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GEOLOGIC MAP OF THE MEADOW VALLEY MOUNTAINS, LINCOLN AND CLARK COUNTIES, NEVADA

By E.H. Pampeyan

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INTRODUCTION

The Meadow Valley Mountains are located in Lincoln and Clark Counties, southern Nevada, in the southern part of the Basin and Range province. They lie east of the interior drainage of the Great Basin and are in the Colorado River drainage system. The center of the range is about 103 km north-northeast of Las Vegas (fig. 1). The range is separated from the Mormon Mountains on the east and Clover Mountains on the north by Meadow Valley Wash, from the Delamar Mountains to the northwest by Kane Springs Wash, from the Sheep Range to the west by Pahranagat Wash and Coyote Spring

Figure 1. Index map of southeastern Nevada showing location of Meadow Valley Mountains.

Valley, and from Arrow Canyon Range to the south by Nevada Highway 168. The map area is bounded on the northwest by Nevada Highway 317 in Kane Springs Valley (a narrow alluviated drainage area commonly referred to as Kane Springs Wash), on the east by Meadow Valley Wash, and on the north by a dirt road connecting Nevada Highway 317 with Lyman Crossing in Meadow Valley Wash. The terrain is hilly to rugged with steep bedrock scarps on the west side and sharply incised gentle to moderately inclined alluviated slopes on the east side. The highest point is an unnamed ridge near the center of the range that stands 1,759 m above sea level, 853 m above the adjacent floor of Kane Springs Wash.

The names Farrier, Rox, Hoya, Galt, Vigo, Carp, Leith, and Elgin formerly marked sites of small railroad maintainence stations spaced about 8 km apart along the Union Pacific Railroad in Meadow Valley Wash. These names now apply to railroad sidings at those sites. Sunflower Mountain, Grapevine Spring, Bunker Hills, Farrier Wash, and Hackberry Canyon are the principal formally named geographic or topographic features in the map area and for lack of other formally named features these are used as reference points. The names "Two Flats" and "Anticline" are informally applied to canyons along the west edge of the range (map sheet 2) where the range front changes direction from north-south to northeast.

PREVIOUS AND PRESENT INVESTIGATIONS

The pre-Tertiary sedimentary rocks of the Meadow Valley Mountains were mapped in a rapid reconnaissance fashion in the late 1950's as part of geologic studies of Clark (Bowyer and others, 1958; Longwell and others, 1965) and Lincoln (Tschanz and Pampeyan, 1961, 1970) Counties, Nev. These early studies include descriptions of the geology and mineral deposits of this map area and the surrounding region (fig. 2). Detailed geologic mapping of small areas in the Meadow Valley Mountains was done by Duley (1957), Webster and Lane (1967), and Webster (1969) as part of stratigraphic studies of Mississippian rocks, and by Heston (1982) who studied the distribution of trace elements in the Chainman Shale near Grapevine Spring. The Tertiary volcanic rocks were examined by Cook (1965; unpub. data, 1955-1968), who measured stratigraphic sections in and near the Meadow Valley Mountains, and by Ekren and others (1977) as part of
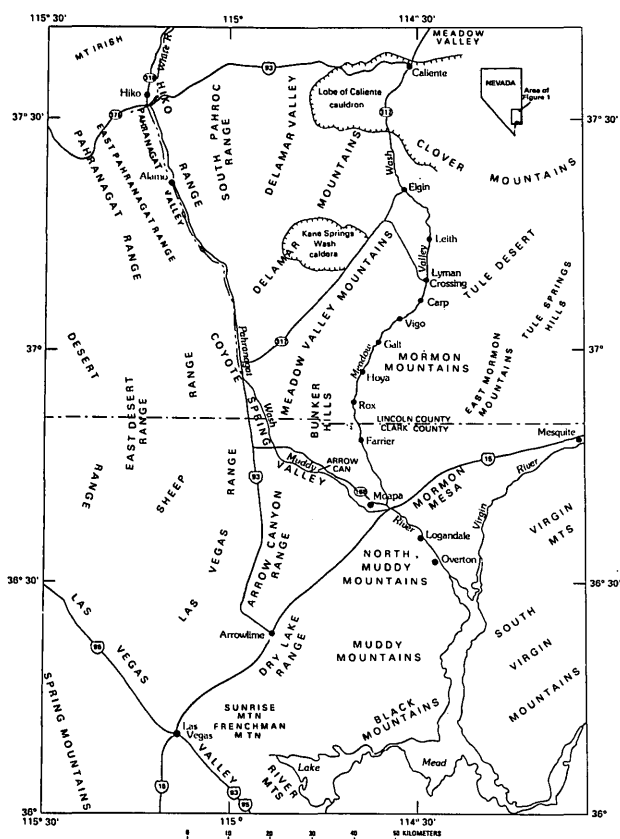
1. Tschanz and Pampeyan (1961, 1970); Ekren and others (1977)
2. Noble (1968)
3. Novak (1984, 1985)
4. Duley (1957)
5. Heston (1982)
6. Webster (1969)
7. Longwell and others (1965); Bowyer and others (1958)
8. P.H. Heckel and A. Reso, south Delamar section (unpub. data, 1960)
9. Pampeyan and others (1988); Campbell (1987)1
10. A, Cook (1965); B, E.F. Cook, Kane Wash section (unpub. data, 1955); C, E.F. Cook, Meadow Valley section (unpub. data, 1956)
11. Scott and others (1988)
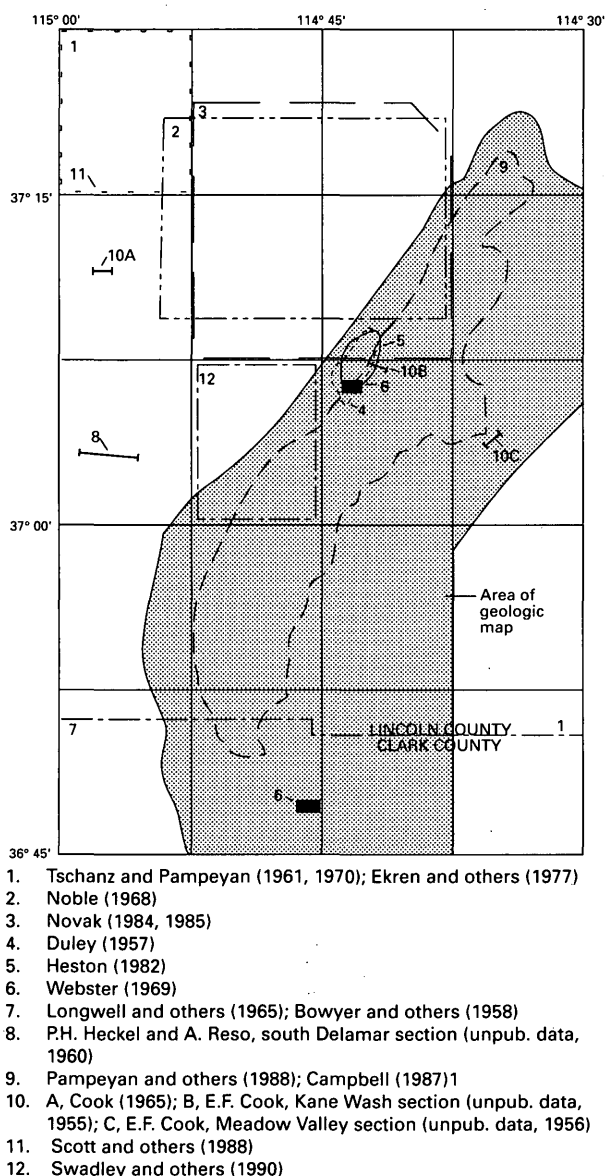12. Swadley and others (1990)

Figure 2. Sources of geologic data used in this report.

regional study that refined the volcanic stratigraphy of Lincoln County. Studies of the Kane Springs Wash caldera in the adjacent southern Delamar Mountains (fig. 1) were made by Noble (1968) and Novak (1984, 1985), and the Paleozoic section there was measured by P.H. Heckel and Anthony Reso (unpub. data, 1960). Detailed mapping in the southern Delamar Mountains (Scott and others, 1988, 1990; Swadley and others, 1990; Page and others, 1990) and northern Meadow Valley Mountains (Anne Harding, written commun., 1987; Harding and others, 1991), some of which overlaps this map area, commenced after this study was completed. The studies by Cook, Novak, Heckel and Reso, Scott and others, and Swadley and others provided stratigraphic information useful in this report.

Mineral resources of the region have been studied by several investigators. Gypsum deposits of the region were described by Jones and Stone (1920) and perlite deposits in and near Meadow Valley Wash were evaluated by K.L.

Cochran (written commun., 1951). The oil and gas potential of a region including the Meadow Valley Mountains was evaluated by Sandberg (1983). A reconnaissance geochemical assessment of the map area was made by Hoffman and Day (1984), and the mineral resources of the map area were described by Campbell (1987).

This map was prepared from data gathered during eight weeks of reconnaissance geologic mapping between April 1985 and September 1987 supplemented with photogeologic interpretation of 1:31,680-scale natural-color aerial photographs of the map area. This work was an integral part of a study requested by the U.S. Bureau of Land Management to evaluate the mineral resource potential of the Meadow Valley Range Wilderness Study Area, a cooperative effort by the U.S. Geological Survey and the U.S. Bureau of Mines (Pampeyan and others, 1988). The Meadow Valley Range Wilderness Study Area covers about 393 km^2 (97,180 acres) or about 30 percent of the area included in this map.

ACKNOWLEDGMENTS

The author was assisted in the field at various times by Jacqueline C. Shulters, David A. Plume, John C. Monroe, and Kari N. Bassett. Paul Henri, James and Donald Bradshaw of Caliente, Nev., and Henry Rice of Logandale, Nev., supplied information on the history of, and access to, the map area. Randy Wilson of the U.S. Department of Agriculture Soil Conservation Service, Caliente District Office, provided information on soil surveys in and near the map area, and oil companies provided some generalized stratigraphic information on the Paleozoic rocks.

GEOLOGIC SETTING

The Meadow Valley Mountains are underlain by a sequence of folded and faulted sedimentary rocks of Cambrian through Triassic age that are well exposed in the south half of the range. The sedimentary rocks are unconformably overlain in the north half of the range by a sequence of interlayered volcanic tuffs and flows of Miocene age, some of which originated just west of the study area in the Kane Springs Wash caldera (fig. 1; Noble, 1968; Novak, 1984). The remainder of the volcanic rocks are thought to have originated to the north in the Caliente cauldron complex (fig. 1; Ekren and others, 1977).

