Appendix C

A 740,000 year tephrochronologic record in Mohawk Valley, northeastern California

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THIS IS A DRAFT.
Andrei is working on part of this ms and there may be changes to some of these correlations and the age estimates for when the ms is finished.

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ABSTRACT

A robust tephrochronologic record from northeastern California includes twenty-six different tephras and sixty-one tephra beds that range in age from 740 to 7 ka and were deposited within lake deposits in Mohawk Valley. Glass compositional data and correlations with previously identified volcanic ash layers have resulted in revised age estimates for tephra beds distributed within, and beyond Mohawk Valley. These results provide age constraints for eleven newly identified tephras and much of the numerical age control for interpretations of the Quaternary history of Mohawk Valley.

Based on stratigraphic context and tephrochronologic correlations, we propose new age estimates for some tephra beds also found in other parts of the western U.S. We revise the age estimate of the East McKay Butte tephra bed, erupted from the McKay Butte Dome of the Newberry Volcanic complex, as 610-480 ka and revised the ages of three Clear Lake ash beds (7 through 9) to <610-570 ka, >610-570 ka (~625 ka), and ~660 ka, respectively. Furthermore, the tuffaceous interval of tephra beds within the Tulelake core has now also been identified in Mohawk Valley. This suggests that this group of tephras that was originally interpreted as reworked or heterogeneous tephra layers, may have, instead, been derived from a series of eruptions, possibly originating from Medicine Lake Volcano or another volcano in northeastern California.

INTRODUCTION

Tephrochronology has played a major role in deciphering and documenting the Quaternary history of many parts of the world because tephra beds provide age control and allow direct correlation between different stratigraphic sections. Within western North America, tephras erupted throughout the Quaternary represent discrete time-stratigraphic markers that have been instrumental in correlating and dating deposits (e.g. Davis, 1985; Sarna-Wojcicki, et al., 1991; Rieck et al., 1992; Sarna-Wojcicki, et al., 2005; Kuehn and Negrini, 2010). These tephrochronologic records have benefited many types of Quaternary studies involving paleoclimate (e.g. Rosenbaum et al., 1996; Cohen et al., 2000; Negrini et al., 2000; Whitlock et al., 2000; Negrini, 2002; Reheis et al., 2002;), faulting and basin evolution (e.g. Knott et al., 1999; Lutz, et al. 2006), depositional environments (e.g. Benson et al., 1997; Adams, 2010), and flood histories (e.g. Busacca et al., 1992). The tephrochronologic record in Mohawk Valley includes twenty-six different tephras deposited over the past 740 ky. This long and detailed record is one of just a few that can provide such a lengthy chronologic framework for Quaternary deposits in the western U.S. (e.g. Sarna-Wojcicki et al., 1987; Busacca et al., 1992; Rieck et al., 1992; Williams, 1994; Kuehn and Negrini, 2010).

Mohawk Valley is located in northeastern California, adjacent to the northern most Sierra Nevada Mountains (Figure 1). Mohawk Lake occupied Mohawk Valley for several hundreds of thousands of years until it reached its threshold and overflowed westward about 180 ka and was replaced by the westward-flowing Middle Fork of the Feather River (MFFR) by 7 ka (Redwine, 2013). In response to this lowering base level, the MFFR and its many tributaries have incised through the margins of the basin and provided numerous exposures of lacustrine sediments. The many outcrops facilitate correlations between the twenty-seven sites where sixty-one tephra beds have been recognized thus far that correlate to one of twenty-six different tephras. Correlation among tephra beds within Mohawk Valley is complicated by deformation along the Mohawk Valley Fault Zone, a primarily right-lateral fault zone with a widely distributed zone of deformation (Redwine, 2013; Sawyer et al., 2013; Gold et al., 2014).

This paper presents a synthesis of tephra analyses from the current study and previously unpublished and published results from within Mohawk Valley (Mathieson, 1981; Mathieson and Sarna-Wojcicki, 1982; Yount et al., 1993; Yount, 1995). This tephrochronologic record allowed new age estimates for tephras located within Mohawk Valley and beyond. The results provide much of the numerical age control used to interpret the Quaternary history of Mohawk Valley (Redwine, 2013). In addition, the ages of some chronostratigraphic marker beds for parts of the western U.S. have been re-evaluated. These include three Clear Lake ash beds (7 through 9) and the East McKay Butte obsidian. These revised ages have important implications for interpretations of the Quaternary history in many locations in the Western U.S.

METHODS

Stratigraphic sections were mapped, measured, described, photographed, and sampled. Standard stratigraphic data was collected including particle size, lithology, and description and measurements of sedimentary features following Tucker (2003). Altitudes were collected from LiDAR data where there was coverage and estimated using a 10 m DEM where there was no coverage. The LiDAR data are available from OpenTopography (www.opentopography.org), where additional details on acquisition and accuracy can be found. Limits of LiDAR data coverage are shown on Figure 2. Tephra beds were sampled using methods outlined in Sarna-Wojcicki (1998). The current and previous tephrochronologic studies used different protocols (summarized below) to analyze the glass in sampled tephra beds.

Tephra samples collected in the current study are preceded by a MV were analyzed by F. Foit in the Geo-Analytical Laboratory, Department of Geology at Washington State University. Analyses and comparisons were run in 2009 and 2011 using sample preparation methods and analytical conditions outlined in Foit et al. (2004). The compositions of the glasses from Mohawk Valley were compared with one another and with the standard glasses in the GeoAnalytical Laboratory's database of Pacific Northwest tephras using the similarity coefficient (SC) of Borchardt et al. (1972) as a discriminator. The similarity coefficient is the average of eight oxide concentration ratios between the glasses in the tephra sample and tephra standard (Foit et al., 2004). In the calculation of the SC, a weighting of 1.0 was used for Si, Al, Ca, Fe, Na, and K oxide concentration ratios and 0.25 for Mg and Ti oxide ratios.

Tephra samples from prior studies were analyzed by the Tephrochronology Laboratory of the U.S. Geological Survey in Menlo Park, Ca. Original sample names are listed in Table 1 and correspond to the individual who did the sampling. Those that begin with a JY were collected by Yount et al. (1993) and Yount (1995), that begin with SAM were collected by Mathieson (1981), and that begin with a RC or RD were collected by J.O. Davis in 1982. Analyses and comparisons of SAM samples were run in 1982 and JY, RD, and RC samples in 1994. Samples were described and processed by E. Wan, G. Swanson, and S. Soles. Samples were prepared in the laboratory following methods outlined in Sarna-Wojcicki (1998). The glass separates were analyzed by C. Meyer using a JEOL 5-channel electron microprobe and following methods outlined in Sarna-Wojcicki et al. (1984). The glass shards were analyzed for six major oxides (SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, and K_2O) and because the deposits are mid to late Quaternary, alkalies were included in comparisons. For those samples that had sufficient MgO and TiO_2 (>~0.20 weight %), a second comparison was run for eight oxides, including MnO and CaO . As described in Reheis et al. (2002), these results were compared with compositions in a database of previously analyzed tephras using statistical programs based on similarity in chemical composition and stratigraphic data. Glass compositions were normalized to 100 weight percent to correct for hydration of the volcanic glass.

We followed the convention described by Sarna-Wojcicki et al. (1984) and Davis (1985) that suggested a similarity coefficient (SC) of 0.95 or greater indicates permissive correlations as long as it is stratigraphically reasonable, an SC of 0.90-0.95 indicates tephra beds are similar, but not necessarily the same, and an SC< 0.90 indicates dissimilar tephras. Correlations of each tephra bed with SCs ≥ 0.90 were then evaluated in terms of stratigraphic position within each exposure relative to other tephra correlations and other sites in Mohawk Valley. Correlations that were both the most reasonable based of glass compositional similarity and stratigraphic context were selected as the most probable. This allowed for probable correlations for all sixty-one analyzed tephra beds in Mohawk Valley.

RESULTS

Seventy-nine analytical results of sampled tephra beds from Mohawk Valley are presented in Table 1. Those results include duplicate analyses because some tephra beds were sampled and analyzed more than once by different investigators. Twenty- five of the analyses are of samples collected by the current study, the remaining fifty-four from earlier and previously unpublished studies and from Mathieson (1981) and Mathieson and Sarna-Wojcicki (1982). A summary of each site listing tephra bed thickness, elevation, correlations and corresponding SC values, and age estimates are presented in Table 2. Ages of tephras found in Mohawk Valley and references for those ages are listed in Table 3. Twenty-six different tephras were identified.

Site MV-315 (Mohawk Cliff section)

Site MV-315, also referred to as Mohawk Cliff, is a 42 m-high exposure along the left (south) bank of the MFFR (Figures 2 and 3). Results from this site provide much of the tephrostratigraphic framework for Mohawk Valley because it has the greatest number of analyzed tephra beds found in one continuous stratigraphic section. The entire exposure gently dips about 4° upstream (NW). The upper part of this stratigraphic section is composed of ~10 m of weakly-cemented sands and gravels. A sample of wood from within those gravels yielded a ^{14}C age of ~18.7 ka BP (Table 4). These relatively coarse-grained deposits overlie 32 m of indurated, inter-bedded, organic-rich, massive to thinly laminated to very thickly bedded silty clay and clayey silt, tephra beds, sand, and lesser pebbles (Figure 3), which are the focus of the description and analyses here.

