplacer gold has been mined at Locke Mine. We interpret the direction of the Eocene-Oligocene paleochannel at Haskell Peak to be northerly; however, Brooks et al. (2003) describe the oldest gravel to be in a northwest trending paleovalley. Auriferous Gravels mapped beneath Miocene andesitic rocks about 5 km west of Haskell Peak (Saucedo and Wagner, 1992; Fig. 7) are now known to be part of the younger volcanic rocks (Brooks et al., 2003), and do not necessarily indicate an Oligocene paleovalley in this area.

Based on the map of Saucedo and Wagner (1992), a logical projection of the channel to the north of Haskell Peak would be to an area of mapped Auriferous Gravel southeast of Clio at the Hayden Mine (Fig. 7); rhyolite ash-flow tuff is shown to crop out nearby. However, no evidence of either Auriferous Gravels or ash-flow tuff could be found in that area in a 2004 visit. The Hayden Mine is a copper prospect in Mesozoic bedrock. Thus, the projection of the paleovalley farther north and northeast of Haskell Peak is somewhat speculative and is based on outcrops of Oligocene ash-flow tuffs. One possible route requires a bend to the east in the vicinity of tuffs exposed along Highway 70 northeast of Graeagle (Fig. 4) and then continuing northeasterly toward similar tuffs at Delleker and Portola. This channel possibly continues farther east to ash-flow tuff outcrops near Chilcoot (or more northeasterly to tuffs exposed in a paleovalley at the south end of Frenchman Reservoir) (Fig. 4), and then east to a well-mapped paleovalley on Seven Lakes Mountain and Dogskin Mountain in Nevada (Henry et al., 2004; C.D. Henry, unpub. mapping, 2004). Oligocene ash-flow tuff (tuff of Campbell Creek) exposed just north of Satley (Fig. 7; Table 1), and in southern Antelope Valley beneath andesite and on Cretaceous granodiorite (this study; Young and Cluer, 1992, Fig. 2) may be on a side channel of this paleovalley. A different interpretation for the Delleker-Portola tuffs is that they lie in the northeast projection of a paleochannel from the Wide Awake-Craycroft channel (Figs. 4, 7) located about 9 km north of Downieville (see the American Hill channel description).

American Hill-Ladies Canyon

Lawler (1995) showed a branch of the Tertiary Yuba River passing northeast from the Snow Point to the American Hill hydraulic workings. There is little evidence to continue this channel to the northeast, except as a possibly eroded inter-andesite channel. Lindgren (1911, p. 135) reported an inter andesite channel northeast of American Hill below lavas. The channel as a branch off the Orleans Flat-Graniteville channel (Fig. 7) is well established (Lindgren, 1911; Jenkins, 1932; Lawler, 1995). There are a number of placer gold mines to the north of American Hill in the vicinity of Negro Canyon; however, based on published descriptions (Turner, 1897; MacBoyle, 1920b) it appears that all those described (i.e., Banner Mine, Burlington Mine, and unnamed placer mines in Negro Canyon) are in Quaternary deposits near or at the canyon bottom. No Tertiary rocks have been mapped in this area or to the northeast

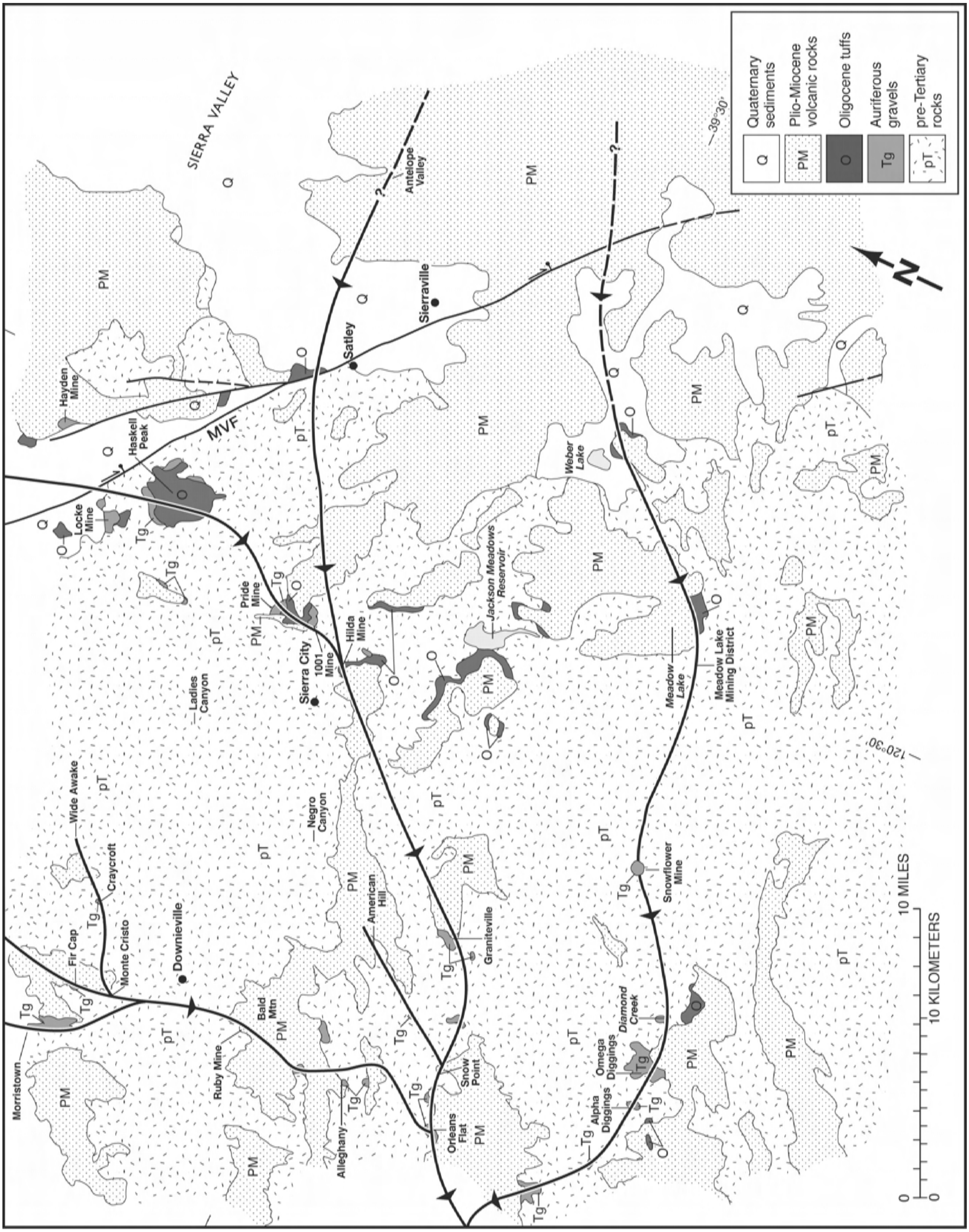

Fig. 7. Geologic map of paleovalleys in part of the central Tertiary Yuba River drainage. Contacts generalized and slightly modified from Saucedo and Wagner (1992). Map location shown on Figure 4.

across California Highway 49 at Ladies Canyon (Saucedo and Wagner, 1992). The only possible argument for the projection of a paleocanyon to this area is that the Quaternary placers derived their gold and some clasts from completely eroded prevolcanic or intervolcanic channels.