The volcanic sequence consists mainly of welded ash-flow tuffs, with minor rhyolitic and basaltic flows, and rhyolite dikes that cut the tuffs and flows. Correlation of volcanic units in the map area is based on field megascopic examination of rocks and comparison with written descriptions by E.F. Cook (1965; unpub. data, 1955-1968), Williams (1967), Ekren and others (1977), and Novak (1984). For details on the mineralogy and chemistry of the welded tuffs see Cook (1965), Williams (1967), Noble (1968), Ekren and others (1977), and Novak (1984, 1985). The volcanic rocks in the northern part of the volcanic terrane, whose stratigraphic relations

are complex and largely unknown, consist of interlayered welded tuffs and flows cut by dikes. Detailed mapping in that area (Harding and others, 1991) has begun to uncover the key to relations between the Kane Springs Wash caldera to the west (Noble, 1968; Novak, 1984), the volcanic rocks in northernmost part of the Meadow Valley Mountains, and the Caliente cauldron complex to the north (Ekren and others, 1977). The volcanic sequence in the south half of the volcanic terrane can be divided into upper and lower halves. The upper half of the volcanic sequence consists largely of rhyolitic ash-flow tuffs and flows of the Kane Wash Tuff, related rocks, and some basalt flows (Cook, 1965; Ekren and others, 1977; Novak, 1984), most of which erupted from in or near the Kane Springs Wash caldera whose east end is in the Meadow Valley Mountains. The rhyolitic flows are locally perlitic, and some of the interlayered tuffs are zeolitized. The lower half of the volcanic sequence consists of four dacitic to rhyolitic welded ash-flow tuff formations which are from youngest to oldest the Hiko Tuff, Harmony Hills Tuff, Bauers Tuff Member of the Condor Canyon Formation, and Leach Canyon Formation, and a basalt flow-breccia that is present only in the southeast corner of the volcanic terrane underlying the Harmony Hills Tuff. The ash-flow tuff formations in the lower half of the volcanic sequence probably erupted from the Caliente cauldron north of the study area (Noble and McKee, 1972; Ekren and others, 1977); the basalt breccia may have originated from a vent a few kilometers west of Vigo, where the thickest section of breccia is exposed.

The total volcanic sequence is about 720 m thick in the escarpment along Kane Springs Wash and thins to about 651 m west of Vigo (fig. 3). The volcanic sequence is of Miocene age, the upper half 15.4 to 11.4 Ma (Novak, 1984), and the lower half 24.6 to 18 Ma (Armstrong, 1970; Noble and McKee, 1972; Marvin and others, 1973; Rowley and others, 1975). Patches of welded tuff are present throughout the southern part of the map area. All but one of these patches appears to be Kane Wash Tuff, and the exception appears to be Hiko Tuff. For convenience, Novak's (1984) nomenclature for the Kane Wash Tuff, where applicable, has been used in this map.

The northwest-facing escarpment along Kane Springs Wash provides an excellent stratigraphic section of the welded ash-flow tuff formations from the Leach Canyon through Kane Wash units. The volcanic section exposed in Hackberry Canyon is somewhat similar but contains other interlayered volcanic units, for example, the thick unit of basalt breccia, a thin amygdaloidal basalt flow, and some thin welded tuff that was not recognized elsewhere in the map area.

Basalt flows (Tb_1, Tb_2, Tb_3) represent separate pulses of activity from different(?) but related sources, some of which were along Kane Springs Wash (Novak, 1984) and others near Hackberry Canyon. Unit Tb_3, the youngest flow in the map area, rests unconformably on units 2 (Tku_2) and 3 (Tku_3) of the Kane Wash Tuff and has a K-Ar age of 11.4 Ma (Novak, 1984); unit Tb_2 consists of thin flows interlayered with rhyolitic flows and tuffs in the upper(?) part of the Kane Wash Tuff (Tk) and rhyolite (Tr)

units; unit Tb_1, an amygdaloidal basalt, rests unconformably on Hiko Tuff (Th) and is overlain by undivided strata of the Kane Wash Tuff (unit Tku). The oldest basalt in the map area is exposed at one locality near the mouth of Hackberry Canyon where it rests on red-bed strata at the base of the volcanic section. This flow and a thin overlying ash-fall(?) tuff pinch out laterally and a lens of conglomerate (Tc) is found at the next exposure of this stratigraphic interval. The old basalt, tuff, and conglomerate, however, are too thin to show at the map scale of 1:50,000. Basalts younger than 11.4 Ma are present outside of the map area, for example, at Leith siding, about 3 km east of the map area (fig. 1), a basalt flow resting on Kane Wash Tuff has a K-Ar age of 8.7 Ma (Ekren and others, 1977).

The Kane Wash Formation, as defined by Cook (1965) in the southern Delamar Mountains, included a basalt flow as the basal unit. Noble (1968) stratigraphically restricted the flow rocks (and unrelated sedimentary rocks) from the formation and applied the name Kane Wash tuff to the remaining units described by Cook (1965) and considered them to have been erupted from the Kane Springs Wash caldera. Novak (1984) refined the stratigraphy of the Kane Wash Tuff and applied letter-symbol names to mappable cooling units, some of which are used in this report. Novak (1984) also determined that the lower two units of the Kane Wash Tuff (Tko and Tkw) had an eruptive source west of the Kane Springs Wash caldera. Subsequently, workers in the southern Delamar Mountains (Scott and others, 1988), in the process of formalizing the member status of the cooling units, have substituted geographic names for Novak's letter-symbol names. In the Meadow Valley Mountains the upper part of the Kane Wash Tuff consists of at least three welded ash-flow tuffs, in ascending order units 1, 2, and 3 (Tku_1, Tku_2, and Tku_3, respectively); the lower part consists of a thick lithic tuff, unit W (Tkw) overlying a densely welded tuff, unit O (Tko). On this map the upper three units are mapped separately near the center of the volcanic terrane but are left undivided (Tku) throughout most of the map area.

In this study, no biotite or plagioclase was recognized in tuff above the Hiko near Cook's Meadow Valley and Kane Wash measured sections, and this agrees with the findings of Noble (1968) and Novak (1984) that plagioclase and biotite are rare or absent in true Kane Wash tuffs. However, R.B. Scott (written commun., 1988) reports xenocrystic plagioclase and biotite in some samples from Cook's (1965) type section of the Kane Wash Formation in the southern Delamar Mountains. It is possible, therefore, that Cook either misidentified altered mafic minerals and sanidine in his modal analyses (fig. 3) or did not recognize the xenocrystic origin of the plagioclase and biotite he reported in his samples.

Occurrences of carbonate-rich Kane Wash lithic-crystal tuff are present 5.6 km northeast of Grapevine Springs in unit 1 (Tku_1) where calcite has replaced the groundmass leaving the crystals suspended in a calcite matrix. This calcification appears to have selectively affected certain layers of tuff, for the lateral extent of the bodies is significantly greater than the vertical extent, and
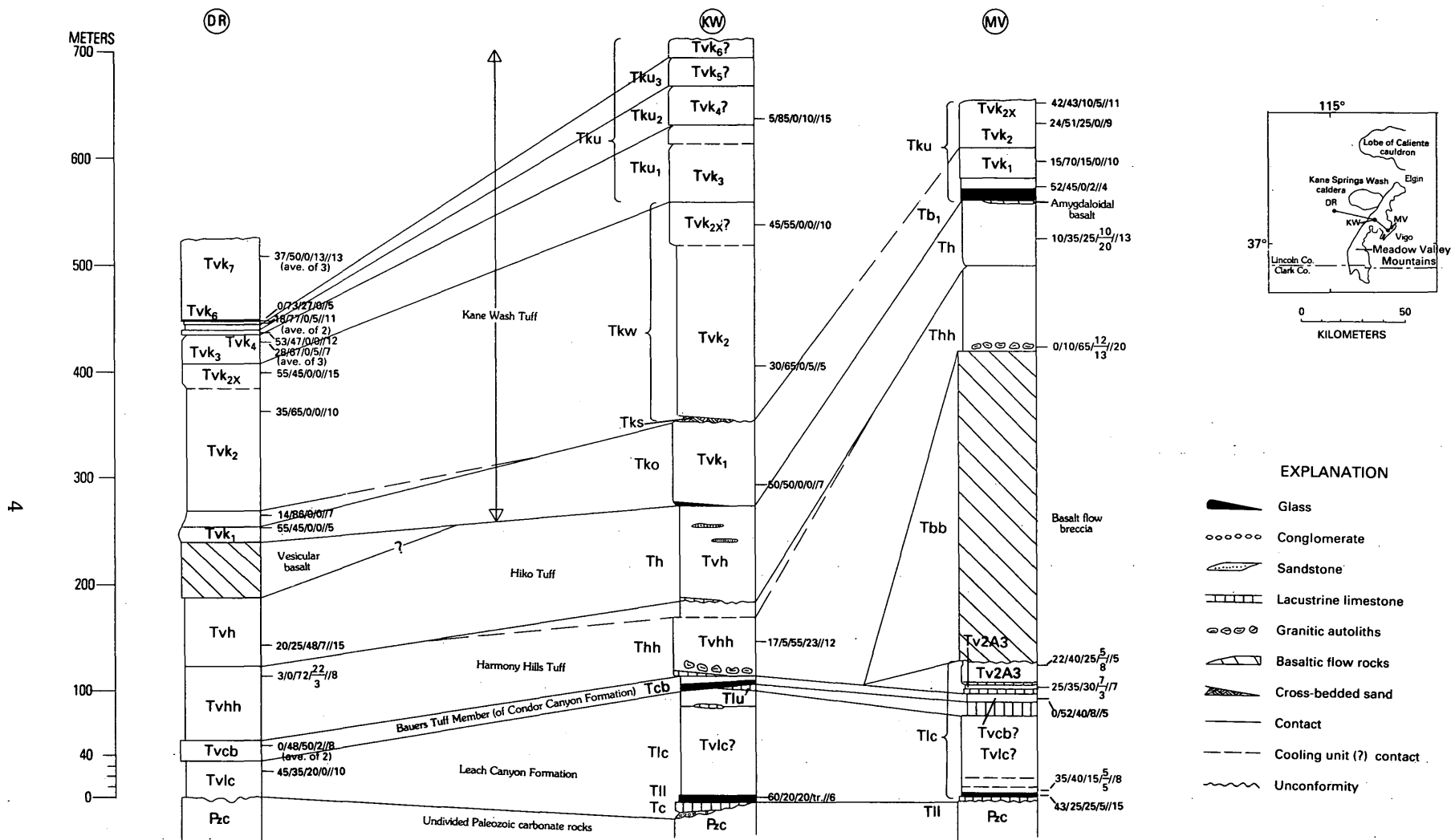
Figure 3. Stratigraphic sections of volcanic rocks in the Meadow Valley Mountains (localities KW and MV) compared with the type section of the Kane Wash Tuff in the southern Delamar Mountains (locality DR), modified from Cook (1965) and E.F. Cook, unpublished data, 1955, 1956 (see also Noble, 1968. Novak, 1984). The exact locations of sections KW (Kane Wash) and MV (Meadow Valley) are unknown. KW appears to be a composite section from the escarpment east of Grapevine Spring. MV probably is along a north trending line 2.4 km west of Vigo siding. Unit symbols inside section columns are from Cook (1965); E.F. Cook, unpub. data, 1955, 1956); unit symbols to outside columns are those used in this report. Numbers to right of columns (for example 45/25/20/ $\frac{7}{3}$//10) represent phenocryst composition, in percent, as percentage of total crystals in specimens collected at these sites—that is: quartz/sanidine, plagioclase/$\frac{biotite}{hornblende}$//crystal content in percent of entire rock (Williams, 1960; Cook, 1965); tr, trace; ave., average of more than one sample. Cook's inclusion of plagioclase and biotite as primary constituents in his modal analyses of the Kane Wash Tuff samples is questionable. The Kane Wash Tuff contains biotite-rich lithic fragments and plagioclase xenocrysts from underlying formations (R.B. Scott, written commun., 1988) but lacks primary biotite or plagioclase (Novak, 1984). Tuffs overlying the Hiko Tuff (unit Th), and shown as the uppermost part of the Kane Wash Tuff (unit Tku) in the vicinity of Hackberry Canyon, near the location of Cook's section MV, do not closely resemble corresponding tuffs near Kane Springs Wash but do contain adularescent (sodic) sanidine, which most commonly occurs in units of the Kane Wash Tuff. See Description of Map Units (map sheet 1) for complete explanation of map unit symbols used in this report.