A stratigraphic column was compiled using descriptions and measurements from two studies carried out about fifteen years apart (Figure 3). Unit descriptions and thicknesses from the base of the exposure up through the top of the Rockland tephra (MC-K) are from the present study and above the Rockland tephra to the top of the section from a 1998 study by J. Yount, M. Reheis, S. Starratt, and M. McGuire. The deposits are exposed along the outer side of a meander bend that is actively eroding, changing the exposure through time. However, the elevations of the top and base of the exposure, taken from recently collected LiDAR data, match those reported in the earlier descriptions and the compiled stratigraphic column height, providing confidence the exposure probably had not drastically changed in the intervening years.

All tephra analyses in this exposure are of samples taken by the prior studies of J.O. Davis in 1982 and of J. Yount and D. Harwood in 1992. Six tephra beds are placed on this stratigraphic column as measured in the field and are designated by black stars on Figure 3. The locations of the remaining nine tephra beds within the stratigraphic column (designated by white stars) are estimated based on their measured depths relative to the six tephra beds that have clear locations on the stratigraphic column. The fifteen analyzed tephra beds from Mohawk Cliff were renamed to simplify the multiple sample names and to correlate with stratigraphic descriptions from this study. Original sample names and laboratory identifications are listed in Table 1.

The composition of glass from the uppermost tephra bed within the Mohawk Cliff section, MC-GG-6, best **Error! Reference source not found.**correlates to Tulelake (T) tephra beds T2036 and T296 (SC=0.98). Both tephra beds were located within Tulelake cores and neither has been directly dated; however, their ages have been estimated based on stratigraphic relations to other tephra beds within the Tulelake core (Rieck et al., 1992). Tephra bed T2036 was located at 53.14 m in a Tulelake core and correlates to an interval from 53.07 m to 53.13 m (Rieck et al., 1992). Tephra bed T296 was located much lower in the Tulelake core (Figure 4) near the depth of the Rockland tephra (Figure 5) (Rieck et al., 1992). The correlation to T2036 is favored because the values for calcium are more similar than with those of T296 and because it is the most stratigraphically reasonable correlation based on underlying tephra correlations in the Mohawk Cliff section (Figure 5). In the Mohawk Cliff exposure, MC-GG-6 overlies, and is younger than, a tephra bed that correlates to Summer Lake tephra bed KK (Figures 3, and 5), with an estimated age range of 215-180 ka (described below).

Tephra bed MC-GG-5 (Figure 3) is a very heterogeneous, andesitic ash. The glass composition best correlates to sample 68-16-1739 (SC=0.95) from an andesite dike at Medicine Lake Volcano (Figure 4) and to three Tulelake tephra beds T2019, T2023, and T1228, all with an SC of 0.94. The andesitic dike at Medicine Lake Volcano is likely the andesite tuff' feeder for the andesite tuff' of Medicine Lake, now referred to as the dacite tuff of Antelope Wells (Donnelly-Nolan, 2010), that correlates to tephra bed T2023 (Herrero-Bervera et al., 1994). All three Tulelake tephra beds (T2019, T2023, and T1228) also correlate to Summer Lake tephra bed KK (Rieck et al., 1992) (Figure 5). Recent numerical age estimates for the dacite tuff of Antelope Wells from Medicine Lake Volcano (Donnelly-Nolan, 2010) and the Summer Lake tephra bed KK (Kuehn and Negrini, 2010) have provided different age estimates, discussed in a following section. We use the range of 215 to ~180 ka for the age of Summer Lake tephra bed KK (Donnelly-Nolan, 2010; Kuehn and Negrini, 2010) in this study.

The composition of glass in tephra bed MC-GG-4 (Figure 3**Error! Reference source not found.**) correlates well to two tephra beds from the Buck Lake (BL) core in Oregon (Figure 4), BL-3491 and 3988 (SC=0.97). Although these Buck Lake tephra beds (BL-3491 and 3988) have not been directly dated, in the Buck Lake core they underlie and are older than the Bend Pumice, (Adam et al., 1994; Sarna-Wojcicki et al., 1991). The Bend Pumice is correlated to the Loleta Ash (Sarna-Wojcicki, 1987) that has a weighted mean of four ages from K-Ar dates on plagioclase of about 300 ± 100 ka (Sarna-Wojcicki et al., 1989). The Bend Pumice was more recently dated as 443 and 437 ka (Lanphere et al., 1999a). Both age estimates are older than is reasonable for the Mohawk Cliff tephra bed MC-GG-4, the age of which is constrained by the overlying Summer Lake tephra bed KK (215-180 ka) and underlying Summer Lake tephra bed LL (~218->180 ka) (described below) (Figure 4). This provides an estimated age range (218-180 ka) for tephra bed MC-GG-4 and shows that despite their compositional similarity, the correlation to the Buck Lake tephras is not stratigraphically reasonable.

The composition of glass in tephra bed MC-GG-3 (Figure 3), a couplet, correlates equally well (SC=0.97) to either Summer Lake tephra bed LL (SC=0.97) or to the Wadsworth Ash. The correlation to the Summer Lake tephra bed LL is favored based on stratigraphic context in the Mohawk Cliff site (Figure 3). The age of the Summer Lake tephra bed LL is closely associated with that of the overlying Summer Lake tephra bed KK (Kuehn and Negrini, 2010). We have used an age range of from 218 ka to >180 ka (Kuehn and Negrini, 2010; Donnelly-Nolan, 2010) in this study.

The composition of glass in tephra bed MC-GG-2 (Figure 3) correlates very well (SC=0.99) to two tephra beds (RC-5 and RC-6) found in Mohawk Valley at site MV-133 (Figures 2). A minimum-limiting age is provided by the overlying Summer Lake tephra bed LL (218->180 ka) in Mohawk Cliff (Figures 3 and 5). In all three Mohawk Valley sites where this tephra is found, the Rockland tephra is stratigraphically lower in the same section and provides a maximum-limiting age. The age of the Rockland tephra is discussed in detail below, but was most recently estimated as 610-570 ka (Lanphere et al., 2004). Based on the stratigraphic position, these tephras are likely closer in age to the Summer Lake tephra bed LL than the stratigraphically much lower and older Rockland tephra (Figure 3).

The composition of glass in tephra bed MC-GG-1 (Figure 3) has five possible correlations; to one of two tephra beds within the Tulelake core, T276 (SC=0.98) or T1244 (SC=0.98), to one of two tephra beds within the Buck Lake core in Oregon, BL3986 (SC=0.99) and BL3495 (SC=0.98), or to the Cougar Butte Obsidian of Medicine Lake Volcano (SC=0.98) (Table 2). The Tulelake core correlations are considered the most stratigraphically reasonable (Figure 5). Of the two Tulelake tephras, the correlation to T276 is more likely because an underlying tephra bed (MC-CC-3) in this same exposure correlates to the underlying tephra bed T1244 in the Tulelake core (Figure 5). Both T276 and T1244 are within the tuffaceous interval of the Tulelake core, and neither has been directly dated. The age range for these tephras was originally estimated to range from ~325 to 260 ka (Reick et al., 1992). Reconsideration of the age estimates (discussed in following sections) suggests this age range is a minimum. The underlying Rockland tephra in the Mohawk Cliff exposure provides a maximum-limiting age of 610-570 ka.

The age of all seven of the MC-CC tephra beds can only be loosely constrained by the broad age range estimates for overlying and younger tephra bed MC-GG-1, (>325-260 ka) and the underlying and older Rockland tephra, MC-Y, (610-570 ka) (Figures 3 and 5). The glass in tephra bed MC-CC-7 (Figure 3) has three compositional modes, none of which have a strong, or even moderate, correlation based on similarity coefficients with a tephra that is stratigraphically reasonable. Based on glass composition, it is suspected this tephra bed may have originated from the Newberry Volcano or nearby.

The composition of glass in tephra bed MC-CC-6 (Figure 3) has a strong correlation with Tulelake tephra bed T2053 (SC = 0.99). This correlation is also stratigraphically consistent with other tephra beds within this exposure (Figure 5). T2053 has not been directly dated, and no age range was provided based on stratigraphic relations in the Tulelake core (Rieck et al., 1992). The compositions of glass in tephra beds MC-CC-5 and MC-CC-4 (Figure 3) are compositionally similar to one another. There are no stratigraphically reasonable matches of either tephra bed with any other tephra within or outside of Mohawk Valley.

The composition of glass in tephra bed MC-CC-3 (Figure 3) is similar to that of several Tulelake tephra beds. The favored correlation is to T1244 (SC=0.98?) because it is stratigraphically consistent with all the other Tulelake tephra bed correlations in the Mohawk Cliff section (Figure 5). Other possible correlations are to T260 or T2102 (SC=0.98), both much higher in the Tulelake core or to T315 (SC =0.95) which is much lower in the Tulelake core and also underlies the Rockland tephra (Figure 5).