Monte Cristo-Craycroft-Wide Awake

Lawler (1995) showed a Tertiary channel from Alleghany to Bald Mountain and the Ruby Mine and continuing north to near Monte Cristo (north of Downieville) where three branches were proposed (Figs. 4, 8). The eastern branch extends northeasterly from Monte Cristo to Craycroft and the Wide Awake Mines. The absence of volcanic clasts in these gravels (Bergquist et al., 1986) and their position below Miocene andesitic rocks suggests that the channel is prevolcanic and possibly Eocene. No Oligocene ash-flow tuffs are known from the area. Lawler (1995) showed this channel to continue from the Wide Awake to the east toward Haskell Peak (Fig. 4), possibly based in part on a somewhat similar proposed channel by Durrell (1987, Fig. 80). There is no evidence to extend the channel east; there are no known placer deposits between the Wide Awake and Haskell Peak. As explained above, the Haskell Peak gravels are probably better interpreted to be in a channel that continues south to the Hilda Mine.

Monte Cristo-Fir Cap-Rattlesnake Peak

Lawler (1995) showed a paleochannel from near Monte Cristo continuing northerly under Fir Cap and then northeast and north nearly 20 km to just west of the Plumas Eureka (lode) Mine. However, we suggest instead (Fig. 8) a continuation north from Fir Cap to just east of Tennessee Mountain. (the Tennessee Mine-Gibraltar Mine area). Bergquist et al. (1986) reported no Tertiary volcanic rock clasts from the paleoplacer deposits along this course. From the Tennessee Mine-Gibraltar Mine area on the north flank of Tennessee Mountain, we project this prevolcanic channel northeast to the Continental Ravine deposit (Fig. 8) on the west side of McRae Ridge. Projection of this channel farther north is highly speculative; if the Wide Awake/Craycroft channel does not continue to the Delleker/Portola area, this channel might (Fig. 4).

Monte Cristo-Eureka Diggings-Morristown Ridge

Lawler (1995) showed a western branch of the Alleghany-Monte Cristo channel that diverges just south of Monte Cristo (Fig. 8). This channel passes through Eureka Diggings and Morristown and northeast under Morristown Ridge to Deadwood. It is possible that the California Mine (Fig. 8) is on a continuation of this channel or a side branch. However, it also appears possible that it is on a side channel of the Port Wine Channel at Howland Flat/Potosi. For example, Bergquist et al. (1986) projected the California Mine gravels north under Table Rock toward Howland Flat. If the main channel is the one from Monte Cristo through Fir Cap, then there is not much room for this channel and it may end somewhere in the area of the California Mine (Fig. 8).

NORTHERN BRANCH OF THE TERTIARY YUBA RIVER

Port Wine Channel

The northern branch of the Tertiary Yuba River has been well defined for over 100 years (Lindgren, 1911; Jenkins, 1932). This branch splits into two main channels near Scales, the eastern Port Wine channel and the western La Porte/Gibsonville channel. The Port Wine channel certainly continues north under Port Wine Ridge to at least Howland Flat (Fig. 8). It is not clear if the channel continues farther north or just forks and ends (Lawler, 1995).

La Porte/Gibsonville Channel

A highly productive channel is well defined from Scales north to La Porte and then northeasterly to Gibsonville and Hepsidam (Figs. 4, 8). Turner (1897) suggested that the Bunker Hill Mine farther northeast across Bunker Hill Ridge was a probable continuation of this channel. A logical continuation of the channel is northeast across the Plumas Trench (Durrell, 1987, p. 51; the Mohawk Valley fault zone of Wakabayashi and Sawyer, 2000; Fig. 5) to Auriferous Gravels in the vicinity of Cromberg, as suggested by Durrell (1987, Fig 80). Durrell (1987, Fig. 80) also proposed a continuation of this channel to the northeast, with a northwest-trending fork to the Cascade Mine and Taylor Diggings (Fig. 8). The confluence of two channels in the area of Cromberg is possible, as there is a considerable area of pre-tuff gravel. We suggest that a northeast-trending channel from the vicinity of Cromberg may continue upstream through an area of Oligocene ash-flow tuff outcrops near Red Clover Creek and then to a thick section of the same tuffs in a paleovalley at Black Mountain (Hinz et al., 2003). The Cascade Mine and Taylor Diggings may instead be on a northerly fork of the La Porte channel (Fig. 8, see below).

La Porte-Richmond Hill-Cascade Mine-Taylors Diggings

A paleochannel branches to the north from the La Porte channel at La Porte (figs. 4, 8), passes northeast under the present Little Grass Valley Reservoir to the Auriferous Gravels at the Feather Fork Mine, Richmond Hill, Sawpit and Union Hill (Turner, 1897; this study). From this point, the course of the channel easterly across the Plumas Trough (Mohawk Valley fault zone) is uncertain. There is some evidence for pre-andesite gravels or material reworked from them near Spring Garden. From there, a speculative channel could trend north to Ward and Peale Diggings and even farther north to Taylor Diggings (Fig. 8). Both