no crosscutting relations were seen. Carbonate-rich float identical to the above described rock was found downslope from a locality at the crest of the volcanic escarpment, 3.6 km northeast of Sunflower Mountain. This locality was described by Tieh and Cook (1971) as an occurrence of carbonate-rich dikes in the Kane Wash Tuff where the carbonate probably originated through melting of limestone by a rhyolite magma.

A thin feldspathic sandstone (Tks) lies between units O (Tko) and W (Tkw) of the Kane Wash Tuff. In one area 1.6 km west of Sunflower Mountain the sandstone is about 12 m thick and consists of an upper half of grayish-yellow, well-sorted and crossbedded sandstone with interlayered ash beds and a lower half of light- to moderate-red, poorly sorted sandstone in graded and cross-stratified beds. Crossbedding in this sandstone is large scale trough type with wavelengths of several meters. The sandstone was not seen north of the vicinity of Grapevine Spring or in the volcanic scarp west of Vigo; its northeastern-most exposure is 9.5 km northwest of Vigo. At a few localities a thin, poorly exposed, partly welded lithic tuff separates the sandstone (Tks) or overlying unit W from an underlying erosion surface developed on densely welded unit O. In most exposures unit O is densely welded—slabs emitting a metallic ring when struck with a hammer—and is easily recognized by its unique eutaxitic texture. Near its northernmost exposure the upper part of unit O appears to be altered to a depth of about 4 m, possibly the result of its proximity to the eastward projection of the Kane Springs Wash caldera boundary.

Volcanic rocks in the northernmost part of the map area consist of rhyolitic flows and ash-flow tuff of the undivided rhyolite and Kane Wash Tuff unit (Trk). Locally some of the tuff appears to have melted and flowed during welding and superficially resembles a rhyolite flow.

Numerous rhyolite dikes, some of which form resistant ridges in the host rocks and others which blend into the host rocks, are present in the volcanic terrane. The dikes commonly have thin, black or dark-green, vitreous margins and yellowish-gray to pale-yellowish-brown, flow-banded cores and do not appear to have significantly altered the enclosing rocks. The dikes average a few meters in thickness and the most prominent ones form a north-trending swarm about 3 km long. Stream-sediment samples from the area cut by dikes contain anomalous amounts of beryllium, tin, thorium, and yttrium (Hoffman and Day, 1984), but subsequent samples of stream sediment and dike rock from the same area were not enriched in those elements (Pampeyan and others, 1988). A dike containing flow-banded rhyolite breccia cemented by color-banded carbonate minerals cuts the Harmony Hills Tuff 1.6 km northeast of Grapevine Spring. This latter dike bears no resemblance to the rhyolite dikes farther north or to the carbonate-rich Kane Wash Tuff noted above.

The Hiko and Harmony Hills Tuffs are easily recognized over most of the volcanic terrane, but the underlying Bauers Tuff Member of the Condor Canyon Formation is thin and mostly concealed by slope wash. About 4 km south of Sunflower Mountain, however, the Bauers is well exposed and appears to be as thick as 80 m. The Leach Canyon Formation is poorly exposed and commonly appears as a light-gray amorphous blanket of poorly welded tuff particles resting on a ledge of lacustrine limestone and overlain by Harmony Hills Tuff.

In Hackberry Canyon and the volcanic escarpment to the south, a distinctive unit of basalt breccia and related rocks (Tbb) underlies the Harmony Hills Tuff. This unit is thickest about 2.4 km west of Vigo and thins away from there suggesting its source was somewhere in the vicinity of the thickest exposure. The source, however, if exposed, was not recognized.

In the south-facing volcanic escarpment west of Vigo, the Leach Canyon Formation is overlain by a sequence of three lacustrine limestones separating three ash-flow tuff units (fig. 3), all of which are too thin to show at this map scale. The lowest tuff unit is mineralogically equivalent to the Bauers. E.F. Cook (unpub. data, 1956) designated the upper two tuff units Tv2A3, a symbol he used for pumice sillars and pumiceous tuffs with interlayered volcanic and lacustrine sediments lying between the Leach Canyon Formation and Harmony Hills or Hiko Tuffs in his draft stratigraphic sections of the Delamar, Pahroc, and Tempiute ranges, Tower Spring, and Black and Condor Canyons, in addition to the Meadow Valley Mountains. These tuff units in all sections except for the Meadow Valley Mountains have no megascopic mafic component; the average phenocryst content is 10 percent, which consists of 46 percent quartz, 42 percent alkali feldspar, and 12 percent plagioclase (Cook, 1965). In Cook's Meadow Valley section (MV, fig. 3) both biotite and hornblende, and a greater amount of plagioclase, are present in tuff he designated Tv2A3.

Lacustrine limestone is present locally at several horizons in the volcanic section but is almost everywhere present at the base of the section, resting on folded and faulted Paleozoic and Mesozoic strata, typically as a single unit about 20 m thick. Locally, a reddish-orange-weathering cobble conglomerate (Tc) underlies the lower lacustrine limestone (Tll), appearing to fill depressions in an erosion surface developed on deformed pre-Tertiary sedimentary strata. In a few places, for example, 3 km northeast of Sunflower Mountain, the lower lacustrine limestone appears to interfinger with the cobble conglomerate. Lacustrine limestone higher in the volcanic section occurs only locally and in places is interlayered with very thin tuff units, for example, as noted above, west of Vigo (MV, fig. 3). Only one occurrence of limestone within the volcanic sequence (unit Tlu 3 km north of Sunflower Mountain) was large enough to be shown on the geologic map. The lacustrine limestone in Lincoln County was considered to be Miocene or younger in age, on the basis of fossil pollen and pre-1960 K-Ar ages of 24 to 28 Ma, and the conglomerate probably Cretaceous to Oligocene (Tschanz, 1960; Tschanz and Pampeyan, 1970). Use of more recent radiometric age data from the volcanic sequence in adjacent areas indicates the lower lacustrine limestone (Tll) of the map area is more likely late Oligocene instead of Miocene; the lower limestone appears to be a partial time-equivalent of the Claron Formation of southwest Utah (Ekren and

others, 1977). The age of the conglomerate is less certain, but it may be as old as Late Cretaceous or as young as Oligocene and in this report is considered to be early Tertiary.

The Muddy Creek Formation ("Muddy Creek beds" of Stock, 1921a; "Muddy Valley beds" of Stock 1921b) was named for exposures along Muddy Valley near Overton (fig. 1), where Stock (1921a, b) believed mammalian remains represented an age earlier than Pliocene, possibly Miocene. Potassium-Argon and fission-track ages indicate the Muddy Creek Formation near Lake Mead, about 35 km southeast of the map area, is no older than 10.6 Ma and no younger than 6 Ma (Bohannon, 1984, p. 14). In the vicinity of Rox and Galt, beds here tentatively assigned to the Muddy Creek Formation contain interbedded welded and nonwelded tuff and a thin white horizon that may be a volcanic ash. The welded tuff (Tku) resembles some Kane Wash tuff but the origin of the white nonwelded tuff (Tk) and ash(?) is unknown. In this report, the Muddy Creek Formation is considered to be Miocene and Pliocene(?) in age.

A high cliff exposure of Muddy Creek strata along the east side of Meadow Valley Wash 1.2 km southeast of Rox has a noticeably coarser texture and may be a near-source facies of the Muddy Creek Formation. Olmore (1971, p. 63), however, describes a section of his Rox conglomerate unit in the same area which he believes may correlate with a conglomerate member of the Horse Spring Formation as mapped by Rubey and Callaghan (1936, pl. 8). In this report the Rox section is included within the Muddy Creek Formation because the lithologic characteristics of the two appear to match.

Meadow Valley Wash marks the approximate boundary between thin Paleozoic shelf deposits on the east and thickening miogeosynclinal deposits on the west (Tschanz and Pampeyan, 1970, p. 105; Wernicke and others, 1984). About 8,200 m of pre-Tertiary sedimentary rocks are present in the map area, but no single location displays a continuous section; the sedimentary section here is almost twice as thick as the age-equivalent section in the nearby Mormon Mountains (fig. 3). The apparent rapid change in thickness and lithology has been emphasized by eastward thrusting of the miogeosynclinal section onto the stable shelf section (Wernicke and others, 1984).

Permian and Triassic red-bed and carbonate deposits are present near the center of the Meadow Valley Mountains but—if present—are not exposed in ranges to the north, west, or south. In the Meadow Valley Mountains the Permian and Triassic rocks are assumed to lie under a thrust plate composed of Bird Spring Formation. In the ridge 5 km west of Vigo, an unbroken section consisting of Moenkopi Formation—716 m of Virgin Limestone Member underlain by 30 m of Timpoweap Member—is exposed, and its Shnabkaib Shale Member is assumed to exist under the covered interval to the west (Olmore, 1971). Map measurements indicate the total thickness of Moenkopi strata between the red beds on the east and Shinarump Member of the Chinle Formation on the west is about 825 m, assuming no repetition or reduction by faulting in the covered

interval. Olmore (1971) describes the Timpoweap Member, made up of siltstone and sedimentary chert breccia lenses, as being conformable with his overlying Virgin Member (of the Moenkopi Formation), and describes an unconformity about 163 m below the top of the Virgin Member indicating uplift and erosion during, as well as before, deposition of the Moenkopi. In addition to Olmore's two unconformities, however, at some places the chert breccia is bounded above as well as below by an angular discordance.