The composition of glass in tephra bed MC-CC-2 (Figure 3) correlates to a tephra bed from the tuffaceous interval of the Tulelake core, from 56.75 m to 57.60 m (SC=0.98). This correlation is favored because it is stratigraphically consistent with all of the overlying correlations (Figure 5). Other possible correlations are to Buck Lake 3492 (SC=0.98) and BL 3495 (SC=0.97). The overlying tephra bed MC-GG-1 also correlates to BL 3495, making this correlation an unreasonable stratigraphic correlation (Figure 5).

The composition of glass in tephra bed MC-CC-1 (Figure 5) correlates to two Tulelake tephra beds, TL2023 (SC=0.97) or TL2019 (SC=0.98). Neither correlation is stratigraphically reasonable because tephra beds much higher within this same stratigraphic section have been correlated to the same Tulelake tephras (Figure 5).

Two well-known tephra beds were found lower in this section and provide maximum-limiting ages for those MC-CC tephras deposited above them. Tephra bed MC-Y was deposited about two meters below the MC-CC tephras (Figure 3). The composition of glass in tephra bed MC-Y strongly correlates to the Rockland tephra (SC=0.99). This ~180 cm-thick tephra bed is by far the thickest in the Mohawk Cliff section (Table 2). The Rockland tephra has been most recently dated to 610-570 ka (Lanphere et al., 2004). Tephra bed MC-K was deposited about ten meters lower in the section (Figure 3). The composition of glass in tephra bed MC-K strongly correlates (SC=0.98) to the Lava Creek B tephra. The Lava Creek B tephra was most recently dated to 639 ± 2 ka (Lanphere et al., 2002).

Two previous studies reported a tephra bed deposited within sediments from a floodplain fluvial terrace that is inset into the Mohawk Cliff exposure and about 2 meters above the modern MFFR, although the precise sample location was not recorded. In both prior studies, the glass composition in this tephra bed strongly correlated to that in the Tsoyawata tephra bed (SC=0.98). The Tsoyawata tephra bed has been dated to 7015 ^{14}C yr B.P. (Davis, 1978; Bacon, 1983; and Rieck et al., 1992). Samples from a fluvial terrace that is about 3 meters above the modern MFFR (site MV-297; Figure 2) provide radiocarbon ages for that surface. Analyses of charred and vitrified pine cone scales collected from 150-210 cm below the terrace surface are about 3,675 and 3,765 ^{14}C yr B.P. (Table 4). The Tsoyawata tephra bed sample location is estimated to be near site MV-314, which is about 4 meters above the modern MFFR (Figure 2).

Mohawk Valley Floor Section

Twelve other sites that contain tephra beds are located upstream of the Mohawk Cliff section and are exposed along the railroad grade, Highway 70, and road cuts near the MFFR near the town of Blairsden (Figure 2). Thick deposits of indurated, interbedded, well to moderately well-sorted sands, silts, silty clay, diatom beds, few fine pebble beds, and thin beds of organic-rich silty clay are exposed in this area. Many small faults exposed in this section hinder clear stratigraphic correlations from site to site (Figure 2). At site MV-10 (Figure 6), the section is less indurated, and relatively coarser-grained (sandy) than the section exposed along the railroad and road cuts to the east of Blairsden (silt and silty clay).

Sites MV-10A and -10B lie ~ 1.5 km to the northeast and across the MFFR from site MV-315, the Mohawk Cliff section (Figures 2 and 6). Four tephra beds were deposited within a 39 m-thick section of sand and fine pebble beds exposed along the railroad grade, two of which were analyzed (MV-10A and MV-10B). Northwest dipping sediments observed at site MV-10B and lineaments visible in LiDAR imagery (Figure 6B) suggest the two sites may be separated by a fault. The nearby site JY-92-1 (Figure 2) has not been correlated to any other tephra within or outside of Mohawk Valley. The composition of the glass in tephra bed MV-10A-lower B has two possible correlations. The first is to a tephra bed located on Keton Island in the Puget Sound (Figure 4) labeled 19-1E-11-73E-1 (SC=0.95). However, tephra bed MV-10A-lower B is more likely correlated to Carp Lake Ash-13, which does have a slightly lower similarity coefficient (SC=0.94), but the Fe_2O_3 content is more similar, making this a better match. The composition of the glass in tephra bed MV-10B is very similar to that in MV-10A (SC=0.98) suggesting it is also the Carp Lake Ash-13. The Carp Lake Ash (Figure 4) is from an unknown source and has not been directly dated. The best age estimate for the Carp Lake Ash-13 and the two tephra beds found at site MV-10 is $<218 \pm 10$ ka and >100 ka (Whitlock et al., 2000).

Eleven sites hosting sixteen tephra beds are located along the railroad grade and roads southeast of Blairsden (Figure 7). The compositions of the glasses from seven sites (MV-174, MV-175, and MV-179, JY-92-11, JY-92-9, SAM 38, and SAM 10B) (Figure 7) are all strongly correlated to the Rockland tephra (SC=0.98 and 0.99). At site MV-178, the composition of the glass in tephra bed MV-178-B is similar to both the Thermal Canyon Ash (SC=0.96) and to Clear Lake Ash bed 9 (SC=0.96). The correlation to the Thermal Canyon Ash is preferred based on comparison of SC values for the three most reliable oxides: Fe_2O_3, K_2O, and CaO. The nearby sites JY-92-13 and JY-92-14 both also had strong correlations (SC=0.98) to the Thermal Canyon ash, which has an age of ~740 ka (Sarna-Wojcicki et al., 1993, 1997).

Six tephra beds were sampled from three relatively closely spaced sites, MV-181, MV-192, and JY-92-2 (Figure 7). Among these three sites and six tephra beds, three different tephras were identified, none of which could be correlated to any known tephra bed outside of Mohawk Valley. The glass in the uppermost tephra bed (MV-181-D middle) at site MV-181 is compositionally similar to that in JY-92-2A (SC=0.??) (Figure 8). The glass composition in the stratigraphically lower tephra bed MV-181-D-lower correlates to JY-92-2B (SC=0.??) and to the glass in tephra bed MV-192-3C (SC=0.98) (Figure 8). Comparison to nearby sites that could provide minimum-limiting age constraints for the three tephras is complicated by many faults in this area (Figures 7 - 9D). Faulted sediments in this area occupied a wide zone, but all offsets observed at this time have been relatively minor (≤ about 30 cm) (e.g. Figures 9B-9D). Based on the position of site MV-192 relative to the stratigraphically and topographically higher sites MV-174, MV-175, and MV-179, it is probably reasonable to conclude that all three tephras are older than the Rockland tephra (Figure 8) and likely also older than the Thermal Canyon Ash at site MV-178 (Figure 8), though the latter may be a more tenuous stratigraphic relationship.

Layman Canyon

To the west, the MFFR and Highway 70 leave Mohawk Valley and cut through the downstream Layman Canyon (Figure 2). Two sites exposed within Layman Canyon, sites MV-133 and MV-312, host a total of fifteen tephra beds that were deposited within the western-most extent of the Mohawk Lake Beds (Redwine, 2013). Both sites were original identified by J.O. Davis in 1983. Site MV-133 is exposed along Highway 70 and was also sampled and described in the current study. This section is composed of 21 m of well-sorted silts and sands interbedded with moderately well sorted pebbles, cobbles, and sands (Figures 10A and B). The exposed sediments are cut by a N70E 75°N striking fault, a splay of the MVFZ (Figure 2).

Glass from twelve tephra beds in this section was analyzed. Four tephra beds were sampled in the present study, some of which maybe duplicates of those sampled by Jonathan Davis in 1983, which were re-analyzed by the U.S. Geological Survey in 1994 (Table 1). The exact positions of the analyzed tephra beds within this section from the prior study are not known, but their relative stratigraphic positions are (Figures 10 A and B). The tephra beds are described here from the base of the exposure to the top.

The composition of glass in tephra bed RC-13 (Figures 10 A and B) was correlated to that in the Thermal Canyon ash (~740 ka) (Sarna-Wojcicki et al., 1993, 1997). The composition of glass in tephra beds RC-12 and RC-9 (Figures 10 A and B) both have strong correlations (SC=0.98) to that in the Lava Creek B tephra (639 ± 2 ka) (Lanphere et al., 2002) The composition of glass in tephra bed MV-133-A (Figures 10 A and B) also has a strong correlation to that in the Lava Creek B tephra (SC=0.98) and a slightly weaker correlation to the Huckleberry Ridge ash (SC=0.97) (2.059 Ma) (Sarna-Wojcicki and Pringle, 1992; Lanphere et al., 2002). Correlation to the Lava Creek B tephra is favored because of the slightly higher weighted average SC (0.98) for Lava Creek B tephra than for Huckleberry Ridge Ash (SC=0.97), its much higher SC for Fe_2O_3 (SC=0.98 vs 0.86), and because it is the most stratigraphically reasonable correlation (Figure 5).

The composition of glass in tephra bed RD-2 correlates to the Dibekulewe ash bed (SC= ??). The age of the Dibekulewe ash bed is constrained by the tephrostratigraphy in this exposure (Figures 10 A and B) and by stratigraphy in the Tulelake, Butte Valley and Buck Lake cores (Figure 4) (Adams et al., 1989, 1994A, 1994B, and 1995). In all three locations, the underlying tephra bed, Lava Creek B tephra (639 ± 2 ka) provides a maximum age and the overlying Rockland tephra (610-570 ka) provides a minimum age.