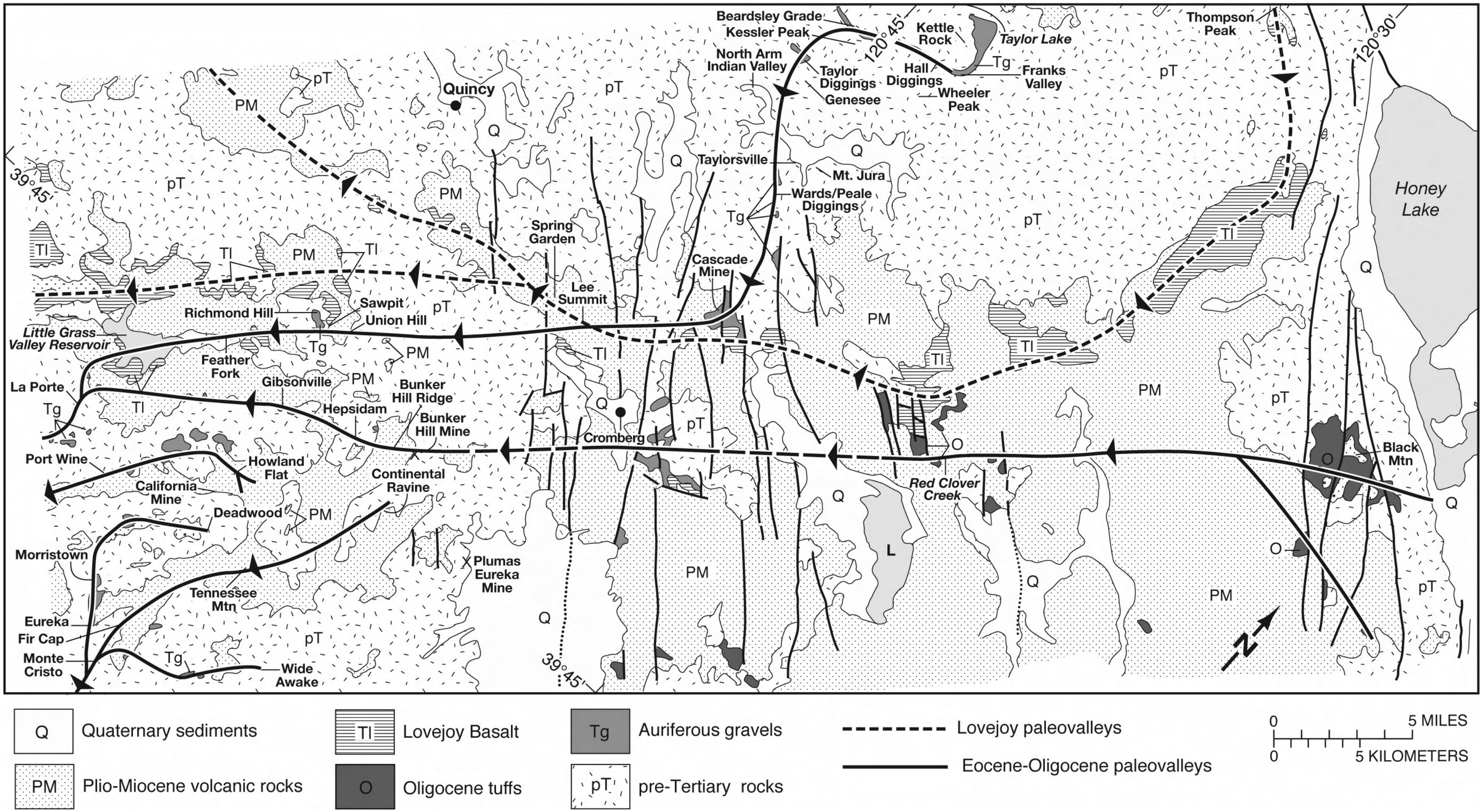

Fig. 8. Geologic map of paleovalleys in a part of Plumas and Sierra Counties, California. Contacts generalized from Saucedo and Wagner (1992) and Grose et al. (1990). Map location shown on Figure 4.

Ward/Peale and Taylor Diggings contain rare clasts of red jasper, suggesting they are on the same ancient stream course.

Wakabayashi and Sawyer (2000, p. 202) reported that the Mohawk Valley fault (Fig. 3) has 600–1200 m of down-to-the east vertical separation. The elevation of the Eocene channel bottom near Cromberg is about 5420 ft (1652 m), whereas the channel bottom at Union Hill on the west side of the Mohawk Valley fault zone is about 6400 ft (1951 m). However, the bottom of the Auriferous Gravel channel at Cascade Mine is about 5760 (1756 m). Because the base of the Miocene andesites has generally the same elevation on opposite sides of the Plumas trench (see Durrell, 1987, Fig. 129), a logical connection across the Mohawk Valley fault zone is from Union Hill through Lee Summit to the Cascade Mine.

Auriferous Gravels in the Richmond Hill-Sawpit area lie beneath the 16 Ma Lovejoy Basalt. The stream valley that the Lovejoy flowed down appears to project northeast (upstream) from the La Porte area to Sawpit and then across the Plumas Trench/Mohawk Valley fault zone (Durrell, 1987) to the Cascade Mine (Fig. 8). From there, the Lovejoy channel can be traced upstream to Red Clover Creek (also see Durrell, 1987, Fig. 80) and then northerly to its probable source near Thompson Peak (Wagner et al., 2000; Fig 8). It appears likely that the channel Lovejoy flows followed was cut along one or more Eocene Auriferous Gravel channels, because the Lovejoy overlies Auriferous Gravels in a paleovalley at several locations. However, because there was probably considerable erosion during the ca. 16 Ma period between Auriferous Gravel and Lovejoy deposition, the Lovejoy channel may not be confined to a single Eocene channel. Drainage was apparently to the southwest from the Eocene to at least 16 Ma (Lovejoy).

Spring Garden—Turner (1897) showed a small outcrop of Auriferous Gravel about 700 m west of Lee Summit (about 2 km southeast of Spring Garden), under what is now called Lovejoy Basalt. The Lovejoy is exposed in a small road-metal pit just west of California State Highway 70 (Durrell, 1987, p. 172; see Stop 1 of Wakabayashi and Sawyer, 2000, p. 203). Scattered smooth rounded cobbles of resistant pre-Tertiary rocks (including vein quartz) are found as float about 300 m west and 300 m southeast of the roadside Lovejoy outcrop. These clasts may be originally from Auriferous Gravel, but there is no clear evidence of Auriferous Gravel outcrop; the clasts could have been recycled into Miocene or later gravels. In fact, Sheeks (1977) showed the gravels in the area south of Lee Summit as Quaternary “sediments of extinct Long Valley,” presumably equivalent to Quaternary Mohawk Valley lakebeds.

Gianella (1956) found thin, platy flakes of gold in gravels exposed in a ravine about 600 m south of the Lovejoy road-metal pit. He reported that these gravels were within the Miocene andesitic lavas and lahars, rather than the Auriferous Gravels, and he estimated that the andesitic rocks were at least 120 m thick below the sampled gravels. Smooth, rounded clasts of resistant pre-Tertiary rocks and at least one rounded clast of Miocene(?) andesite were observed during this study. Because Auriferous Gravel, Lovejoy, and younger andesite may all be found in channels that place younger units topographically lower than older units, it is not certain if Auriferous Gravels are present in the Lee Summit area, either in outcrop or subcrop. Gold-bearing Auriferous Gravels do underlie Lovejoy about 10 km to the northeast at the Cascade Mine (Fig. 8). Gianella (1956) also reported a rumor that the Spring Garden Railroad Tunnel cut older gold-bearing gravel that could have been prevolcanic and rest on the Paleozoic Shoo Fly Complex. Gravel clasts were reported to make up railroad grade fill west of the northwestern portal of the tunnel. The source of this information may have been Lindgren (1911, p. 111) who mentioned that a gravel channel was encountered in the Western Pacific Railroad tunnel near Spring Garden. No clasts were seen in fill along the railroad grade during a visit for this study, although a few smooth, rounded clasts were observed in railroad cuts in predominantly andesite-clast lahars of the post-Lovejoy andesite units.