Exposures of cherty limestone in Hackberry Canyon and in the outlier to the north were assigned to the lower part of the undivided Kaibab Limestone and Toroweap Formation (Pkt) on the basis of lithology. At these localities, however, there is no chert breccia or chert-rich conglomerate between the cherty strata and underlying red-weathering sandy carbonate beds assigned to the Permian red beds (Prb). An outlier of cherty limestone exposed at Rox was previously mapped as Kaibab Limestone (Tschanz and Pampeyan, 1961, 1970; Wernicke and others, 1984).

The Bird Spring Formation is widely exposed in the Bunker Hills where an incomplete folded section is estimated to be about 1,650 m thick. A prominent pinkish-weathering silty dolomite interval (d) 106 to 150 m thick, is present about 900 m above the base of the formation. Fossils collected from strata immediately below this interval in Farrier Wash include a primitive *Schwagerina* species of probable early Wolfcampian age (C.H. Stevens, oral commun., 1987) and suggest that the Pennsylvanian-Permian boundary lies a short distance below the silty dolomite interval. The silty dolomite interval loses its characteristic appearance south of Farrier Wash. Near Arrow Canyon, in the Arrow Canyon Range, the Pennsylvanian-Permian boundary is about 25 m below a silty dolomite and limestone interval, unit **BSe** of Langenheim (1964), which is possibly the same as the silty dolomite interval (d) of this report. This boundary occurs about 732 m above the base of the Bird Spring Formation as used herein.

About 305 m of the uppermost part of the Bird Spring is exposed along Meadow Valley Wash between Vigo and Galt, conformably underlying the section of Permian red beds. The relation of this partial section to the Bunker Hills section is unknown, but at least the uppermost 150 m of this section was not recognized in the Bunker Hills.

The undivided Scotty Wash Quartzite and Chainman Shale unit (Msc) is based on stratigraphic nomenclature previously used for rocks widely exposed to the north and west of the map area (see Tschanz and Pampeyan, 1961, 1970). The individual formations are recognizable along Kane Springs Wash in the vicinity of Grapevine Spring (Duley, 1957), and a similar but much thinner interval of shaley rocks is present in the south half of the range. This interval is lithologically equivalent to the Chainman Shale and Indian Springs Formation of Webster and Lane (1967) and Webster (1969) in the Meadow Valley Mountains and to the Indian Springs Member of Longwell and Dunbar (1936) of the Bird Spring Formation in its type section. According to Duley (1957, p. 41) the

Chainman Shale at Kane Springs Wash is, at least in part, correlative with the upper part of the Monte Cristo Limestone at Arrow Canyon, the result of a facies change between clastic rocks of eastern Nevada and carbonate rocks of southern Nevada, an opinion also shared by Webster and Lane (1967). Duley (1957) tentatively placed the Mississippian-Pennsylvanian boundary within the upper part of the Scotty Wash Quartzite and reported no faunal change between the Scotty Wash and lowermost beds of the Bird Spring Formation. Webster and Lane (1967) and Webster (1969), however, place the Mississippian-Pennsylvanian boundary in the Meadow Valley Mountains and at Arrow Canyon in the lower part of the Bird Spring Formation at the top of the *Rhipidomella nevadensis* zone, 15 m above the top of their Indian Springs Formation. Unit Msc, as mapped, consists of a predominantly weak, yellow-, red-, red-brown-, and black-weathering shaley interval with thin interbeds of fossiliferous limestone, siltstone, and quartzite, lying between thick-bedded dark Mississippian limestone and medium-bedded cherty Pennsylvanian limestones of the Bird Spring Formation.

Mississippian limestone (Mmc) exposed in the southern Meadow Valley Mountains appears to be a geographic extension of the Arrow Canyon Range Mississippian section, which was divided into Dawn, Anchor, Bullion, and Yellowpine Limestones of the Monte Cristo Group of Langenheim and others (1962). In Bunker Hills, however, the Yellowpine Limestone appears to be absent, and at the north end of the outcrop area some silty to sandy limestones and fragmental limestones are present in the Dawn and Anchor Limestones. These clastic intervals may have good petroleum reservoir characteristics (Pampeyan, 1988). Mississippian limestone north of Sunflower Mountain is correlated with the Joana Limestone (Tschanz and Pampeyan, 1970).

In the Bunker Hills area the Pilot Shale, which was previously shown on maps by Tschanz and Pampeyan (1961, 1970), does not exist. Instead, the dark Devonian and Mississippian limestones are separated by a light-gray-to white-weathering Upper Devonian limestone that is here mapped as the uppermost part of the Guilmette Formation. Only a partial section of Pilot Shale is exposed in the Meadow Valley Mountains, along the Meadow Valley thrust east of Sunflower Mountain, where it is representative of a different facies of Upper Devonian and Mississippian strata described in a later section.

Devonian strata in the Meadow Valley Mountains are represented by the Sevy Dolomite, Simonson Dolomite, and Guilmette Formation. The Guilmette and Simonson are readily recognizable, but the Sevy is not as distinctive here as it is across Kane Springs Wash in the southern Delamar Mountains and farther north. The Guilmette Formation, as used in this report, consists of a thin, upper, light-gray, white-weathering limestone unit, a thick, middle limestone unit with some interbedded dolomite and sandstone layers, and a thin, basal yellowish-gray-weathering dolomite unit, the so-called yellow bed. These three units are correlated with, in descending order, the Crystal Pass Limestone, Arrow Canyon Formation, and Moapa Formation of Langenheim and others (1962) in

the Arrow Canyon Range. North of the Bunker Hills, the Guilmette Formation is overlain by a platy limestone unit that most closely resembles the Upper Devonian and Lower Mississippian Pilot Shale.

The Simonson Dolomite occurs in both halves of the map area, but more detailed studies will be required to identify specific lithologic differences between its northern and southern exposures. The Sevy Dolomite also is present from the vicinity of Sunflower Mountain southward, and its outcrop color and thickness change southward, becoming darker and thinner until in the southern part of the range it is difficult to distinguish from the underlying Laketown and overlying Simonson Dolomites. The Simonson and Sevy Dolomites are correlated with the Piute Formation of Langenheim and others (1962) in the Arrow Canyon Range. One area 9 km southwest of Sunflower Mountain, herein mapped as undivided Devonian and Silurian carbonate rocks (DSc), has subsequently had its complex structural and stratigraphic details resolved by Swadley and others (1990).

Ordovician and Devonian strata of the map area are separated by Middle and Upper Silurian strata of the Laketown Dolomite. Across Kane Springs Wash in the southern Delamar Mountains the Laketown is easily recognized as a three-part section consisting of an upper thin, black dolomite, a middle, light-gray cherty dolomite, and a lower, dark-gray cherty dolomite (Heckel and Reso, 1962), all of which are fossiliferous. In the map area the upper interval and part(?) of the middle interval appear to be absent, as they are in the Arrow Canyon Range (Heckel and Reso, 1962), and the dolomites are more medium to dark gray. Thicknesses reported are 296 m in the southern Delamar Mountains (Heckel and Reso, 1962) and 78 to 101 m in the Arrow Canyon Range (Langenheim and others, 1962). In the Meadow Valley Mountains the Laketown ranges in thickness from about 70 to 150 m.

In the map area as well as in adjacent ranges to the north, west, and south, Upper Ordovician strata are represented by the Ely Springs Dolomite. This formation is a distinctive black-weathering, cliff-forming unit lying between medium- to dark-gray dolomite above and slope-forming, medium- to brownish-gray limestone below. In much of the Great Basin the Ely Springs is underlain by the Eureka Quartzite, another distinctive marker formation. In the map area, however, the Eureka ranges from a maximum thickness of 4.5 m on the west side of the range to less than 1 m on the east side—too thin to portray on the map—and therefore is included with the underlying Pogonip Group (Oep). The Pogonip has not been subdivided into its component formations in this report even though a three-part breakdown is evident in much of its outcrop area. In the map area the Pogonip Group is about 460 m thick and appears to thin gradually eastward from 545 m in the southern Delamar Mountains (P.H. Heckel and Anthony Reso, unpub. data, 1960) to 260 m in the Mormon Mountains (Wernicke and others, 1984). The Pogonip section in the Arrow Canyon Range is 741 m thick (Langenheim and others, 1962).

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Conformably underlying Pogonip limestone is a section of Upper Cambrian carbonate rocks here assigned to the upper part of the Nopah Formation (€nc); these rocks were previously referred to as Upper Cambrian limestone and dolomite by Tschanz and Pampeyan (1961, unit eld; 1970, upper part of unit €ld). The upper half is a distinctive black-white-black interval which contrasts with the overlying brownish-gray Pogonip limestone and the underlying lower half of yellowish-gray and light-olive-gray color-banded carbonate rocks. A continuous section is not exposed in the map area but the total thickness is estimated to be about 365 m. A section equivalent to the carbonate member of the Nopah Formation exposed in the southern Delamar Mountains (fig. 4) was measured by P.H. Heckel and Anthony Reso (unpub. data, 1960) and correlated with the Desert Valley Formation of Reso (1963) exposed in the Pahranagat Range, about 50 km to the northwest. In the southern Delamar Mountains section the Cambrian-Ordovician boundary was placed about 120 m below the Pogonip-Desert Valley contact; in the Meadow Valley Mountains no fossil control on which to locate the Cambrian-Ordovician boundary was found. The carbonate member of the Nopah Formation, like the Pogonip Group, thins eastward (fig. 4) from 679 m for equivalent rocks in the southern Delamar Mountains to 190 m in the Mormon Mountains (Wernicke and others, 1984). The Dunderberg Shale Member of the Nopah Formation is exposed at several localities as the basal part of the Nopah, but it typically is distorted by faulting and folding so its true thickness is uncertain. In the southern Delamar Mountains the Dunderberg is 105 m thick (P.H. Heckel and Anthony Reso, unpub. data, 1960) and it appears to be absent in the Mormon Mountains (Wernicke and others, 1984).

The lowest stratigraphic unit in the map area is the Highland Peak Formation, which is best exposed in a faulted anticline between the Two Flats canyon and Anticline canyon faults along the west side of the Meadow Valley Mountains (map sheet 2). Possibly as much as 700 m of Middle and Upper Cambrian section is exposed here, and correlative strata in the Mormon Mountains (Bonanza King Formation of Wernicke and others, 1984) are about 580 m thick. A composite section of Highland Peak in the Delamar Mountains 55 km north, is more than 1,000 m thick (Callaghan, 1937; Wheeler, 1948).