The composition of glass in five samples, RC-10, RC-7, MV-133-D, MV-133-E, and MV-133-F, correlates well (SC=0.98) to that in the Rockland tephra (610-570 ka). Tephra beds analyzed in the current study (MV-133-D, MV-133-E, and MV-133-F) are located on both sides of a fault (Figures 10A and B). Tephra beds MV-133-E (lower) and MV-133-F (higher) are separated by a sand-sized pumice deposit and are on the south side of the fault, apparently offset by about four meters from the base of MV-133-D (Figure 10A).

The composition of glass in tephra beds RC-5 and RC-6 does not correlate to any tephra outside of Mohawk Valley, but is correlative to each other (SC=0.99) and to glass within tephra bed MC-GG-2 (SC=0.98) within the Mohawk Cliff exposure (Figure 3). At site MV-133, the location of these tephra beds is unknown other than they stratigraphically overlie the Rockland tephra (J. Davis, written comm. to A. Sarna-Wojcicki, 1983). In the Mohawk Cliff exposure, the age of the correlative tephra bed (tephra bed MC-GG-2) is constrained by the overlying MC-GG-3, (218-180 ka) and the underlying tephra bed MC-GG-1, (>325-260 ka and <610-570 ka) (Figures 3 and 5).

Prior studies report a site ~1.3 km downstream from site MV-133, the approximate location is shown as site MV-312 (Figure 2). Two tephra beds were analyzed from this section. The composition of glass in tephra bed JY-92-79 correlates to that in the Rockland tephra (SC=0.98). The composition of glass in tephra bed JY-92-77 correlates to that in the Lava Creek B tephra (SC=0.98).

Gray Eagle Creek

Glass was analyzed from five tephra beds sampled from three different sites (MV-65, MV-66, and MV-284) along Gray Eagle Creek (Figure 11). The depositional setting of the sediments along Gray Eagle Creek is important to the correlation of these tephra beds to one another. This section is composed of indurated, parallel bedsets of mostly fine-grained sediments and lesser bedsets of cobbles and pebbles (Figures 12 and 13). The deposits display horizontal bedding with a gentle basinward (north) dip of ~4º and lack evidence for major erosional events in the form of cut and filled channels (Figure 12). The sediments are interpreted to have been deposited into an aggrading delta of a fluctuating, but overall rising, lake (Redwine, 2013). Coarse-grained outwash gravels and fluvial terraces overlie and cut into the indurated, fluvial-deltaic section (Figures 11- 13). The outwash terraces are progressively inset to one another (Figure 11). In places, these fluvial deposits are underlain by loose, fine-grained, lacustrine sediments, which are relatively younger than the underlying indurated lacustrine section (Figures 13A and B, unit V).

Tephra bed MV-284-V upper was deposited within lacustrine sediments composed of loose silt, fine sand, and diatom-rich beds. At site MV-284, this tephra bed is overlain by about 1 meter of coarse grained outwash gravels (unit W) and overlies a 19 m-thick section of indurated, parallel bedded, fine-grained, silts, clays, sands, and lesser pebbles exposed at site MV-65 (Figures 13A and B). The composition of glass in tephra bed MV-284-V upper is correlated (SC=0.96) to a Tulelake tephra bed at 9.34 m, which correlates to Summer Lake tephra bed E1, and is 33.7-29.9 ka (Negrini et al., 1984; Davis, 1985; Reick et al., 1992; Benson et al., 2013) (Figure 5).

The indurated section at site MV-65 is about 19 meters-thick (~1369 m to ~1388.5 m). The base of a ≥ 2.5 m-thick tephra bed (MV-65-F) lies at ~1375.5 m, about four meters above the base of the section (Figures 13A and C). The top of conformable sediments within this exposure are at about 1388.5 meters (Figure 13A). The composition of glass in tephra bed MV-65-F has a strong correlation (SC=0.98) to the Rockland tephra (610-570 ka).

Site MV-66 is located 0.16 km upstream of site MV-65 (Figures 11 and 12). The section at site MV-66 is exposed from 1400 m to 1385 m, topographically higher, and interpreted to be stratigraphically above and relatively younger than, site MV-65 (Figure 12). Three tephra beds sampled from site MV-66 are all located between the elevations of 1393.6 m to 1392.5 m (Figure 14A) and are also interpreted to be stratigraphically higher, and relatively younger than, tephra bed MV-65-F (Figures 12).

The glass composition within the lowest of the three analyzed tephra beds, MV-66-C11, (Figures 14A and C) could not be correlated to any known tephra and is only constrained by a maximum age from the stratigraphically lower Rockland tephra (610-570) ka. Tephra bed MV-66-C13 lies about 20 cm above MV-66-C11 (Figures 14A and C). The composition of glass in tephra bed MV-66-C13 appears to correlate (SC=0.94) to the Game Hut Obsidian flow that originated from the Newberry Volcano during the East Lake Eruptive Period 7300 cal yr B.P. (Jensen, 2006). This is not considered a stratigraphically reasonable correlation given that the overlying tephra bed MV-66-C18 correlates to the much older East McKay Butte Obsidian (discussed below). In addition, the overlying outwash gravels (Figure 14A) are mapped as between about 33 and 18 ka based on elevation, stratigraphic relations to tephra beds (including site MV-284), ^{14}C ages, and soil development (Redwine, 2013). The age of tephra bed MV-CC-C13 is constrained by the stratigraphically lower Rockland tephra (610-570 ka) (Figure 12) and by tephra bed MV-66-C18, which lies 1.9 m above (Figures 14A - C).

The composition of glass in tephra bed MV-66-C18 is strongly correlated (SC=0.97) to the East McKay Butte Obsidian at Newberry Volcano (Figure 4). K-AR analysis on obsidian from the rhyolitic McKay Butte Dome provides an age of 580 ka ± 100 ka for this eruption (McKee et al., 1976). This age overlaps, within the margin of error, with the age range for the underlying and stratigraphically older tephra bed MV-65-F correlated to the Rockland tephra (610-570 ka). The age of tephra bed MV-66-C18 and the East McKay Butte Obsidian is interpreted to be from 610 to 480 ka.

Jamison Creek

Glass was analyzed from two tephra beds that were sampled from two different sites (MV-70 and -45.5) along Jamison Creek (Figures 2 and 15). Jamison Creek is another deeply incised tributary to the MFFR with well-exposed fluvial-deltaic sediments similar to those observed in Gray Eagle Creek. Similar to the Gray Eagle Creek section, this Jamison Creek section also lacks evidence for major erosional events in the form of large cut and filled channels, is composed of indurated clays, silts, sands, pebbles, and cobbles, and displays horizontal bedding with a gentle basinward (northeast) dip. The sediments within this section are interpreted as fluvial-deltaic deposited into an aggrading delta of a fluctuating, but overall rising, lake (Redwine, 2013). All elevations along Jamison Creek were obtained from a 10-m DEM and are only approximate although sections were measured so the relative distances between units in the stratigraphic columns are reliable.

At site MV-70 (Figures 15A and B), the fluvial-deltaic section is exposed from about 1432 to 1416 meters. Tephra bed MV-70-downstream B, lies in the middle of that section between ~1423 and 1422 m (Figure 16). The composition of glass in tephra bed MV-70-downstream B correlates to that in tephra bed MV-66-C18 from the Gray Eagle Creek section based on a SC of 0.97 and similar individual oxide weight percentages. Tephra bed MV-66-C18 is correlated to the East McKay Butte Tephra, as discussed above, and has a preferred age range of 610-480 ka (Figure 5).

Correlation of tephra beds found at sites MV-70, MV-45.5, and MV-45 is problematic because of the poor elevation control and because there may be faults in between the sites (Figure 15 B). Sites MV-45 and MV-45.5 are both located 1.2 km downstream from site MV-70 (Figure 15). An approximately 26 m-thick section (from 1428 to 1402 meters) of sediments is exposed at these site MV-45, inclusive of the elevation range of the tephra bed exposed at site MV-70 (Figure 15B). Tephra bed MV-45.5D was found at site MV-45.5, which is located on a forested hillslope without exposed stratigraphy to provide stratigraphic context (Figure 17). The gps location from this sample site, under the forest canopy, was only approximate and the elevation from the gps location and the 10 m-DEM is only very roughly estimated at about 1426 m. Immediately downstream of site MV-45.5 the sediments are well exposed at site MV-45 (Figure 17). A blue box highlights where tephra beds were located within section MV-45 from an interval of about 1427-1423 m (Figures 17). Samples from these tephra beds had poorly preserved glass and were not analyzed. Tephra bed MV-45.5D may lie within that stratigraphic interval. No tephra beds were recognized below that interval at site MV-45 and tephra bed MV-45.5D was a relatively thick deposit, similar to the thick white beds at site MV-45 (Figure 17). The glass composition within tephra bed MV-45.5-D has a strong correlation (SC=0.97) to tephra bed MV-66-C13, found in Gray Eagle Creek. The age of tephra MV-66-C13 is constrained by the overlying tephra bed correlated to the East McKay Butte tephra (610 to 480 ka) and by the stratigraphically lower Rockland tephra (610-570 ka).