Thus, it is possible that prevolcanic Auriferous Gravels are present in the subsurface near Spring Garden, or that they were previously present and eroded by streams that cut a channel for the Lovejoy Basalt or younger Miocene andesitic units.

Cascade Mine—The Cascade Mine is located nearly 10 km northeast of Spring Garden (Fig. 8). Auriferous Gravels appear to lie on Cretaceous biotite hornblende granodiorite, which is exposed just upstream from the mine. The approximate elevation of the base of the gravels is 5760 ft (1756 m). The gravel clasts consist of a considerable variety of metavolcanic and metasedimentary rocks as well as light-colored biotite hornblende granodiorite. One metavolcanic type observed was metaigneous porphyry, which could have been derived from the Permian Reeve Formation (E.R. Brooks, oral commun., 2004) which is exposed nearby, both to the northeast and southwest. A few smooth clasts of black chert were seen, as well as one fine-grained black-tourmaline(?)-bearing clast. Notably absent are white vein quartz clasts. The clasts are commonly well-rounded, and range in size from 1 cm to over 60 cm; some clasts that were apparently separated from the gravels by hydraulic mining have local patches of limonite-cemented sand matrix still attached. Sand lenses in the Auriferous Gravel consist of locally derived quartz, feldspar, biotite, and hornblende (arkose). The Auriferous Gravels are overlain here by andesite lahars and flows; however, about 2 km to the southeast Lovejoy basalt flows are found in a channel cut on and into the Auriferous Gravels channel (Durrell, 1987; Grose, 2000).

Lindgren (1911, p. 112) reported that large granite boulders in the gravel were probably derived from an area of granite immediately to the south, bolstering his belief that the paleoriver (the Jura River) flowed north. The proposal that the boulders suggest a northerly flowing river originally came from Turner (1897; see Diller, 1908, p. 63). However, granitic rock underlies at least a small area of the Auriferous Gravel at the Cascade Mine and nearly all of the gravels in the main part of the paleochannel 1–3 km to the southeast (see geologic map by Grose, 2000). Also, granitic rocks crop out a short distance east of the Cascade Mine, and these outcrops could have been the source of the large granitic boulders. Thus, the presence of the granitic boulders does not confirm a northerly direction of transport.

Bedding of sands and gravels observed in the face left by hydraulicking is nearly horizontal. Tangential foreset beds of trough(?) cross-bedding in a sand lens suggests a downstream direction of S45°W to S90°W. Durrell (1987, p. 183) also reported that cross-bedding indicated a southwest paleo-downstream direction, and he noted as well that the clasts at the Cascade Mine came from the north in the Taylorsville district and possibly farther away in northwestern Nevada. The Mesozoic metavolcanic rocks exposed on Mt. Jura and elsewhere near Taylorsville are much more likely sources for the metavolcanic clasts at the Cascade Mine than are the mostly Paleozoic bedrock units to the south. The one black-tourmaline-bearing clast seen probably also has a source to the north in areas of Jurassic porphyry mineralization (i.e., the vicinity of the Walker Mine (Fig. 4) only 2.5 km to the northeast or the Lights Canyon district farther to the north (see the Taylor Diggings description for a more complete discussion).

At the exposed gravel face of the Cascade Mine, a few (probably <1%) disk-shaped cobbles appear to have their long or intermediate-length axes inclined in the same general direction as the dip of cross bedding foreset beds (southwest). Except for one observed case, these cobbles are not definitively shingled against similarly inclined clasts. Most of the clasts in the gravels are not imbricated and their long axes are nearly parallel to the plane of deposition. If the inclined clasts truly represented imbrication (shingling) or preferential inclination of single platy cobbles in a finer matrix, they should dip upstream (unless they represent cobbles deposited flat on foreset beds). The origin of the inclination of the few inclined clasts is not clear; they could suggest a northeast paleostream direction, they could represent random orientations, or they could indicate that some coarse conglomerate units include indistinct, unrecognized foreset beds. Because paleocurrent directions determined from the dip of plane cross beds seem to be subject to fewer ambiguities, the probable conclusion is that at the Cascade Mine the paleostream flowed southwesterly. This is in agreement with the southwesterly direction of the apparently coincident 16 Ma Lovejoy Basalt channel (Wagner et al., 2000).

Wards Diggings/Peale Diggings—Auriferous Gravel caps the higher parts of Peal(e) Ridge, about 6 km north of the Cascade Mine (Diller, 1908, p. 62; McMath, 1958, p. 74, Plate 2). Based on the descriptions of Diller (1908, p. 62) and Lindgren (1911, p. 116), workings in this area of gravels have been called Wards or Peale Diggings (Fig. 8).

The placer workings are reported to have exposed about 100 feet (30 m) of gravels; clasts of metarhyolite and quartzite were reported to be the most common, with some of dark igneous rock and a few of granite (Diller, 1908, p. 62). Diller reported clasts from 6–10 in. (15–25 cm) with rare ones as large as 2 ft (60 cm). No exposures of the gravels were seen during a 2003 visit to Peale Ridge, but smooth, rounded to well rounded clasts of pre-Tertiary rock types were seen as float in several areas along the ridge. The clasts include the following observed rock types: greenschist (epidote, chlorite) facies meta-andesite; glomeroporphyritic meta-andesite; dark metabasalt(?); spherulitic and flow-banded metarhyolite; red slate; quartz-veined, black chert; distinctive red jasper; sparse vein quartz; rare light gray chert, and rare black tourmaline(?) breccia. Most of the clasts are in the 15 cm size range, but dark metabasalt boulders up to 1.5 m long were seen. The gravels are apparently near horizontal and less than 20 m thick on the ridge top.

Diller (1908, p. 62) reported that imbrication (shingling) of clasts at Peal Diggings indicated a northerly direction of current flow. He also suggested that quartz porphyry clasts were more likely to be from the Grizzly Mountains to the south. This was considered evidence for a northerly flowing Tertiary Jura River, from the Haskell Peak area to the vicinity of Susanville (Lindgren, 1911, p. 33; see Fig. 2, 4). However, more recent studies have discounted the northerly flowing Tertiary Jura (see Introduction). Most of the clasts described above are more likely to have been derived locally in the Mount Jura area or from the north near Kettle Rock and Lights Creek (Figs. 4, 8). In particular, the tourmaline(?) breccia cobble probably had a source in the area of the Lights Canyon district (see the description for the source of gold and of the Cascade Mine, above), and the red jasper may well have been derived from pre-Tertiary outcrops near Taylor Diggings. Because no exposures of gravel were seen, it was not possible to check for pebble imbrication; however, imbrication-like features seen at the Cascade Mine are probably related to pebble inclination on indistinct foreset beds, an indication of south current direction.