STRUCTURAL SETTING

The Meadow Valley Mountains are in the Sevier orogenic belt (Armstrong, 1968), a south-southwest-trending zone of large-scale overthrusting and folding extending from western Utah through southern Nevada to southeastern California. Within the orogenic belt overthrusting was from west to east juxtaposing thick miogeosynclinal and thin shelf stratigraphic sequences (Fleck, 1970; Stewart, 1980) along the east edge of the Basin and Range province. This episode of crustal compression took place in Cretaceous time (Armstrong, 1968) and was followed by a period of erosion during which coarse clastic deposits accumulated on the erosion surface. Time of cessation of thrusting is unknown, but

coarse clastic deposits (Tc) unconformably overlie folded and thrust Paleozoic and Mesozoic strata in the Meadow Valley, Delamar, and Clover Mountains. The coarse clastic rocks are, in turn, overlain by upper Oligocene lacustrine limestone and a thick sequence of lower to middle Miocene welded tuff formations. In general the volcanic formations are conformable, with local lenses of limestone or sandstone between formations or members of formations. The sedimentary units indicate quiescent intervals during early Miocene volcanic activity. The hiatus between units O and W of the Kane Wash Tuff marked by up to 12 m of crossbedded sandstone (Tks), is recognized over a wider area than are the intravolcanic limestones. No similar sandstone or limestone units were seen in the Kane Wash Tuff above unit W. During middle to late Miocene time an episode of crustal extension began that resulted in the present-day landscape of deformed sedimentary strata unconformably overlain by gently dipping, broadly warped volcanic rocks cut by high-angle normal faults. Continuing tectonic activity is indicated by northeast-trending normal faults parallel to the range front cutting alluvial fan deposits and by the ongoing seismic activity of the region (Smith and Sbar, 1974; Rogers and others, 1987).

Regional structural interpretations indicate that the Meadow Valley Mountains are part of the Keystone-Muddy Mountain-Glendale thrust plate of the Mormon Peak allochthon and are characterized by a structural style of local tight folding and minor thrust faulting (Wernicke and others, 1984). The structural style and Paleozoic sections of the Meadow Valley, Arrow Canyon, and Las Vegas ranges are reported to be extremely similar to the part of the Spring Mountains between the Keystone and Wheeler Pass thrust faults (about 100 km to the southwest) (Wernicke and others, 1984, p. 482).

Most of the west edge of the Meadow Valley Mountains is bounded by the northeast-trending Kane Springs Wash fault, a narrow zone of faults subparallel to the Pahranagat shear system of Tschanz and Pampeyan (1970, p. 84). The southwest boundary is along north-trending faults that appear to be related to the Kane Springs Wash fault in the same sense as the Maynard Lake fault and Delamar Mountains and Sheep Range breakaway faults are related (Liggett and Ehrenspeck, 1974; Wernicke and others, 1984, figs. 9, 10), that is, the Kane Springs Wash fault may be an oblique-slip fault that connects with a breakaway fault zone towards the south. In general, the range is a gently east dipping block with the dip steepening eastward and reversing to form a major syncline and anticline in the Bunker Hills and a faulted syncline in the hills west of Vigo. The Paleozoic and Mesozoic sedimentary strata locally are tightly folded and overturned, commonly in proximity to thrust faults, and are cut by numerous high-angle faults. The sedimentary rocks were folded, faulted, and eroded prior to eruption of the Miocene volcanic rocks, for flat-lying to gently dipping welded tuffs are found both capping the folded and thrusted strata and prevolcanic conglomerate and in canyons eroded along steeply dipping faults. Near the center of the map area, parts of the sedimentary section are missing and are
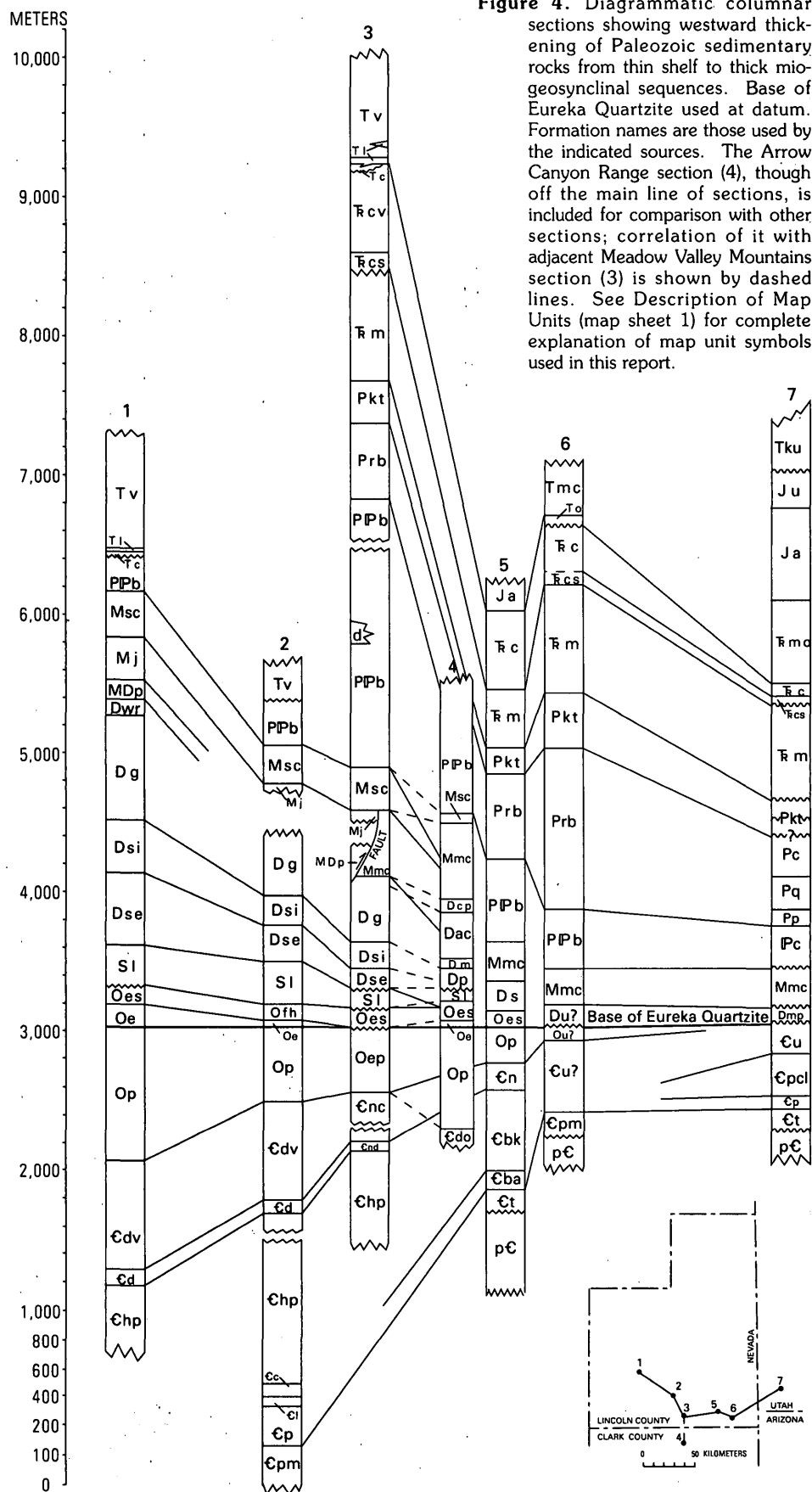
Figure 4. Diagrammatic columnar sections showing westward thickening of Paleozoic sedimentary rocks from thin shelf to thick miogeosynclinal sequences. Base of Eureka Quartzite used at datum. Formation names are those used by the indicated sources. The Arrow Canyon Range section (4), though off the main line of sections, is included for comparison with other sections; correlation of it with adjacent Meadow Valley Mountains section (3) is shown by dashed lines. See Description of Map Units (map sheet 1) for complete explanation of map unit symbols used in this report.

Figure 4. continuation

GEOLOGIC UNIT SYMBOLS

Tmc	Tertiary Muddy Creek Formation
To	Tertiary Overton(?) Fanglomerate
Tv	Tertiary volcanic rocks
Tl	Tertiary limestone
Tc	Tertiary conglomerate
Tku	Tertiary and Cretaceous rocks, undivided
Ju	Jurassic rocks, undivided
Jn	Jurassic Navajo Sandstone
Ŧmo	Triassic Moenave Formation
Ŧcv	Triassic upper sandstone member (of Chinle Formation)[3]
Ŧc	Triassic Chinle Formation
Ŧcs	Triassic Shinarump Member (of Chinle Formation)
Ŧcs	Triassic Shinarump Conglomerate (of Chinle Formation)[6,7]
Ŧm	Triassic Moenkopi Formation
Pkt	Permian Kaibab Limestone and Toroweap Formation, undivided
	Permian Kaibab LimestoneFormation and Toroweap Formation, undivided[6,7]
Prb	Permian red beds
Pc	Permian Coconino Sandstone
Pq	Permian Queantoweap Sandstone
Pp	Permian Pakoon Formation
PPb	Permian and Pennsylvanian Bird Spring Formation—Includes silty dolomitic interval (d) present in the Bunker Hills
	Permian and Pennsylvanian Bird Spring Group[4]
IPc	Pennsylvanian Callville Limestone
Msc	Mississippian Scotty Wash Quartzite and Chainman Shale, undivided
	Mississippian Scotty Wash Quartzite and Chainman Shale, undivided[1]
Mmc	Mississippian Monte Cristo Limestone
	Mississippian Monte Cristo Group[4,7]
	Mississippian Monte Cristo Group[5]
Mj	Mississippian Joana Limestone
MDp	Mississippian and Devonian Pilot Shale
	Mississippian and Devonian Pilot Formation[1]
Du	Devonian(?) rocks, undivided
Dwr	Devonian West Range Limestone
Dcp	Devonian Crystal Pass Limestone
Dg	Devonian Guilmette Formation
Dac	Devonian Arrow Canyon Formation
Dm	Devonian Moapa Formation
Dp	Devonian Piute Formation
Dsi	Devonian Simonson Dolomite
	Devonian Simonson Formation[1]
Dse	Devonian Sevy Dolomite
Ds	Devonian Sultan Formation
Dmp	Devonian Muddy Peak Limestone
Sl	Silurian Laketown Dolomite
Ou	Ordovician(?) rocks, undivided
Oes	Ordovician Ely Springs Dolomite
Ofh	Ordovician Fish Haven Dolomite
Oe	Ordovician Eureka Quartzite
Oep	Ordovician Eureka Quartzite and Pogonip Group, undivided
Op	Ordovician Pogonip Group
€u	Cambrian rocks, undivided
€dv	Cambrian Desert Valley Formation
€n	Cambrian Nopah Formation
€nc	Cambrian carbonate unit (of Nopah Formation)[3]
€do	Cambrian dolomite—Correlative with Nopah Formation
€nd	Cambiran Dunderberg Shale Member (of Nopah Formation)
€d	Cambrian Dunderberg Formation[1]
	Cambrian Dunderberg Shale[2]
€bk	Cambrian Bonanza King Formation
€hp	Cambrian Highland Peak Formation
	Cambrian Highland Peak Limestone[2]
€pcl	Cambrian Peasley Limestone, Chisholm Shale, and Lyndon Limestone, undivided
€c	Cambrian Chisholm Shale
€l	Cambrian Lyndon Limestone
€p	Cambrian Pioche Shale
€pm	Cambrian Prospect Mountain Quartzite
€ba	Cambrian Bright Angel Shale
€t	Cambrian Tapeats Sandstone
P€c	Precambrian crystalline rocks

———— Contact

〜〜〜〜〜 Unconformity

Superscripts indicate columnar sections in which informal names or stratigraphic terminology not presently accepted by the U.S. Gological Survey appear.