Eastern Mohawk Valley

An approximately 90 m- thick package of fluvial-deltaic sediments is well exposed along Clio Road and Willow Creek (Figure 18). Sites MV-5 and JY-92-7 are located in the upper 34 meters of this Clio Road section (Figure 19A). Tephra bed MV-5-F, is laterally continuous and was deposited at about 1435.5 meters within indurated, horizontally bedded silt and sand and also within fine-grained channel fill (Figures 19B and C). The composition of glass in tephra bed MV-5-F correlates to the Summer Lake tephra bed LL (SC=0.96) (218->180 ka) (Negrini et al., 2000; Kuehn and Negrini, 2010; and Donnelly-Nolan, 2010) and to the Wadsworth ash bed (SC=0.95) (201 ± 45 ka) (Berger, 1991). The correlation to Summer Lake tephra bed LL is favored because it has a higher average SC and weighted SC for the key oxides, Fe_2O_3, K_2O, and CaO. The composition of glass in tephra bed JY-92-7 also strongly correlates (SC=0.98) to Summer Lake tephra bed LL and to the Wadsworth Ash.

Two more tephra beds, SAM-25A and B, were deposited about 21 meters lower (estimated elevation ~1414 m) within this same stratigraphic section at site SAM 25 (Figures 18 and 19A). These tephra beds were sampled and analyzed by Mathieson (1981). The composition of glass in both tephra beds SAM-25A and B is correlated to (SC=??) the Rockland tephra (610-570 ka). Two tephra beds, JY-91-7 and 8, collected during a prior study, are located nearby (Figure 18), and also correlate to the Rockland tephra (SC=0.98).

There are three more sites in eastern Mohawk Valley where the glass composition of the sampled tephra bed(s) correlates to the Rockland tephra (610-570 ka). Two sites, MV-90 and MV-91, are exposed along Portola Road (Figure 18). The composition of glass in tephra beds MV-90-E and MV-91-C both have strong correlations (SC=0.98) to the Rockland tephra (610-570 ka). Tephra bed JY-92-6, sampled from earlier studies, is nearby and is likely the same sampled tephra bed as MV-90-E. Tephra bed MV-90-E was deposited in fine to medium sands that dip gently, ~4º northward, away from the basin. A moderately well-developed soil extends through the Rockland tephra at this location (Redwine, 2013).

The soil is associated with the small overlying remnant fluvial terrace remnant (Figure 18, unit Qdr2) and formed well after deposition of the now nearly exhumed Rockland tephra (Redwine, 2013). Site MV-91 is located 250 m to the south and 26 m below site MV-90 (~1398 m) (Figure 18). Tephra bed MV-91-C was deposited in similar sediments as those at site MV-90, but the bedding dips gently basinward (south) and the tephra bed is faulted along a N45W 58°NE striking fault (Figure 18). There is not similar soil development into tephra bed MV-91-C as observed at site MV-90.

Site MV-139 is exposed along Highway 89 (Figure 2). Tephra bed MV-139-B was deposited within of silty clay, sand, and silt near the base of a 95 m-thick package of fluvial-deltaic sediments exposed along Highway 89. The composition of glass in tephra bed MV-139-B (SC=0.98) has a strong correlation to the Rockland tephra (610-570 ka). The nearby tephra bed JY-92-47, sampled from earlier studies, also correlates to the Rockland tephra.

DISCUSSION

A total of twenty-six different tephras, ranging in age from ~740 ka to ~7 ka, were deposited in Mohawk Valley. We have presented the glass analytical results for sixty-one tephra beds found in twenty-seven locations within Mohawk Valley (Tables 1 and 2; Figure 2). Eleven of these tephras, MV-181-D middle and JY-92-2A, MV-181-D lower and MV-192-3C and JY-92-2B, MV-192-2D, MV-66-C13 and MV-45.5, MV-66-C11 and MV-70-downstream B, MV-133-RC5 and MV-133-RC6 and MC-GG-2, MC-GG-4, MC-CC-7, MC-CC-5, MC-CC-4, and MC-CC-1, have only been identified in Mohawk Valley at this time. We have provided age estimates for these eleven tephras using stratigraphic contexts within Mohawk Valley and tephrostratigraphic correlations to dated tephras outside of Mohawk Valley (Figures 5 and 20). We also re-assessed the ages of some tephra beds found in locations outside of Mohawk Valley based on either new age and stratigraphic control from Mohawk Valley or updated numerical ages from other studies. In addition, correlations of Mohawk Valley tephras with the tuffaceous interval within the Tulelake core may indicate additional volcanic eruptions occurred in northeastern California than were previously recognized.

Ages of Previously Recognized Tephras

Age estimates of tephras and tephra beds change through time as new numerical dating techniques become available or methodologies change. Because of this, the ages cited in the past literature can vary. We provide a summary of the numerical ages and a discussion of our favored age estimates for the important tephras relative to this study.

Tsoyowata (~ 7 ka)

The Tsoyawata tephra was erupted from Mount Mazama, now Crater Lake, Oregon (Fig. 4). This tephra was erupted from a relatively smaller eruption that preceded the climactic eruption of the Mazama ash by 100-200 years (Davis, 1978, 1985; Bacon, 1983; Young, 1990, Rieck et al., 1992; Bacon and Lanphere, 2006).

Tulelake T 2438 and Summer Lake E1 (33.7-29.9 ka)

The Tulelake tephra bed T2438 at 9.34 m has been correlated to Summer Lake Summer Lake tephra bed E1 (Fig. 4) (Davis, 1985; Reick et al., 1992) (Fig. 5) and neither have been directly dated. In the Tulelake core T2438 was deposited 2.1 meters below the Trego Hot Springs (THS) tephra bed and within the upper part of sediments correlated to the Mono Lake magnetic excursion (Rieck et al., 1992). In Summer Lake deposits, the E1 tephra bed is constrained by the underlying Wono and overlying THS tephra beds. The age of Summer Lake tephra bed E1 was constrained to 26-27 ka by sedimentation rates in the Tulelake core and relations to the Mono Lake excursion (Negrini et al., 1984) and as 25.1 ka by stratigraphic relations to the THS and Wono tephra beds and an age-depth model (Kuehn and Negrini, 2010).

The ages of the Wono and THS tephra beds have been revised several times (Davis, 1983, 1985; Negrini and Davis, 1992, Benson et al., 1997; Benson et al., 2013). The most recent ages were generated from the age of surrounding sediment in a core from Pyramid Lake and are 27.3 ka ± 0.3 ^{14}C yr B.P. for the Wono Tephra and 23.2 ka ± 0.3 ^{14}C yr B.P. for the overlying Trego Hot Springs (THS) tephra (Benson et al., 1997). Benson et al. (2013) constructed a GISP2-based time scale for the Pyramid Lake core that provided calibrated ages of 29.9 and 33.7 ka for the THS and Wono tephras, respectively. Therefore, the most recent age estimate for the Tulelake tephra bed T2438 and Summer Lake Summer Lake tephra bed E1 is 33.7-29.9 ka cal yr B.P.

Carp Lake Ash 13 and Puget Sound tephra bed (~200-100 ka)

Carp Lake Ash-13 from core 93 has not been directly dated and it is not known from which volcano it was erupted (Whitlock et al., 2000). The age of Carp Lake Ash-13 is constrained by tephrostratigraphic relations within cores 93 and 90. A maximum age is provided by the underlying Carp Lake Ash-14 in core 93 that correlates to tephra bed layer 'E' at Pringle Falls, Oregon (Figures 4 and 5), which was dated using magnetostratigraphy to <218 ± 10 ka (Herrero-Bervera et al., 1994). In addition, the underlying Carp Lake Ash-15 is correlated to the andesitic tephra layer at Tulelake in California and to the correlative Summer Lake tephra bed KK. The ages of these tephras are discussed in detail below, but here are estimated to be about 180 ka (Donnelly-Nolan, 2010).

A minimum age was provided for Carp Lake Ash-13 from its correlation to Carp Lake Ash-11 from core 90 (Whitlock et al., 2000). In core 90, the overlying Carp Lake Ash-10 was estimated to be ~100 ka using sedimentation rates based on ten radiocarbon dates (Whitlock et al., 2000). This age estimate is supported by the correlation of the same tephra bed, Carp Lake Ash-10, to an unnamed ash in the Palouse Formation (Whitlock et al., 2000) (Figure 5). The ash in the Palouse Formation (Figure 4) is also estimated to be ~100 ka based on sedimentation rates using radiocarbon dates, a paleosol, and thermoluminescence dates (Busacca et al., 1992). Together, these limiting ages for Carp Lake Ash-13 suggest the best age estimate is <218 ± 10 ka and >100 ka. The Keton Island, Puget Sound tephra bed (Figure 4) has no associated age correlation (Walsh et al., 2003), though it is likely that this is the same tephra as Carp Lake Ash-13.