Taylor Diggings—Diller (1908, p. 61) described Taylor Diggings as follows:

> Taylor Diggings, a mile northeast of the summit of Mount Jura, were operated years ago by a ditch from Taylor Lake, near Kettle Rock, and expose about 100 feet of gravel, at the bottom of which lies a bed of impure lignitic coal about 5 feet in thickness. Prospect tunnels have been run into this bed for a short distance to the west and south and about a ton of coaly material removed and tried for blacksmithing. The coaly material lies on Jurassic bed rock and is overlain by gravel, varying in size, but through a thickness of 100 feet rarely as much as 6 inches in diameter. The pebbles are chiefly metarhyolite, like the rock so well exposed along the eastern slope of Grizzly Mountains [Peak]. The remaining pebbles are for the most part granite and basic igneous rocks, some of which are rich in pyroxene.

This location, when plotted on the Taylorsville 7.5-minute quadrangle, is located in Hinchman Ravine (however, Diller (1908, Plate III) applied that name to a canyon about 0.8 km [0.5 miles] to the east). The Taylorsville 7.5-minute topographic map labels an adit in Section 29, T26N, R11E as Taylor Diggings; this is obviously in error, as the workings there are on hematite mineralization in Paleozoic rocks. Crawford (1896. p. 289) reported the Taylor Diggings gravels to be 4–60 ft (1.2–18.3 m) thick and to carry fine gold throughout.

The Auriferous Gravels can be examined in float on a ridge above the probable location of Taylor Diggings (Fig. 8). The mostly well-rounded clasts observed in float range from a few to about 20 cm in diameter. Except for fine-grained, resistant rock types, they are not highly polished. The lithologic types of the clasts include: light-gray biotite meta(?)-andesite, pyroxene meta(?)-andesite, aphyric metabasalt(?), light- and dark-gray chert, aplite, granite, and quartz-eye porphyry. The rarer clast lithologic types include pyritic black-tourmaline breccia, black-tourmaline-veined granitic rock, white vein quartz, and white-quartz-veined red jasper. The Auriferous Gravels lie nearby on Jurassic slightly foliated meta-andesite (McMath, 1958, Plate 2). The probable source of the tourmaline-bearing clasts is porphyry- and vein-type mineralization associated with the Lights Creek stock (Lights Canyon district) about 15 km to the north (i.e., Putman, 1975; McFarlane, 1981; Grose et al., 1990). The jasper clasts were probably derived from an area of bedrock outcrop of hematite and jasper nearly 2 km to the northeast (see below). The coal mentioned by Diller (1908; see above) is in a similar stratigraphic position to coal reported from Lights Canyon (McFarlane, 1981; see Moonlight Valley description below).

The short adit that is incorrectly labeled Taylor Diggings on the Taylorsville 7.5-minute quadrangle explores a N20°W, 70°SW zone of banded red jasper and specular hematite in pods 0.5 to 1 m thick. The wall rock is red metasiltstone. The jasper zone appears to be parallel to compositional layering in the wall rocks, which include probable subaqueous intermediate pyroclastic volcanic rocks; these rocks have been mapped as part of the Carboniferous Peale Formation (Grose et al., 1990). The jasper and specular hematite probably represent metamorphosed submarine exhalative deposits. Diller (1908, p. 85) reported that pebbles of red jasper are found in conglomerate of the Jurassic Kettle tuffaceous meta-andesite and that the jasper may come from Carboniferous rocks; this comment suggests that the source of the jasper pebbles found at Taylor Diggings and Wards Diggings could be recycled pebbles in Jurassic clastic units or the exhalative bands in the Peale Formation. About 200 m to the east of the adit, along the road and near the remains of an old cabin, cobbles observed in float consist of volcanic-pebble conglomerate, feldspar porphyry, and jasper. These cobbles apparently represent float from poorly exposed Auriferous Gravel on the ridge immediately to the east.

Hull Diggings—Diller (1908, p. 61, Plate III) described Hull Diggings as being at the head of the north Fork of Hosselkus Creek along the Lucky S road, and described exposures of Auriferous Gravels along that road. The Hull Diggings area of gravels would be located in N$^1/_2$ NW$^1/_4$ Section 14, and SE$^1/_4$ SW$^1/_4$ Section 11, T26N, R11E, along a well-traveled road from the North Arm of Indian Valley to Taylor Lake (Fig. 8). A narrow (<0.5 km) northeast-trending band of Auriferous Gravel has been mapped along this road, from a ridge top just east of the North Arm of Indian Valley, traveling between Kettle Rock to the north and Kessler and Wheeler Peaks to the south (e.g., Grose et al., 1990). Diller (1908, p. 61) has referred to this as the Mt. Jura Divide. The eastern end of this band connects with a more extensive mapped area (about 2 km^2) of gravel east of Taylor Lake mainly in Section 36, T27N, R11E (Christe, 1987, Plate 2).

Diller (1908, p. 61) reported that the workings at Hull Diggings exposed over 100 ft (30 m) of gravel, including 15 ft (4.5 m) of fine sand and gravel in the upper part. Clasts were reported to be mostly smaller than a man's head (~25 cm), but some near the base were up to 5 ft (1.5 m). Diller (1908, p. 61) also reported that the boulders were hornblende-andesite metaporphyry, and that although many pebbles consist of igneous rocks, none were derived from Tertiary units.

Gravels are poorly exposed along most of mapped band as described above. No evidence of placer mining in the presumed area of Hull Diggings was found during this study, although there are remnants of a ditch along this zone that transferred water from Taylor Lake to Taylor Diggings. Almost all of the subrounded to rounded clasts seen in float (and presumed to be from the Auriferous Gravels) are of hydrothermally altered or metamorphosed andesite or basalt. They are a few to 25 cm in diameter, and some contain phenocrysts of biotite (sericitized) and rare quartz. Their age is uncertain; they could be either metamorphosed Mesozoic rocks or propylitized Tertiary rocks. In an area east of Taylor Lake, similar altered or metamorphosed volcanic rock clasts are subangular to subrounded, and in poor exposures along a road (SE$^1/_4$ SE$^1/_4$ NE$^1/_4$ Section 35, T27N, R11E), vesicular andesite pebbles in a conglomerate are almost certainly Tertiary, as they are unaltered and vesicles are unfilled. Larger clasts there are rotted granitic rock and altered or metamorphosed andesite of undetermined age. Also, a Tertiary andesite lahar is exposed about 3.5 km to the south-southeast, along the road in Center NW$^1/_4$ SE$^1/_4$ Section12, T26N, R11E (Franks Valley). This is in an area mapped as Eocene gravel by Christe (1987, Plate 2). At the west end of the band of gravel, near the top of Beardsley Grade (NW$^1/_4$ NW$^1/_4$ NE$^1/_4$ Section 20, T26N, R11E) the matrix to the gravels is clay-rich and arkosic.