EXPLANATION

1 **Pahranagat Range**—Modified from Reso, 1963

2 **Delamar Mountains**—Bird Spring Formation to Joana Limestone, Tschanz and Pampeyan, 1970; Joana Limestone to Dunderberg Shale, P.H. Heckel and A. Reso, unpub. data, 1960; Highland Peak Limestone to Prospect Mountain Quartzite, Wheeler, 1943, and Callaghan, 1937. With minor modifications

3 **Meadow Valley Mountains**—Scotty Wash Quartzite and Chainman Shale, Duley, 1957

4 **Arrow Canyon Range**—Bird Spring Group to Upper Cambrian dolomite, Langenheim and others, 1962; Scotty Wash Quartzite through Monte Cristo Limestone, Duley, 1957

5 **Mormon Mountains**—Modified from Wernicke and others, 1984

6 **East Mormon Mountains**—Modified from Olmore, 1971

7 **Beaver Dam Mountains**—Modified from Langenheim and Larson, 1973

believed to have been cut out along thrust faults. On the basis of abrupt changes in thickness and lithology across faults, the Paleozoic rocks present in the Meadow Valley Mountains appear to represent more than one facies (as described below) that have been juxtaposed by faulting.

For convenience of description, the area underlain by sedimentary rocks is divided into three fault-bounded blocks (fig. 5): (1) the Bunker Hills block includes most of the south half of the map area bounded on the north by a concealed northwest-trending fault, referred to as the Bunker Hills fault, and a vertical, northeast-striking fault, referred to as the Two Flats canyon fault; (2) the Sunflower Mountain block north of the Bunker Hills block bounded by the Kane Springs Wash fault and a thrust fault, referred to as the Vigo West thrust, juxtaposing Bird Spring and Moenkopi strata; and (3) the Vigo block lying east of the Vigo West thrust fault and west of the Mormon Mountains. As noted above, the major structural relations exposed are pre-Miocene in age.
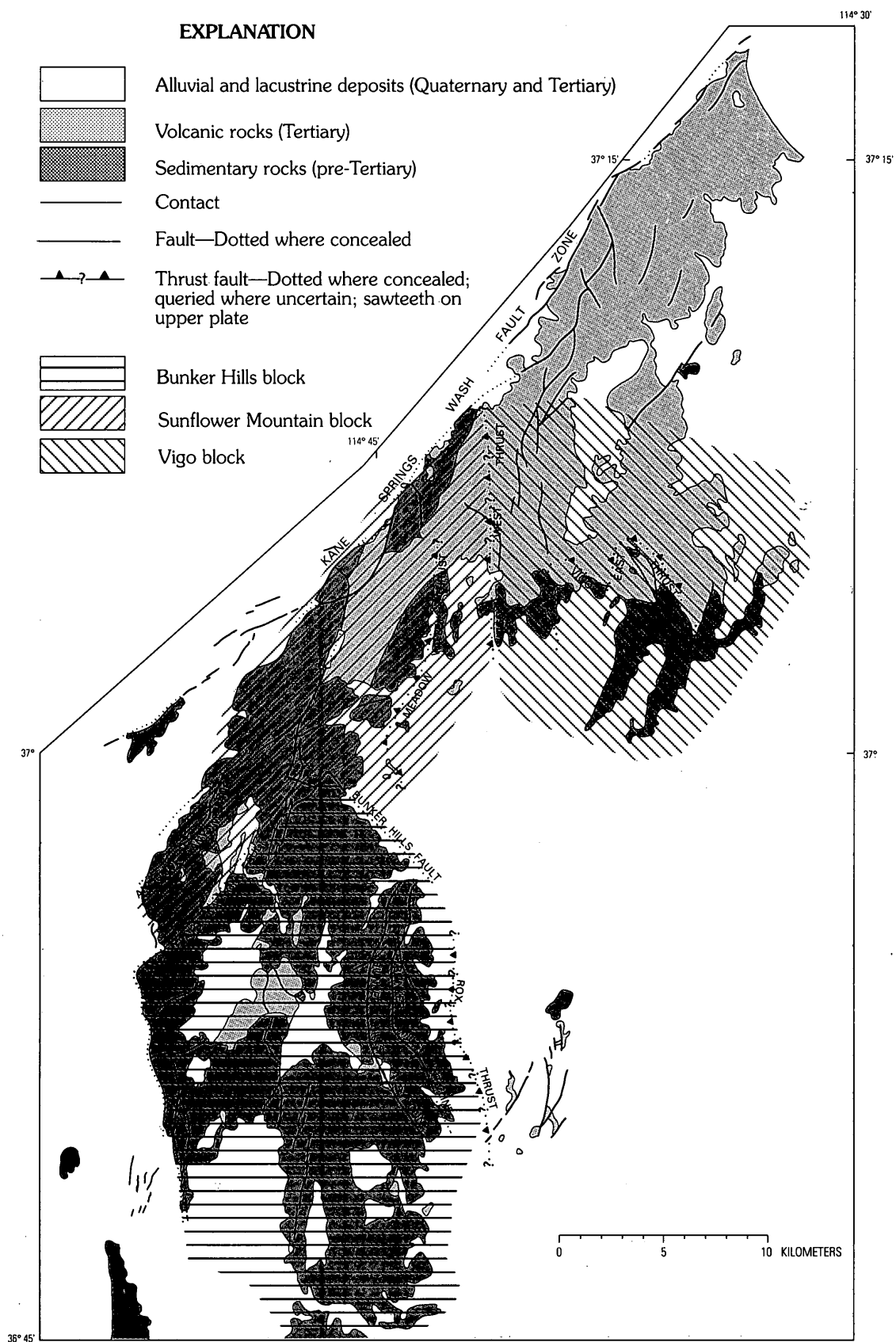
The west-facing part of the Bunker Hills block is bounded and cut by several high-angle, west-dipping normal faults with relatively small offsets, similar to those in the west face of the Arrow Canyon Range to the south. There is, however, a significant structural break between the two ranges, concealed by flat-lying Muddy Creek deposits, that separates northward-plunging Monte Cristo strata at the north end of the Arrow Canyon Range from Pogonip strata at the south end of the Meadow Valley Mountains. This break may possibly be the northward continuation of the Dry Lake thrust (Longwell and others, 1965) or a breakaway boundary of the Meadow Valley Mountains. In this area a swarm of small-offset high-angle faults cuts both Muddy Creek and alluvial fan deposits. Most of the offsets are down to the west but a few appear to have formed east-facing scarps. Geomorphic features along the range front indicate that the faults are young, and exposures of alluvial fan deposits faulted against Pogonip strata confirm that observation.

The northeast end of the Bunker Hills terminates abruptly in a northwest-trending front that is aligned with an exposed fault. The linear aspect of this edge of the Bunker Hills strongly suggests fault control, and the name Bunker Hills is applied to this lineament and short segments of fault actually exposed. The Two Flats canyon and Bunker Hills faults separate Ordovician to Permian strata of one facies from Cambrian to Pennsylvanian strata that appear to represent another facies, the differences being most noticeable in the Upper Devonian through Upper Mississippian part of the section. The Two Flats canyon and Bunker Hills faults come together in a complex of fault blocks where the Two Flats canyon fault appears to split. The west branch steps left and continues north-northeast beyond Sunflower Mountain to the Kane Springs Wash fault; the east branch continues northeast, but major offset appears to end at the intersection with the Bunker Hills fault. The Two Flats canyon fault separates gently dipping Ordovician to Mississippian strata in the Bunker Hills block to the southeast from folded Cambrian strata on the northwest, indicating a stratigraphic throw of about 2,500 m. Where exposed, the Two Flats canyon fault dips vertically but no

evidence indicating sense of movement was seen. The linear trace and offset of the range front suggest strike-slip movement, but the movement may be largely normal, placing folded strata of one thrust plate against undeformed strata of another thrust plate. At the intersection of Two Flats canyon and Bunker Hills faults the stratigraphic throw between Bunker Hills and Sunflower Mountains blocks is about 1,600 to 2,000 m, but north of the intersection the throw on the Two Flats canyon fault is only about 150 m, suggesting that the northeast continuing fault is unrelated to the large-offset fault.

The east half of the Bunker Hills block is underlain by Bird Spring strata folded into a syncline and anticline, and locally along the east edge the dips are steep to the east or overturned to the west suggesting eastward transport of the block. This block also is cut by many east-trending faults with small offsets, only a small number of which are shown on the map. The adjacent bedrock exposures to the east are the Kaibab Limestone in Meadow Valley Wash at Rox, strata that should be structurally and stratigraphically higher than the Bird Spring strata. According to Wernicke and others (1984) the Kaibab outliers and Meadow Valley Mountains are part of the Glendale thrust plate (Mormon Peak allochton) that is characterized by local tight folding and minor thrusting. The east edge of the Bunker Hills block may be bounded by a minor thrust within the Glendale plate. It is possible that the Meadow Valley Mountains are part of a breakup zone at the edge of the Glendale plate, and the various fault-bounded blocks described here resulted from the breakup. A well drilled on the axis of the Bunker Hills anticline bottomed in the lower part of the Monte Cristo Formation at a depth of 2,143 m without crossing any major fault (Texaco Inc., log of Texaco Federal No. 1), so any major surface of large-scale displacement probably lies below that depth.

The Sunflower Mountain block lies north of the Bunker Hills block forming the main scarp of the range along Kane Springs Wash. The Kane Springs Wash fault, a narrow zone of northeast-striking high-angle faults along the southeast edge of Kane Springs Wash, was originally described as a normal fault (Tschanz and Pampeyan, 1970) but later Ekren and others (1977) considered it to have left-lateral strike-slip or oblique-slip displacement of at least 8 km on the basis of an abundance of horizontal slickensides near the head of Kane Springs Wash, offset post-Kane Wash Tuff rhyolitic lavas, and apparent offset of Bird Spring strata and thrust and fold belts (Delamar Mountains thrust and fold belt and Meadow Valley thrust of Tschanz and Pampeyan, 1970). One other line of evidence suggestive of left slip is found in the aeromagnetic map of this region which shows the east end of an anomaly over intrusive rocks of the Kane Springs Wash caldera curving northward as though in response to left-lateral offset of the source (Pampeyan and others, 1988), an interpretation confirmed by recognition of the east end of the Kane Springs Wash caldera in the northern Meadow Valley Mountains (Harding and others, 1991). The Paleozoic strata in the Meadow Valley and Delamar Mountains, on opposite sides of the fault, cannot

EXPLANATION

☐ Alluvial and lacustrine deposits (Quaternary and Tertiary)

▦ Volcanic rocks (Tertiary)

▨ Sedimentary rocks (pre-Tertiary)

——— Contact

——·—— Fault—Dotted where concealed

▲–?–▲ Thrust fault—Dotted where concealed; queried where uncertain; sawteeth on upper plate

▤ Bunker Hills block

▧ Sunflower Mountain block

▨ Vigo block

Figure 5. Sketch map of Meadow Valley Mountains showing subdivision into structural blocks based on stratigraphy and style of deformation. See text for discussion.