Summer Lake tephra bed KK and dacite tuff of Antelope Well (formerly andesitic tuff of Medicine Lake Volcano) (215-180 ka)

The Summer Lake tephra bed KK is an ash-fall tephra deposit that was erupted from the Medicine Lave Volcano and correlates to the andesitic tuff (Anderson, 1941) of Medicine Lake Volcano (Sarna-Wojcicki et al., 1991), now referred to as the dacite tuff of Antelope Well (Donnelly-Nolan, 2010). An early age estimate for the Summer Lake tephra bed KK (Rieck et al., 1992; Sarna-Wojcicki et al., 1991) of 160 ± 25 ka was based on K-Ar dates on over- and underlying ashflow tuffs at Medicine Lake Volcano (Donnely-Nolan, J.M. and L.B. Pickthorn, 1989, written comm. in Rieck et al., 1992). The Summer Lake tephra bed KK was directly dated using thermoluminescence, which yielded an age of 201 ± 27 ka (Berger, 1991). An analytical date directly on the andesitic tuff from Argon dating of a pumice lump resulted in a whole-rock ^{40}Ar/^{39}Ar plateau age of 171 ± 43 ka (Herrero-Bervera et al., 1994). The Summer Lake tephra bed KK was later constrained by overlying sediments within the Summer Lake core (Negrini et al., 1994). The glass composition in the overlying Summer Lake tephra bed GG correlates with layer D at Pringle Falls, Oregon that was correlated to the Pringle Falls magnetic excursion (Negrini et al., 1994, Herrero-Bervera et al., 1994; McWilliams, 1995; Negrini et al., 2000). The Pringle Falls magnetic excursion was correlated to a geomagnetic excursion in the northwestern Atlantic Ocean that is found worldwide in marine sediments and has been dated to 190 ± 10 ka (Henyey et al., 1995; McWilliams, 1995; Negrini et al., 2000). Based on these relations and ages, Negrini et al. (2000) prefer the older limits within the age ranges for the Summer Lake KK tephra bed reported as 200 ± 30 ka (Negrini, 2002), and based on a revised aged-depth model in Summer Lake, perhaps ~215 ka (Kuehn and Negrini, 2010). However, recent mapping and dating efforts at the Medicine Lake Volcano have also revised previous age estimates (Donnelly-Nolan, 2010). An ^{40}Ar/^{39}Ar age of 180 ± 28 from a basaltic andesite under Giant Crater lava field (Donnelly-Nolan and Lanphere, 2005) that overlies the dacite tuff of Antelope Wells (Donnelly-Nolan, 2010) provides a minimum limiting age. This age range is permissive of the favored age of 215 ka by Kuehn and Negrini (2010). However, the dacite tuff of Antelope Wells is interpreted to have erupted when ice was present over the caldera (Donnelly-Nolan and Nolan, 1986) and the age of the dacite tuff of Antelope Well is considered to be approximately 180 ka (Donnelly-Nolan et al., 2008; Donnelly-Nolan, 2010) based on comparison to marine oxygen-isotope climate records (Martinson and others, 1987; Bassinot and others, 1994) that indicate a cold period existed from 185 to 130 ka (Donnelly-Nolan, 2010). Kuehn and Negrini (2010) offer alternative possibilities regarding timing of glaciations at Medicine Lake Volcano compared to worldwide marine oxygen isotope records. In this study, we consider that the age of the Summer Lake tephra bed KK is likely between 215-180 ka.

Wadsworth (201 ± 45 ka)

The Wadsworth tephra of Davis (1978) was directly dated using thermoluminescence, and yielded an age estimate of 201 ± 45 ka (Berger, 1991). The Wadsworth tephra has a similar glass composition to the Summer Lake tephra bed KK tephra bed and the two may be correlative (Negrini et al., 1994). The possible correlation of the Wadsworth tephra to the Summer Lake tephra bed KK is supported by age estimates, which, within the margin of error, are permissibly similar.

Summer Lake tephra bed LL (218->180 ka)

The Summer Lake tephra bed LL was directly dated by thermoluminescence yielding an age of 162 ± 35 ka that was considered a minimum age because of an unusual dose-rate response curve (Berger, 1991). Other age estimates include a range from about 230-210 ka (Negrini et al., 2000) and, based on a revised aged-depth model, perhaps ~218 ka (Kuehn and Negrini, 2010). Summer Lake tephra bed LL is closely associated with the overlying Summer Lake tephra bed KK in exposures in Summer Lake basin (Negrini et al., 2000; Kuehn and Negrini, 2010) and likely are close in age. We infer that the age of the Summer Lake tephra bed LL ranges from 218 to >180 ka based on age estimates from Kuehn and Negrini (2010) and on the age of the overlying Summer Lake tephra bed KK (Donnelly-Nolan, 2010; Kuehn and Negrini, 2010).

Cougar Butte Obsidian (437 ± 7 ka)

The age of the obsidian from the rhyolite near Cougar Butte at Medicine Lake Volcano was reported as 430 ± 40 ka (K-Ar analysis) by Mertzman (1982). More recent analyses yielded age estimates using K-Ar of 590 ± 22 ka and 547 ± 16 ka and of 437 ± 7 ka with $^{40}Ar/^{39}Ar$ analyses (Donnelly-Nolan and Lanphere, 2005). The age of this unit reported as 437 ± 7 ka by Donnelly-Nolan (2010) is used here.

Rockland tephra (610-570 ka)

The Rockland tephra is hypothesized to have erupted from a caldera located at the present site of Brokeoff Volcano (Clynne and Muffler, 2010) near Lassen Peak in northern California, about 100 km to the northwest of Mohawk Valley (Figure 4). This tephra has been found in many locations in the western U.S. including several cores from different lake basins and offshore in the Pacific Ocean (e.g. Sarna-Wojcicki et al., 1985; Sarna-Wojcicki and Davis, 1991; Alloway et al., 1992; Lanphere et al., 2004) and in ten locations in Mohawk Valley. Because of the widespread distribution and depositional settings where the Rockland tephra has been identified, its age is very important to numerous tephrochronologic and Quaternary studies in the western U.S., including Mohawk Valley. As techniques to date tephras evolve, the age estimates of some tephras, including the Rockland tephra, have changed through time and these changes affect age estimates of several other key chronostratigraphic markers as well.

There have been several techniques used to date the Rockland tephra in the past 30 years, most of which are summarized in Lanphere et al. (1999, 2000, 2004). One of the early efforts to date this tephra used zircon fission-track on discrete grains of the Rockland tuff breccia (Meyer et al., 1980, 1991). This method was chosen to avoid complications from detrital and xenocrystic contamination (Meyer et al., 1980, 1991; Sarna-Wojcicki, 2000). The study yielded fission track ages of 370 ± 50 ka and 400 ± 50 ka on proximal sites, and 420 ± 80 ka and 460 ± 90 ka on distal sites (Meyer et al., 1980, 1991). Older ages were found for zircon crystals in the same study and they were considered re-worked and detrital, therefore analyses of those grains were not included in the final age calculation (Meyer et al., 1980, 1991; Sarna-Wojcicki, 2000). Subsequent analyses by Alloway et al. (1992) used isothermal plateau fission-track on glass of the Rockland pumice tuff breccia and estimated an age of 470 ± 40 ka for the Rockland tephra. Lanphere et al. (1999) used incremental-heating $^{40}Ar/^{39}Ar$ on amalgamations of plagioclase from a proximal ash flow and estimated an average age-spectrum-plateau age of 614 ± 8 ka. Further study was warranted because of these age discrepancies of this prominent chronostratigraphic marker (Sarna-Wojcicki, 2000; Lanphere et al., 2000).

A recent study re-examined the age of the Rockland tephra and tested the hypothesis that detrital xenocrysts may have contributed to an older age estimate using four approaches: $^{40}Ar/^{39}Ar$ analyses of plagioclase from pumice, U/Pb analyses of zircon grains and zircon rims, stratigraphic context and ages of over- and underlying and independently dated deposits, and stratigraphic context within a single core (Lanphere et al., 2004). The results of measured incremental-heating of $^{40}Ar/^{39}Ar$ on plagioclase from pumice yielded plateau ages of 607 ± 9 and 622 ± 9 ka from one sample and 587 ± 12 ka from a second sample (Lanphere et al., 2004). The weighted mean of the three analyses yielded a mean plateau age of 609 ± 7 ka (Lanphere et al., 2004). This mean plateau age is considered the best available $^{40}Ar/^{39}Ar$ age for the Rockland tephra and is the age cited by Clynne and Muffler (2010).

An alternative approach used analyses of individual zircon grains analyzed from three samples of the Rockland tephra to identify crystallization intervals that immediately preceeded the eruption (Lanphere et al., 2004). The analyses used isotopic U/Pb, determined by the Stanford/USGS SHRIMP-RG ion probe, on 57 spots from 52 different zircon grains, resulting in a broad range of ages from 810 to 450 ka (Lanphere et al., 2004). This range of ages was interpreted to likely represent a suite of crystals that formed prior to eruption (Lanphere et al., 2004). Results that focused on analysis of zircon rims, which were interpreted to more closely approximate the time of eruption, resulted in a younger age, a weighted mean average of 573 ± 19 ka (Lanphere et al., 2004).