The evidence for the gravels of the Jura Divide to be Eocene and a part of Eocene paleochannel deposits is equivocal. One possibility is that most of the gravel along the elongate band from Beardsley Grade nearly to Franks Valley is Eocene, but most gravel mapped east of Taylor Lake is younger. The elongate band along the road from Beardsley Grade to Franks Valley may represent the actual course of the stream that deposited the gravels, no matter their age. The ridge-capping nature of the gravels at the west end of the band suggests they are nearly horizontal, and their base appears to gain elevation to the east. Both Diller (1908, p. 61) and McMath (1958, p. 162) reported that there are no Tertiary clasts in the Auriferous Gravels of this area. However, McMath (1958) did not map the gravels east of Taylor Lake. McMath (1958, p. 162) also reported that in the elongate band, "the progressive appearance of rock types derived from the subjacent Kettle Formation indicates the gravel was carried in a westerly direction." McMath (1958, p. 162) also suggested that "the rather continuous east-west trending channel-like segment of gravel on the south side of Kettle Rock is almost certainly bounded on the north by a significant fault." His evidence for this was that this gravel is almost 1000 ft (~300 m) lower than Auriferous Gravel mapped north of Kettle Rock by Diller (1908, Plate III). However, that gravel (near Eisenheimer Peak; Fig. 4) is clearly andesite lahar units of probable Miocene age and thus not related to the channel-like segment. Additionally, more recent mapping by Christe (1987, Plate 2) does not confirm an east-west fault in this area.

The evidence available suggests a west-flowing Eocene stream in this area. At its west end, it may turn south to include probable Eocene gravels in the vicinity of Taylor Diggings.

TERTIARY BUCKEYE-BEAN HILL CHANNEL

Oroville-Walker Plains (Buckeye)-Bean Hill-Moonlight Valley-Cheney Valley

The evidence for this speculative channel is that middle to upper Eocene gravels (Creely, 1965) at Cherokee and Oroville (Fig. 4) must have had a source somewhere in the higher Sierra Nevada. Also, 16 Ma Lovejoy Basalt is found on Auriferous Gravels in several areas along the proposed channel, suggesting that it flowed in one or more of these older Auriferous Gravel channels. Lovejoy flowed south and then southwest from its source near Thompson Peak toward Spring Garden, where it appears to follow at least two different channels (Fig. 8), an interpretation that can be made from the geologic map of Sheeks (1977; simplified in Saucedo and Wagner, 1992). A northerly Lovejoy channel apparently goes toward Meadow Valley and Walker Plains (near Buckeye), where Lovejoy lies on Auriferous Gravels. Lavas that flowed in this paleovalley may have fed the Table Mountain basalt flows at Oroville and to the northwest, where flows are known to be present in the subsurface in the Sacramento Valley (Durrell, 1959b, Map 1; Fig. 1). A more southerly Lovejoy channel apparently followed a course toward Richmond Hill, where basalt sits on Auriferous Gravels, and Little Grass Valley Reservoir (Fig. 8). The southwest trend of outcrops in this channel suggests it may lead to flows known from the subsurface in the central Sacramento Valley (Durrell, 1987, Map 1).

There is limited evidence for a ~40 Ma channel through part of this area, particularly between Cherokee and Buckeye, between Buckeye and Bean Hill, and between Bean Hill and Moonlight Valley. We suggest, based on the gravels and channel at Oroville/Cherokee, that the paleochannel course was northeast to Buckeye, Meadow Valley, Indian Valley and Moonlight Valley (Fig. 4). A branch of this valley may have continued farther north to the Eocene flora site at the head of Cheney Creek (14 km southwest of Susanville). Based on the presence of andesite clasts of probable Miocene age or interbedded Pliocene basalt flows, it appears that any Eocene gold-bearing gravels that were originally present between Moonlight Valley and Bean Hill (Meadow Valley) have been eroded and redeposited one or more times in the Miocene (i.e., Monte Cristo Mine on Spanish Peak) and Pliocene (i.e., Dutch Hill Mine near Seneca). Additional evidence for the younger age of gold-bearing gravels in this area is available at: ftp://comstock.nbmg.unr.edu/pub/dix/paleochannel/Lead_web_page.htm.

But there are a few probable remnants of the gravels in this projected channel. Gravels at Bean Hill (Fig. 4), for example, appear to be entirely prevolcanic. They are in a steep, probably side channel; the main channel may have been completely eroded later. Evidence against this paleovalley course includes the apparent absence of clasts of quartz-tourmaline vein material in any gravels of this channel or recycled from this channel, which might be expected from the Lights Creek stock in the Lights Canyon district, and the presence of such clasts at Taylor Diggings, on a paleochannel that might connect to the south to the Cromberg area and across the Plumas Trench in the vicinity of Spring Garden to a channel at Sawpit/Richmond Hill (Fig. 8, see above).

Buckeye—The abandoned camp of Buckeye is located just west of the Oroville-Quincy Highway (Forest Highway 119) at Walker Plains (Fig. 4). The site was a stop on the Beckwourth Emigrant Trail, and is marked by a Trails West Trail Marker. Turner's (1898) map shows a drift mine at the site, but no indications of underground workings can be seen today. MacBoyle (1920a, p. 21) also described the drift, but that may be based only on Turner (1898).

Near the Trails West marker, arkose and quartz-pebble conglomerate lie on hornblende quartz diorite. The sands and conglomerates are overlain by Lovejoy Basalt (Durrell, 1959; Hietanen, 1973; Table 1), which lies directly on the quartz diorite in many places. Apparently, these Auriferous Gravels were locally cut out by later, pre-Lovejoy, erosion or were not deposited. The Lovejoy is well exposed in a quarry along the highway about 1 km to the northwest. Durrell (1959) reported a thickness of about 60 m for the Lovejoy near Buckeye. The outcrop of Lovejoy appears to be a remnant of paleovalley-filling flows; the most likely direction of this channel was west or southwest. Probable cross beds and cut-and-fill features in underlying Eocene(?) sandstone suggest a southerly direction of transport. Lovejoy basalt that flowed down a paleovalley here may have once continued to the Oroville area where Lovejoy caps Table Mountain. Any evidence of prevolcanic Auriferous Gravels between Oroville or Cherokee and Buckeye has apparently been destroyed by Miocene or Quaternary erosion.

The Auriferous Gravels at Buckeye consist of nearly horizontal beds of clean arkosic sandstone, pebbly sandstone, and quartz-pebble to cobble conglomerate. Feldspar grains in the sand were probably derived from underlying granitic rock. Pebbles are well rounded to subrounded. Chert cobbles have crescentic percussion marks related to high-energy stream transport. No Tertiary volcanic clasts were observed.