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be used with any certainty to determine displacement across the Kane Springs Wash fault largely because the Upper Cambrian, Silurian, and Lower Devonian formations in the southern Delamar Mountains are considerably thicker and may represent a different facies. The Kane Springs Wash caldera appears to be offset about 4.5 km in a left-lateral sense, but a significant component of dip slip is suggested by the high scarp along the south edge of the wash. As noted above, the Kane Springs Wash fault zone may be an oblique-slip or transfer fault or it may mark a breakaway zone rotating the southern Delamar Mountains away from the Meadow Valley Mountains.

Splays of the Kane Springs Wash fault cut alluvial fan deposits and mark the north edge of an isolated block of Devonian strata near the mouth of Kane Springs Wash. This block is made up of light- and dark-gray limestone and dolomite and brown-weathering sandy limestone and sandstone, a lithology resembling the sandy limestone facies of the Guilmette Formation (Tschanz and Pampeyan, 1970, p. 37) in contrast with limestone-facies Guilmette strata present in the adjacent Delamar and Meadow Valley Mountains. This block better resembles the Guilmette Formation of the Pahranagat Range to the northwest; Swadley and others (1990), however, consider it to consist of the Sevy and Simonson Dolomites. South of this block the range front is controlled by north-trending faults. The change in direction occurs in an area where three northeast-striking vertical faults emerge from the range, the Two Flats canyon or southernmost fault juxtaposing gently eastward-dipping Ordovician to Mississippian and folded Cambrian formations in a canyon informally referred to as Two Flats canyon. The second fault emerges about 4 km north and is referred to as the Anticline canyon fault after an anticline developed in Highland Peak and Nopah strata. The anticline's east limb dips moderately to steeply east with some minor overturning in the Dunderberg Shale Member; the west limb has been thrust over the main fold axis and contains minor folds cut by low-angle normal faults. The third fault, about 1.2 km farther north, also is formed in Cambrian and Ordovician strata and consists of several en echelon right-stepping segments suggesting a component of left slip. Strata of the Pogonip Group are tightly folded between the Anticline canyon fault and unnamed third fault as are strata in the upper part of the Nopah where the Anticline canyon fault branches and steps left. The three faults merge northward, the Two Flats canyon fault being the main trace, and continue north-northeast. The northern part of this fault juxtaposes relatively undeformed Upper Cambrian to Lower Ordovician and Middle Devonian strata indicating a stratigraphic throw of about 1,100 m, somewhat more than the 793 m estimated by Tschanz and Pampeyan (1970, p. 107). The Kane Springs Wash fault, the three sub-parallel faults described above, and the faults cutting Cenozoic deposits in Kane Springs Wash appear to be part of a system of northeast-trending faults that occupy a narrow zone at the head of Kane Springs Wash and widen to the southwest by branching (fig. 5). A second system of north-trending faults is exposed along the west edge of the Bunker Hills

block, as well as the west edge of the Arrow Canyon Range, and the shape and development of the Meadow Valley Mountains has been controlled by interaction of these two systems.

About 40 m of Joana Limestone, in fault contact with Guilmette strata, is present on the northwest side of the Sunflower Mountain block, but all of the Joana and part of the Chainman Shale are cut out on the southeast side along a fault which juxtaposes platey limestones of the Pilot Shale and shaley beds of the undivided Scotty Wash Quartzite and Chainman Shale unit. The fault on the southeast side was named the Meadow Valley thrust and was interpreted to extend north under the volcanic cover and join at depth with the fault on the northwest side (Tschanz and Pampeyan, 1970, fig. 3). The Meadow Valley thrust is projected south between the continuous Devonian exposures and an outlier of Bird Spring strata. The Middle Devonian to Lower Pennsylvanian sections (Guilmette Formation, Pilot Shale, Joana Limestone, Chainman Shale, Scotty Wash Quartzite, and Bird Spring Formation) on opposite sides of the Sunflower Mountain block appear to belong to the same facies but have been telescoped by thrusting.

The east boundary of the Sunflower Mountain block is drawn along the Vigo West thrust. The Vigo West thrust has at least 2,400 m of stratigraphic throw, the amount of displacement required to account for the juxtaposition of strata of the lower part of the Bird Spring and Moenkopi, and an amount considerably larger than the 1,372 m estimated by Tschanz and Pampeyan (1970, p. 106). The actual Bird Spring-Moenkopi contact is overlain by Tertiary conglomerate (Tc) at the head of a linear arroyo separating the two formations, but deformation in the Bird Spring near the contact and low-angle, west-dipping structures in the Moenkopi strata in the ridge east of the Bird Spring contact strongly suggest the Bird Spring is thrust over the Moenkopi. In addition, the contact is the west edge of a Permian and Triassic red-bed and limestone sequence in southern Nevada, and the abrupt disappearance of more than 3,400 m of section composed of these rocks is more easily explained by an overriding thrust than by normal faulting. The Vigo West thrust may consist of at least two imbricate faults, and the thrust contact is inferred to extend north under the volcanic terrane east of Grapevine Spring and to be truncated by the Kane Springs Wash fault zone. East of the Vigo West thrust Paleozoic and Mesozoic strata of the Vigo block, namely the red-beds unit and Moenkopi Formation, are increasingly deformed northward towards the volcanic cover. Within the Vigo block the Moenkopi is thrust over the Moenkopi(?), Chinle Formation, and red beds with large angular discordances between the units visible at three localities along the Vigo East thrust. In addition, it is possible that the basal contact of the Moenkopi in the linear ridge 4.2 km west of Vigo may be part of the Vigo East thrust owing to angular discordances of up to 20° between the Moenkopi and the underlying undivided Kaibab Limestone and Toroweap Formation (Pkt) and folded Permian red beds.

In the north half of the map area (sheet 1) the volcanic section appears to rest on an erosion surface of

low relief, while in the south half (sheet 2), patches of Kane Wash Tuff (Tku) are present at various levels on an irregularly eroded surface, for example, in the vicinity of Two Flats canyon welded ash-flow tuff of the same(?) cooling unit caps the highlands and coats the canyon walls over a vertical range of more than 200 m. In general the tuff dips eastward 10°-35°, but in a few places the dip is as steep as 65°. Some of the steep dips, for example in and near Two Flats canyon, appear to be due to compaction during welding and elsewhere are due to post-volcanic extensional faulting. In the vicinity of Sunflower Mountain the tuff is warped into open folds, either in response to compaction over buried topography or to post-volcanic deformation. In the Kane Springs Wash escarpment, dips decrease upwards in the volcanic section from about 35° to less than 10°. Numerous steeply dipping, north-trending normal faults cut the volcanic sequence, but the offsets on these faults are less than a few tens of meters. In the vicinity of Sunflower Mountain, however, the volcanic section is offset a minimum of 250 m along a branch of the Two Flats canyon fault. Structural and stratigraphic relations of the volcanic sequence near Vigo are less evident than they are to the west, and in the northernmost part of the map area the relations are even more complex. Detailed mapping will be required to unravel the problems left unanswered in this report. According to R.B. Scott (written commun., 1988) the northern part of the volcanic area may contain outflow from an older buried caldera to the north.

The linear escarpment along Kane Springs Wash displays the complete stratigraphic section of welded ash-flow tuffs and strongly resembles a fault scarp. However, no evidence of faulting was seen along the Paleozoic rocks-volcanic rocks contact so the escarpment probably is a fault-line scarp along the Kane Springs Wash fault zone. The conspicuous hill composed of Bird Spring strata located between Sunflower Mountain and Grapevine Spring and the outliers of Permian strata in the volcanic terrane appear to be erosional remnants on the low-relief surface subsequently indundated by ash-flow tuffs.

Along the west bank of Meadow Valley Wash opposite Hoya siding, strata of the Muddy Creek Formation have collapsed into the drainage channel forming an area of jumbled slump blocks 0.2 to 0.4 km wide by 3.5 km long in response to undercutting of the bank. The linear drainage and headwall scarp may have been controlled by faults or fractures similar to the subparallel linear feature, less than 1 km to the west, visible on aerial photographs. Similar but smaller slumps are present just north of Hoya. Other landslide deposits of sedimentary and volcanic rocks are present in the north-central map area.

Along the range front near Grapevine Spring patches of the Hiko and Kane Wash Tuffs rest directly on Paleozoic strata. Ekren and others (1977) show the tuffs in normal contact on Paleozoic rocks but assign them tentatively to their unit Tt3 which includes the Hiko Tuff through the Leach Canyon Formation. Stewart and Carlson (1978) show these tuffs as one northwest-dipping low-angle fault block. These volcanic rocks are cut by