Maximum and minimum-limiting ages based on stratigraphic context where the Rockland tephra was deposited were also assessed. In several locations in the western U.S., including this study, the Rockland tephra is stratigraphically underlain by the Lava Creek B tephra, which has a preferred age 639 ± 2 ka, discussed below (Lanphere et al., 2002; 2004). The Hootman Ranch basaltic andesite overlies the Rockland tephra in the Medicine Lake Volcano (Lanphere et al., 2004, Donnelly-Nolan, 2010). Using incremental-heating of $^{40}Ar/^{39}Ar$ the plateau age of the Hootman Ranch basaltic andesite was estimated to be 565 ± 29 ka and 530 ± 42 ka for plagioclase and groundmass, respectively (Lanphere et al., 1999b). In a more recent interpretation, the $^{40}Ar/^{39}Ar$ plateau age of the groundmass sample was 565 ± 12 and the isochron age 576 ± 12 (Lanphere, et al., 2004). These stratigraphic relations provide an age range of (639 ka to 565 ka) for the Rockland tephra.

Additional age constraints come from stratigraphic relations in the ODP core 1018 offshore of central California. Sedimentation rates estimated from within the ODP core, using a linear sedimentation rate extrapolated between the underlying Brunhes-Matayuma boundary and an overlying extinction layer, provide an estimated age of the Rockland tephra of about 600 ka (Lanphere et al., 2004). In addition, a close spatial association of the Rockland tephra in ODP core 1018 with a redwood pollen peak 64 cm above, that is itself associated with oxygen isotope stage 15.1, provides an age estimate of about 580 ka for the Rockland tephra (Lanphere et al., 2004). Together, the stratigraphic relations within ODP core 1018 provides a similar age range (600 to 580 ka) for the Rockland tephra. In summary, the four approaches used to re-examine the age of the Rockland tephra provided a similar range of possible age estimates. Lanphere et al. (2004) consider that the best age range using those analytical measures places the age of the Rockland tephra from 610 to 570 ka (Lanphere et al., 2004), which is the age range used in the present Mohawk Valley study.

Lava Creek B tephra (~639 ka)

The Lava Creek B tephra (LCB) was erupted from the Yellowstone Caldera system (Izett, 1981) (Figure 4) and is correlated to the Pearlette type O ash bed (Izett and Wilcox, 1981). The age of LCB was originally considered to be 610 ka (Christensen, 1979), was revised from results of K- Ar analysis of sanidine and glass to 617 ± 4 ka (Obradovich and Izett, 1991), and again revised from results of $^{40}Ar/^{39}Ar$ analysis of sanidine to 610 ± 104 ka (Obravodich, 1992), 660 ± 10 ka, and 670 ± 10 ka (Izett et al., 1992). Gansecki et al. (1996) used laser-fusion $^{40}Ar/^{39}Ar$ dating of individual sanidine and plagioclase grains to establish eruption ages related to the Lava Creek tuff. This is considered more accurate because this method allows single-crystal dating which minimizes the contamination by older xenocrysts and results in an age estimate for the LCB of 631 ± 62 ka (Gansecki et al., 1996). Most recently, $^{40}Ar/^{39}Ar$ ages were determined using total-fusion and incremental- heating ages of sanidine, which yielded a mean age of 639 ± 2 ka (Lanphere et al., 2002).

Thermal Canyon (~740 ka)

The Thermal Canyon ash has not been directly dated and it is not known from which volcano it was erupted (Sarna-Wojcicki et al., 1993). The Thermal Canyon ash has been found stratigraphically above the Bishop Ash in three locations. In the Borrego badlands, the Thermal Canyon ash was found 25 and 80 m above the Bishop Ash (Lutz et al., 2006), in the Mecca Hills (Figure 4) 40 m above the Bishop Ash (Sarna-Wojcicki, 1997; Dorsey, 2002), and in the Owens Lake (Figure 4) core 7.9 m above the Bishop Ash (Sarna-Wojcicki et al., 1993). The most recent age estimate of the Bishop Ash of 758 ± 2 ka is from laser-fusion $^{40}Ar/^{39}Ar$ on sanidine crystals (Sarna-Wojcicki and Pringle, 1992; Sarna-Wojcicki et al., 2000). The age of the Bishop Ash is further constrained by the underlying Brunhes Matuyama boundary, with age estimates of 775 ± 5 ka (Sarna-Wojcicki and Pringle, 1992) and ~780 to ~790 ± 10 ka (Baksi et al., 1992; Spell and McDougall, 1992, Obradovich and Izett, 1992). The age estimate for the Thermal Canyon ash is based on data from the Owens Lake Core. Mass accumulation rates calibrated with radiocarbon dates within the upper 24 m (30 ka) of the core (Bishoff et al., 1997) and sedimentation rates lower in the core calibrated using ten paleomagnetic events that ranged from 783 ka to 28 ka (Glen and Coe, 1997) together provided an age estimate of ~740 ka for the Thermal Canyon ash (Sarna-Wojcicki et al., 1997).

New Tephras from Mohawk Valley and Their Age Estimates

Eleven tephras newly located in Mohawk Valley cannot be correlated to any known tephras within or beyond Mohawk Valley. Limiting ages for six of these new tephra beds are provided based on relative position to known tephra beds in the Mohawk Cliff exposure (Figure 3; Table 5). Ages are also generally estimated using sedimentation rates derived from the lacustrine sediments exposed at the Mohawk Cliff section (Figure 3; Table 5). A study of the Mohawk Lake history that was based on geomorphology and stratigraphy preserved in the valley concluded that after deposition of the Rockland tephra, there are indications of a fluctuating, but overall rising lake that persisted for several hundred thousand years (Redwine, 2013). The stratigraphic section exposed at the Mohawk Cliff section reflects a different lake history prior to the deposition of the Rockland tephra than after. Stratigraphically below the Rockland tephra there are weak paleosols and erosion from small channels below that indicate there were periods of desiccation and lowered lake levels prior to its deposition (Figure 3). Stratigraphically above the Rockland tephra, there are no clear indications of significant pauses in deposition or erosion within the lacustrine sediments that would clearly affect averaged sedimentation rates throughout that time (Figure 3). However, throughout the several hundreds of thousands of years when Mohawk Lake persisted there were multiple glaciations during which times ice extended into Mohawk Lake, and streams and melting glaciers deposited subaqueous deltaic deposits along the southwestern margin of the lake, turbidites and fine grained silt and clay in the center of the basin, and thick fluvial-deltaic sediments in the eastern part of the basin (Redwine, 2013). During this time period there were almost certainly changes in the rate of sediment deposition. With those caveats, and because the tephra beds with known ages in the Mohawk Cliff section span such a long time period, ~ 400 ky, the long term average sedimentation rate during this time period is used here to very loosely place the intervening tephra beds within that timeframe.

While the elevations of the tephra beds within the Mohawk Cliff section are estimated, the relative elevation differences between them are reported from the measured sections of previous studies. We used those reported elevation differences and the age estimates for the Summer Lake tephra bed KK (MC-GG-5) and the Rockland tephra (MC-Y) (Figure 3; Table 5) to estimate an average sedimentation rate of about 0.029-0.024 mm/yr (Figure 3). This range of sedimentation rates, age ranges of the Rockland tephra, and distance above the top of the Rockland tephra were used to make very general age estimates for five tephra beds: MC-GG4, MC-GG2, MC-CC7, MC-CC5, MC-CC4, and MC-CC1 (Table 5).

Correlations of three new tephra beds found at sites MV-181 and MV-192 to nearby known tephra beds are complicated by the depositional environment and faulting. Tephra beds found at both sites correlate to one another, yet are separated in elevation by about 27.5 m and 200 m (Figures 9A). Some or part of the elevation difference may be attributable to the depositional setting. The tephras were deposited in a deltaic setting and the sediments may have draped a sloping landscape. However, there are numerous faults exposed in the Blairsden area that are most likely part of the active Mohawk Valley Fault Zone (Redwine, 2013) that is mapped 200 m to the southwest (Gold et al., 2014) (Figure 7). Most of these faults have only small offsets, for example, the tephra beds at site MV-181 have been apparently vertically offset about 16 cm. However, there may be larger active faults nearby that are not well exposed. Less likely, but possible, is that some of these small “faults” could have resulted from landsliding. There are some small slumps within this section. Further suggestion of tectonic complications is that although the majority of the section near Blairsden is relatively horizontal, the entire exposure at site MV-192 dips up to 7°W. This steep of a dip suggests there may be tilting due to faulting. Another possibility is that at least some of this dip could be a function of the deltaic setting. These complications make correlations to nearby sites with well-correlated tephras based on elevation and stratigraphic position tenuous. It may be reasonable to infer that site MV-178, which contains the Thermal Canyon ash, is stratigraphically above site MV-192 and therefore provides a minimum-limiting age. However, our conservative approach relies on the three sites where the Rockland tephra was located from 18 to 24 meters above MV-192 at sites MV-174, -175, and -179 to provide a minimum-limiting age for the tephra beds at sites MV-192 and, by correlation, for tephra beds at site MV-181 (Figure 9).

Ages and Revised Ages of Known Tephras

Age estimates of tephras and tephra beds change through time as new dating techniques become available or methodologies change. The ages of some previously known tephra beds have changed based on stratigraphic relations and new age estimates of tephra beds in Mohawk Valley. These correlations and new constraints are summarized below.