Monte Cristo Mine—Turner (1898) described gravel, capped by andesite breccia, cropping out at the south end of a ridge that projects south from Spanish Peak (Fig. 4). The gravels do not crop out, but clasts observed in float near the probable contact with underlying granodiorite consist of both pre-Tertiary and Tertiary rocks. The clasts of pre-Tertiary rock are well rounded and polished, 1–15 cm long, and consist of light brown and reddish quartzite, black chert, dark gray to black chert-pebble conglomerate, white vein quartz, light gray pebbly quartzite, and quartz-veined dark gray silicified schist. The clasts of Tertiary rocks are well rounded but not polished; they include light gray pyroxene-plagioclase andesite and finely crystalline, black, magnetic basalt (Lovejoy Basalt?). Turner (1898) also reported pebbles of pyroxene andesite in the gravels, as well as fossil leaves of late Miocene age. Miocene pollen is reported from the gravels and sands (Howard Schorn, written commun., 2003). Deposits of gravel in a similar stratigraphic position to those of the Monte Cristo Mine site are reported to the north on Spanish Peak (Fig. 4) and about 1.5 km to the northeast of the peak (Hietanen, 1973).

Because the gravel deposits in the Spanish Peak/Monte Cristo Mine area are apparently Miocene, and apparently represent an interandesitic channel or channels, geologic information from the area is not as useful for projection of Eocene-Oligocene channels as older gravel deposits. The presence of cobbles of possible Lovejoy Basalt in the gravels suggests that the channel below the andesite lahars on Spanish Peak is younger than ~16 Ma. The clasts of pre-Tertiary rock may have been eroded from older Eocene(?) gravels, possibly those which crop out at Bean Hill and vicinity (see below).

Bean Hill—Bean Hill is an area of relatively extensive hydraulic mining over at least 15 acres (6 hectares) along the main road about 4 km north of Meadow Valley (Fig. 4). Based on the clasts observed in the piles of hydraulically mined material, the smooth, well rounded clasts consist of about 80 percent white vein quartz, and most of the remainder metasedimentary rocks. A few clasts that lie directly on the ultramafic bedrock are derived from that rock type, consisting of a carbonate-rich ultramafic alteration product. One boulder from the bedrock contact consists of a feldspar metaporphyry. Hietanen (1973, p. 57) reported that pebbles on Bean Creek in the vicinity of this area consist of about 80 percent vein quartz, 8 percent gray chert, and 12 percent quartzite from the Silurian(?) Shoo Fly Formation and that larger pebbles and cobbles consist of 60 percent vein quartz and 40 percent Shoo Fly. Locally, one can see blocks of the original conglomerate that hydraulic mining did not completely break up. The cement in these conglomerates is, at least in part, iron oxide minerals (possibly originally pyrite).

Because the gravel has been stripped to bedrock over most of the mined area, it is possible to estimate the channel width and direction. Just east of Bean Hill, the channel appears to trend nearly north, but turns to the northeast (to about N30°E) upstream. The channel is only about 100 m wide and rises steeply to the northeast, probably about 1000 ft/mile (190 m/km). This channel cannot be the main course of an Eocene river, but more likely a side channel or possibly the gutter part of a much broader channel that has been removed by erosion. Hietanen (1973, p. 57) reported that the clasts of Shoo Fly probably come from Shoo Fly outcrops about 2 km to the northeast, suggesting a southwest transport direction for the paleostream. Similar gravels lie below younger andesitic mudflows both to the northwest and southeast; we interpret them to have been deposited in side channels similar to the Bean Hill channel.

Moonlight Valley-West Branch Lights Creek—Diller (1908, p. 66) reported that Tertiary sandstone and conglomerate crop out in the vicinity of Moonlight. McFarlane (1981, p. 42–43) reported that the Tertiary sedimentary rocks of Moonlight Valley consist mainly of arkose and less conglomerate, with coal seams that locally contain leaf fossils. Diller (1908, p. 66, 92) also reported that collections of the fossil leaves were made, from an area "near the eastern end of Moonlight on the slope toward the west fork of Lights Creek at an elevation of about 6000 feet." Elsewhere in Diller (1908, p. 66), Moonlight is described as being 12 miles (19.3 km) north of Taylorsville at the head of Surprise Creek. It appears from the usage in Diller (e.g., 1908, p. 118), that Moonlight is a peak, probably Moonlight Peak of the Moonlight Peak 7.5-minute quadrangle. According to Durrell (1959, p. 215), Diller's flora locality is near the center of Section 36, T28N, R10E. The sedimentary rocks crop out for a distance of about 4.5 km along Moonlight Valley (Fig. 4) and the West Branch Lights Creek (Grose et al., 1990). According to Diller (1908, p. 117) Auriferous Gravels were mined "near the border of Moonlight." The exact location of these placer workings is unknown.

Sedimentary rocks exposed along the West Branch of Lights Creek consist of yellowish weathering arkosic sandstone, granite wash, pebbly sandstone (with pebbles of rotten granite), and interbedded, reddish weathering, light gray pebbly siltstone (with at least one black pebble of tourmalinized? rock). The underlying diorite of the Lights Creek stock crops out about 500 m to the north. The arkose and granite wash appear to be derived from rock more silicic than the Lights Creek stock, probably from light-colored Cretaceous granodiorite exposed about 1 km to the east (as mapped by Grose et al., 1990). Well rounded pebbles and cobbles of resistant pre-Tertiary rocks are seen as float or lag on the sandstone beds; these clasts may have been derived from nearby beds of coarser conglomerate. However, McFarlane (1981, Plate 1 and p. 43) showed Pleistocene(?) gravels having rounded to well rounded clasts exposed just to the south. The cobbles that litter the surface are all of pre-Tertiary rocks, and consist of black tourmaline-bearing diorite, tourmalinized and pyritic rock and breccia (both presumably from the Lights Creek stock), light-gray chert, light-gray quartzite, and reddish chert-pebble conglomerate (from some Mesozoic metasedimentary unit).

To the southwest along the West Branch of Lights Creek, cross beds in the arkose are inclined to the southwest (S20°–50°W) while some channel-like features trend northeast-southwest. Probably the best indication of stream direction is the northeast-southwest trend of the outcrop of the sedimentary rocks in an apparent channel down the West Branch of Lights Creek toward Moonlight Valley (see McFarlane, 1981, Plate 1; Grose et al., 1990). We interpret this west-trending paleovalley to connect with a southerly trending paleovalley from the head of Cheney Creek (Fig. 4, see below).

Lindgren (1911, p. 63) reported that the fossils from the lower beds south of Susanville (presumably Moonlight) and a locality "7.5 miles southwest of Susanville"(see the description of the Cheney Creek area below), are clearly Eocene. Axelrod (personal commun., in Durrell, 1959) also confirmed the Eocene age based on a later collection from the same locality.

Head of Cheney Creek (Susanville Flora)—Diller (1889, p. 417) reported fossil leaves from a thin, lenticular shale in conglomerate a short distance north of the summit on the Lights Canyon-Susanville Road. The complete description is:

> … about three fourths of a mile north of the point where the Light Cañon and Susanville road crosses the summit. The surest way to reach the exposure is to start from the first small bridge, one-fourth of a mile below the summit on the Susanville side, and go up the gulch almost directly west for a few hundred yards to the summit of a partially bare ridge. Cliffs of conglomerate appear on the left (south side) as the summit is approached. The ridge or rather spur extends northerly and upon its sides soon appear two deep, precipitous, rocky gulches which unite about a quarter of a mile below. More than half way down the spur on its northwesterly slope, in an open space about fifty feet above the bottom of the gulch, the very limited exposures may be found.