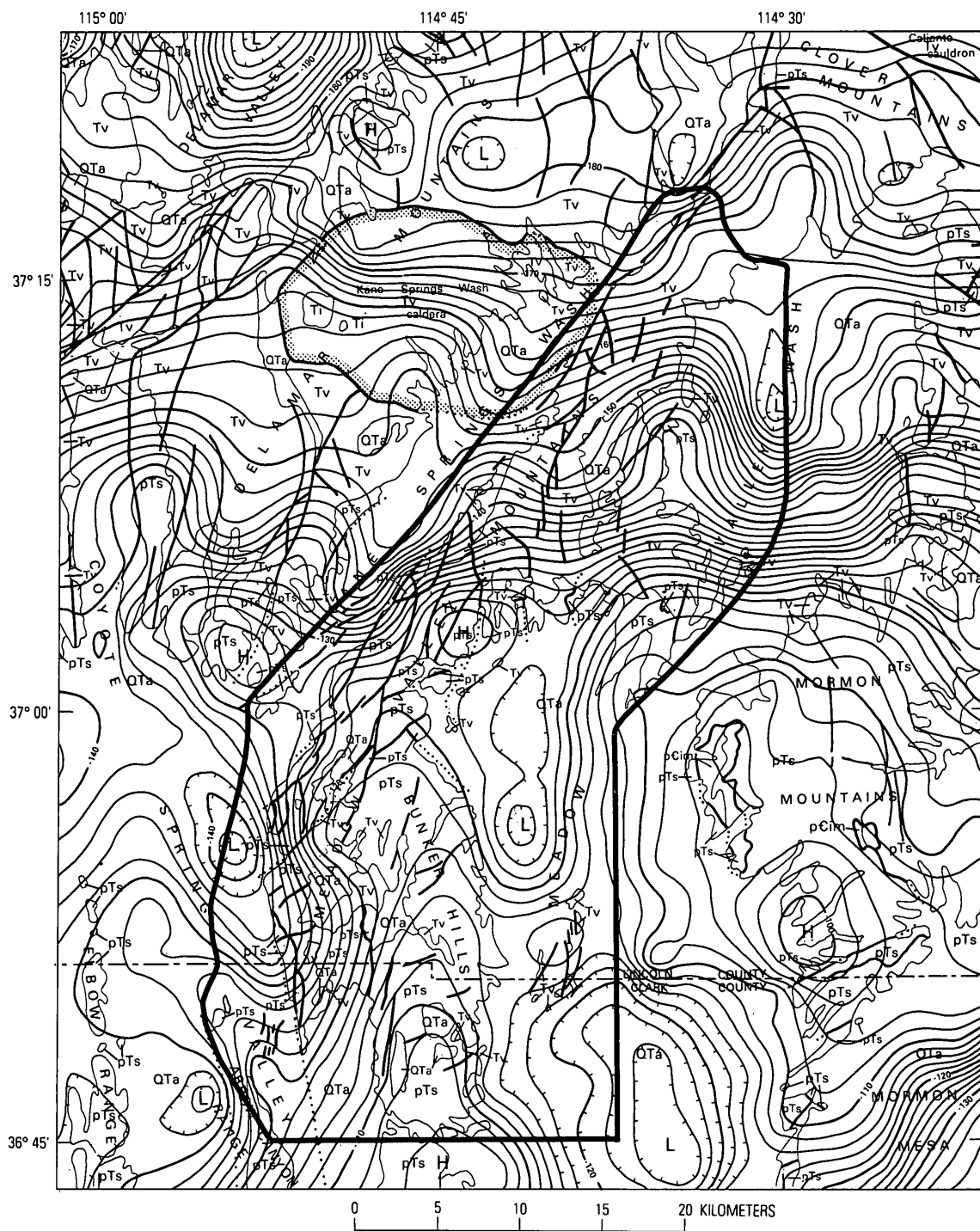many faults and may be remnants of old landslide blocks shed from a retreating volcanic scarp.

GEOPHYSICAL SETTING

The gravity of the region surrounding the Meadow Valley Mountains is dominated by a strong down-to-the-north gradient of more than 50 mGals north of the south edge of the volcanic terrane (fig. 6). Eaton and others (1978) analyzed this gradient and pointed out that it roughly coincides with the south edge of a vast field of predominantly rhyolitic rocks and concluded that it mainly reflects a density contrast resulting from emplacement at shallow depth of large volumes of silicic magma in middle Tertiary time. Precambrian crystalline basement rock exposed in the Mormon Mountains is neither exposed nor does it have magnetic expression north of the gravity gradient. A down-to-the-north step of Precambrian basement in the vicinity of latitude 37° N. may account for part but not all of the gradient (Eaton and others, 1978). Other gravity lows that appear as perturbations of the regional gradient in Kane Springs and Meadow Valley Washes and Coyote Spring Valley reflect thick deposits of Miocene and younger unconsolidated sedimentary deposits (Pampeyan and others, 1988).

An aeromagnetic map of the region (fig. 7) shows positive anomalies centered over the Mormon, Clover, and Delamar Mountains. The anomaly over the Mormon Mountains is thought to represent a domoform uplift of strongly magnetic Precambrian crystalline basement and a possible Tertiary granitic intrusive body (Shawe and others, 1988), whereas the Clover and Delamar anomalies most likely are due to middle Tertiary intrusive bodies in eruptive centers. One of these anomalies in the Delamar Mountains coincides roughly with the Kane Springs Wash caldera (fig. 7) and extends eastward over the northern Meadow Valley Mountains where the east end of the anomaly curves northward, either in response to left-lateral displacement of the causative source along the Kane Springs Wash fault, or structural control of the source by a north-curving arcuate fracture (Pampeyan and others, 1988). According to Harding and others (1991) the Kane Springs Wash caldera does extend east into the Meadow Valley Mountains and is offset 4.5 km in a left-lateral sense along the Kane Springs Wash fault. The anomaly low north of the volcanic center coincides with a deep gravity low and suggests that an older buried collapse caldera is present north of the Kane Springs Wash volcanic center (Moring and others, 1988).

ECONOMIC GEOLOGY

Much of the Permian clastic rocks are red-bed deposits, some of which contain bedded evaporite deposits of gypsum (Jones and Stone, 1920). These deposits have been prospected but, to date, none have been developed. Locally the Chainman Shale contains phosphatic beds that have been explored for vanadium (Heston, 1982) and siltstone beds that have been quarried for ornamental stone. In addition, the Mississippian carbonate rocks of a region including the Meadow Valley
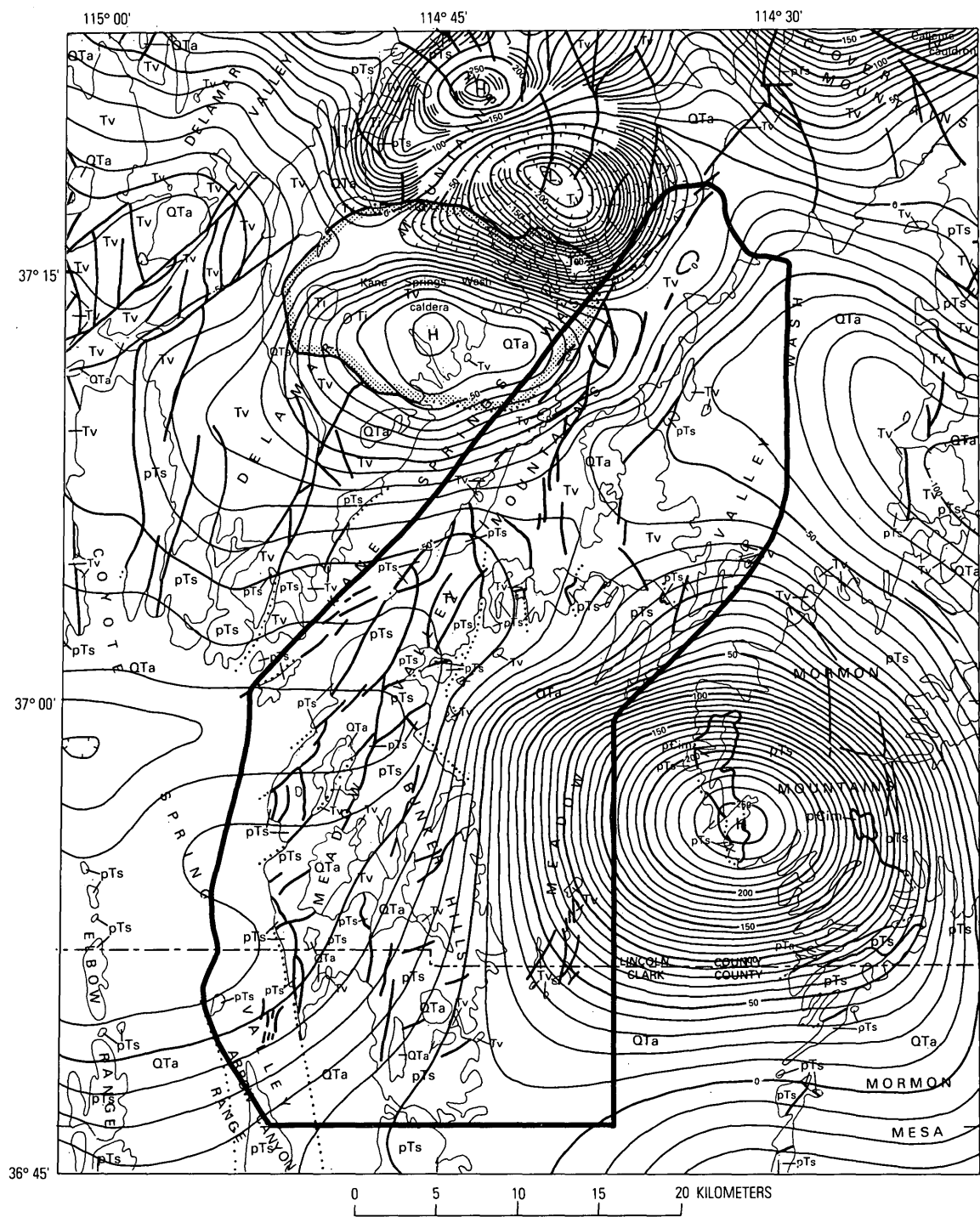
EXPLANATION

QTa, Alluvial and lacustrine deposits (Quaternary and Tertiary); Ti, Intrusive rocks (Tertiary); Tv, Volcanic rocks (Tertiary); pTs, Sedimentary rocks (pre-Tertiary); pЄim, Igneous and metamorphic rocks (Precambrian); ———— Contact; ———▶ Fault; ▦▦▦▦ Edge of collapse caldera; ▬▬▬▬ Approximate boundary of geologic map area. x, gravity station.

Figure 6. Complete Bouguer gravity-anomaly map of the Meadow Valley Mountians and vicinity, Lincoln and Clark. Counties, Nev. Contour interval, 2 mGals; reduction density, 2.67 f/cm^3; H, gravity high; L, gravity low. Adapted from Pampeyan and others (1988).

Figure 7. Residual and total-intensity aeromagnetic map of the Meadow Valley Mountains and vicinity, Lincoln and Clark Counties, Nev. Contour interval, 10 nT; altitude of observation, 12,500 ft above sea level; H, magnetic high; L, magnetic low. Adapted from Pampeyan and others (1988)..

Mountains have been classified as having a medium potential for occurrence of oil and gas on the basis of Conodont Alteration Index and other lithologic and stratigraphic characteristics (Sandberg, 1983; Pampeyan, 1988). In 1972 a well was drilled to test the Mississippian rocks in the Bunker Hills anticline, but no shows of oil or gas were reported (Garside and others, 1977). The uppermost part of the Guilmette Formation in the Bunker Hills block is composed of light-gray limestone occupying the same stratigraphic position as the Crystal Pass Member of the Sultan Limestone (Crystal Pass Limestone of Langenheim and others, 1962) which is mined as high-calcium limestone at Arrowlime, 62 km south of the map area (Longwell and others, 1965). Purity of the limestone here is unknown.

The rhyolitic lavas in the northernmost part of the Meadow Valley Mountains contain large tonnages of perlite and much of the interlayered lithic tuff contains zeolites, but neither commodity has been produced commercially from this area. Near the north end of the map area, the Sunshine prospect was staked on rhyolite dikes cutting rhyolitic volcanic rocks. Samples from this prospect contained no silver or gold. In Two Flats canyon Devonian carbonate rock in contact with rhyolitic welded tuff is silicified and cut by quartz veinlets, and samples of silicified rock from the D and D prospect on this contact contained trace amounts of silver but no gold (Pampeyan and others, 1988). For additional information on actual and potential mineral resources of the Meadow Valley Mountains the reader is referred to reports by Campbell (1987) and Pampeyan and others (1988).

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