The above location is apparently the same one referred to by Diller (1908, p. 74) to be "three-fourths of a mile north of the road summit between Taylorsville and Susanville, at an elevation of 6000 feet on the slope of Gold Run, and about 7$^1/_2$ miles southwest of Susanville." Diller (1908, p. 76) reported that "The small lens of shale collected in 1886 was exhausted, but another shaly lens nearby in the same conglomerate furnished the material collected by James Storrs in 1904." Storrs was a field assistant to Diller. Diller (1908, p. 77) reported that "The lenses differ lithologically and the floras are different, but they are reported by Storrs to be in the same mass of conglomerate and therefore essentially the same age." The 1889 Diller location is very close to a site location provided by Howard Schorn (written commun., 2003). This site is along a ridge that follows the Section 32-33 boundary, in SW$^1/_4$ NW$^1/_4$ SW$^1/_4$ Section 33, T29N, R11E. This is certainly very close to the sites described by Diller (1878, 1908), although Diller's 1878 description may refer to an area slightly closer to the gulch east of the ridge. It may be that the site visited for this study is Storrs' later site (Diller, 1908, p. 68). The gravels at the Storrs' site are reported to be cut by dike-like bodies of hornblende andesite (Diller, 1908, p. 68), which were not observed during a visit for this study. However, Diller (1893, p. 399) did mention that the area where the gravels are cut by dikes is at the head of Cheney Creek (Fig. 4), essentially the area examined in 2003 for this study. Lindgren (1911, p. 115) described what is apparently this same site as being "7$^1/_2$ miles southwest of Susanville near the head of Willard Creek." Although the head of Willard Creek is 5 or 6 km southwest of this locality on Cheney Creek, the description otherwise appears similar. Knowlton 1911, p. 60) described the earlier collected flora locality as being in a deep ravine and the later collected flora as being "apparently at a higher horizon." We conclude that the site on the ridge, where leaf fossils can still be found, is the later collected site discovered by Storrs.

The fossil leaves are found as impressions and darker films on bedding planes of light grayish green, fine-grained sandstone to siltstone. The leaf-bearing sandstone is underlain by a dark greenish to purplish gray conglomerate containing pebbles and cobbles of andesite and granodiorite in a sandy matrix consisting of small rock grains, and granodiorite- and andesite(?)-derived feldspathic sand. The andesite is somewhat altered, containing cloudy plagioclase and chloritized mafic minerals (including biotite). The beds are subhorizontal. To the south up the ridge approximately 400 m (about 120 m vertically up section), a hornblende andesite flow is interbedded with conglomerate containing clasts of hornblende andesite, gray quartzite, metaconglomerate, and white granitic rock. The conglomerate beds exposed along the ridge are all somewhat similar, and there does not appear to be any significant stratigraphic change or break between the flora beds and the hornblende andesite flow higher in the section. Knowlton (1911, p. 63) regarded the Susanville flora as clearly Eocene and older than the other known flora from the Auriferous Gravels of California. This flora age determination poses somewhat of a problem, because no Eocene volcanism has been dated from this area. Grose (1993) mapped the gravels in the vicinity of Cheney Creek in his unit Tvg (Miocene?), and he reported that the gravels intertongue and are transitional with overlying andesite flows (Grose et al., 1990). Based on available K-Ar dating in the Susanville area, the overlying andesite flows are only ~11 Ma (Grose et al., 1990, Table 1). Thus, based on present knowledge, it does not seem reasonable that the leaf-bearing beds are Eocene while somewhat stratigraphically higher beds are 25–30 million years younger.

Gravels of probable Miocene age (unit Tvg of Grose, 1993) are widespread in the area southwest of Susanville. They were considered by Diller (1906) to be evidence for an Eocene delta at the mouth of the Tertiary Jura River. Much of the gravel contains clasts of probable Miocene andesite, and is, thus, considerably younger than the Auriferous Gravels. Probably some Auriferous Gravels were reworked in the Miocene, with consequent destruction of evidence for Eocene paleovalleys.

If the andesitic flows and conglomerates of the Cheney Creek area are Eocene, they may represent a southern extension of the Clarno Arc (Walker and Robinson, 1990) of central Oregon. Andesitic rocks of this arc are as old as about 39 Ma in the vicinity of Cedarville (Myers, 1998, p. 11), 150 km to the northeast (Fig. 1). Any evidence of Eocene(?) gravels between Cedarville and Susanville is limited to two areas: Deans Ridge, just east of Eagle Lake (19 km northwest of Susanville), and Crest Lake Reservoir (42 km northeast of Susanville).

Deans Ridge—Grose et al. (1992) showed two small outcrops of siliceous pebble-cobble conglomerate near the north end of Deans Ridge (Figs. 1, 3), 19 km northeast of Susanville. Clasts from the conglomerate at one site include subrounded to subangular cobbles and pebbles of metaigneous rock, probably mainly meta-andesite. The other clasts consist of schist, gneiss, flaser gneiss, and amphibolite. At a nearby site, the conglomerate consists of well rounded pebbles, up to about 5 cm in diameter, of light gray quartzite, black chert, and less aplite in a matrix of granite wash and dark metamorphic sand. The light gray quartzite pebbles resemble those from the Crest Reservoir area (see below), suggesting a possible source to the east or northeast, in northern Nevada.

Crest Lake Reservoir—Smooth, rounded pebbles of pre-Tertiary rocks have been observed in float near the old railroad siding of Crest, 42 km northeast of Susanville (oral commun., 2004, T.L.T. Grose, M.C. Reheis, R. Bowers). The clasts are smooth to somewhat pitted, rounded pebbles of resistant rock types (chert, vein quartz, quartzite) that occur as a small percentage of the pebbles and cobbles on the surface of a dry lake or reservoir (Crest Reservoir; Fig. 1)). Most of the pebbles and cobbles that litter the surface of the dry lake are subrounded to rounded vesicular basalt. Some of the smooth pre-Tertiary pebbles display crescentic percussion marks. Because of the differences in maturity, the smooth pebbles are almost certainly multicycle with respect to the basalt clasts. Although the source conglomerate for the float clasts on the playa was not observed, it is apparently a unit or units within the Miocene and Pliocene mafic flows and interbedded tuffs and gravels (see Grose and Abrams, 1991). Outcrops of pre-Miocene Tertiary rocks are unknown in the vicinity. The nearest outcrop of older Tertiary conglomerate is 70 km to the northeast near Eagleville and Cedarville and 35 km to the southwest at Deans Ridge (see above). The presence of the smooth rounded pebbles here suggests that an Eocene paleochannel may have existed somewhere in this area before being at least partly eroded in the Miocene.

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