Ash beds 7 - 9 in the Clear Lake Core

Ash beds 7, 8, and 9 were found in Clear Lake core CL-80-1 and their ages were estimated based on the stratigraphic position relative to the Rockland tephra (Sarna-Wojcicki et al., 1988). Ash bed 7 correlates to Tulelake T296 (Figure 4) and lies 11 cm above the Rockland tephra in a Tulelake core (Sarna-Wojcicki et al., 1988). This stratigraphic position demonstrates that Clear Lake ash bed 7 is younger than and likely close in age to the Rockland tephra, at the time was considered to be about 400 ka (Sarna-Wojcicki et al., 1988) and now revised to 610-570 ka (Lanphere et a., 2004). Revised ages of these three Clear Lake ash beds (7 through 9) based on this revised age of the Rockland tephra are <610-570 ka, >610-570 ka (~625 ka), and >610-570 ka (~660 ka), respectively (Table 6).

Tuffaceous Interval within the Tulelake Core

There are nine tephra beds within the Mohawk Cliff exposure that correlate well with tephra beds found in the Tulelake core (Figure 4), six of which are within the tuffaceous interval of the Tulelake core (Rieck et al., 1992). Within the tuffaceous interval, only one tephra bed, T2023, had previously been correlated to a site outside of Tulelake, in Summer Lake, Oregon (Davis, 1985; Rieck et al., 1992) and this tephra now also correlates to MV-GG-5 in Mohawk Valley (Figure 4). Reick et al. (1992) suggested that the homogenous and coarse nature of the tephras within the tuffaceous interval may indicate a nearby source, perhaps the Medicine Lake Volcano near Lassen Peak (Figure 4). However, because all but one of the tephras in the tuffaceous interval had no matches outside of the Tulelake basin, it was interpreted more likely that they were mixed tephra layers rather than indicating separate eruptions (Rieck et al., 1992). The correlation of the tuffaceous interval to tephra beds in Mohawk Valley suggests these are not mixed or re-worked tephras but instead may be from volcanic eruptions, perhaps at Medicine Lake Volcano as Rieck et al. (1992) suggested.

The age estimate for the tuffaceous interval of ~600-155 ka (Rieck et al.,1992) is supported by tephra correlations in the Mohawk Cliff section with some modifications. Within this tuffaceous interval in the Tulelake core and in the Mohawk Cliff section, the uppermost tephra bed, T2036 and MC-GG-6, overlie the Summer Lake tephra bed KK providing a maximum-limiting age range of 215-180 ka (Figure 5). In the Tulelake core and in Mohawk Cliff, the underlying tephra beds T1202, T2023, and T2019 and MC-GG-5 correlate to Summer Lake tephra bed KK (215-180 ka) (Donnelly-Nolan, 2010; Kuehn and Negrini, 2010). In the Tulelake core, the ages of the underlying tephra beds T276 and T1244 were previously estimated to be ~325 to 260 ka and >325-260 ka respectively, based on sedimentation rates that were calculated using two known tephra beds within the Tulelake core (Reick et al., 1992). Both of these known tephras now have different age estimates. The uppermost tephra bed used to calculate a sedimentation rate is the andesitic tuff of Medicine Lake, at that time thought to be 160 ka (Reick et al., 1992). This is similar to the updated age estimates of 171± 41 ka (Herrero-Bervera et al., 1994), ~180 ka (Donnelly-Nolan, 2010), or 215 ka (Kuehn and Negrini, 2010). The lower tephra bed used in sedimentation rate calculations was the Rockland tephra, at that time estimated to be 400 ka, but now estimated to be much older, ~610-570 ka (Lanphere et al., 2004). The larger difference in age between the two tephras used in sedimentation rate calculations decreases the sedimentation rate, which would result in older age estimates. This slower sedimentation rate suggests the age range estimated by Reick et al., (1992) of ~325-260 ka is a minimum age estimate for tephra bed T276. T276 can also be constrained to >218-180 ka based on its correlation to MC-GG-1 from the Mohawk Cliff section (Figure 5; Table 2). Based on an average sedimentation rate from the Mohawk Cliff section of from 0.029 to 0.024 mm/yr, MC-GG1 may be about 335-238 ka (Table 6).

There are three more tephra beds within Mohawk Cliff that correlate to the Tulelake tuffaceous interval tephras. In the Tulelake core, these tephras are stratigraphically below, but within 63 cm of, the overlying T276 and are designated T2053, T1244, and 56.60 - 59.76 m (Figure 5). The correlative tephra beds in Mohawk Cliff (MC-CC-6, MC-CC-3, and MC-CC-2) are all found significantly (5.5 - 7 m) below MC-GG-1 (Figures 3 and 5). The thickness between the MC-GG-1 and the underlying MC-CC group of tephra beds in Mohawk Cliffs and the intervening stratigraphic changes (Figure 3) suggest a fair amount of time passed between their deposition and that of the overlying MC-GG-1. In Mohawk Cliff, all of these tephra beds are 2.5 to 4 m above the Rockland tephra (Figure 3). The ages of tephra beds, MC-CC-6, MC-CC-3, and MC-CC-2 are somewhere between those constraining ages (<610-570 and >218-180 ka). Using a sedimentation rate from the Mohawk Cliff section of from 0.029 to 0.024 mm/yr, the ages of MC-CC6, MC-CC-3, and MC-CC-2 may be approximately 532-476, 575-528, and 576-529 ka, respectively (Table 6).

East McKay Butte tephra and obsidian (610-480 ka)

The East McKay Butte tephra and the correlative East McKay Butte Obsidian erupted from a rhyolitic dome in the Newberry Volcano (Figure 4) named the East McKay Butte Dome (McKee et al., 1976). K-AR analysis on the obsidian provides an age of 580 ka ± 100 ka for this eruption (McKee et al., 1976). This age overlaps, within the margin of error, with the age range for the underlying and stratigraphically older tephra bed MV-65-F correlated to the Rockland tephra (610-570 ka). The age of tephra bed MV-66-C18 and the correlative East McKay Butte Obsidian is now revised to 610 to 480 ka.

Dibekulewe (639-570 ka)

The Dibekulewe ash bed of Davis (1977, 1978) has been found in several locations in Oregon (e.g. Adams et al., 1989, 1994A, and 1994B) and California (e.g. Sarna-Wojcicki et al., 1993; Knott et al., 1999) (Figure 4). It is not known from which volcano it was erupted, though it likely came from the Cascade Range (Sarna-Wojcicki et al., 1991). The age of the Dibekulewe ash bed is constrained by tephrostratigraphy in Mohawk Valley at site MV-133 and in the Butte Valley, Buck Lake, and Tulelake cores (Figure 4) (Adams et al., 1989, 1994A, 1994B, and 1995; Rieck et al. 1992). In all four locations, the underlying tephra bed, Lava Creek B tephra (639 ± 2 ka) provides a maximum age and the overlying Rockland tephra (610-570 ka) provides a minimum age.

The age of the Dibekulewe ash bed was previously estimated to be ~610 ka based on sedimentation rates and its position relative to the Lava Creek B tephra within the Tulelake core (Rieck et al., 1992). However, those sedimentation rates were calculated using a previous age estimate of the Rockland tephra (400 ka), and should be revised. In the Owens Lake core, the age of the Dibekulewe ash bed was estimated to be ~510 ka based on sedimentation rates, dry bulk density, and magnetostratigraphy (Bischoff, 1993; 1997; Glen et al., 1993; Sarna-Wojcicki et al., 1997), which is too young based on the stratigraphic relation to the overlying Rockland tephra (610-570 ka).

Thermoluminescence Dating of Volcanic Ashes

Although thermoluminescence dating of tephra beds was carried out by G. Berger in the 1980s and 1990s, this technique has not been employed since. When thermoluminescence results were initially published there was an apparent discrepancy between the analytical results for, and accepted ages of, the Rockland, Thompkins Hill, and Dibekulewe ashes (Berger, 1991). A recent revised age of the Rockland tephra (Lanphere et al., 2004) has, by association, also revised the age estimate of the Thompkins Hill tephra bed. These new comparisons confirm the results of Berger (1991), with the exception of those for the Dibekulewe ash bed, which he estimated to be 210 ± 30 ka. However, Berger (1991) wrote that J. O. Davis "admitted the possibility of doubt" with the correlation of the analyzed tephra bed to the Dibekulewe ash bed (J.O. Davis, personal communication, 1990 in Berger, 1991), therefore that discrepancy may or may not reflect the credibility of the dating technique. Additionally, recent dates on the Summer Lake tephra beds KK and LL (Donnely-Nolan, 2010; Kuehn and Negrini, 2010) are within the margin of error of the ages provided by thermoluminescence analyses (Berger, 1991), which also suggests the luminescence ages are credible.

Observations of the Rockland tephra in Mohawk Valley

The Rockland tephra erupted an estimated volume of ~50 km^3 of material (Sarna-Wojcicki et al., 1985) from the Brokeoff Volcano near Lassen Peak, about 100 km to the northwest of Mohawk Valley (Lanphere et al., 2004; Clynne and Muffler, 2010) (Figure 4). Among all four Mohawk Valley tephrostratigraphic studies, the Rockland tephra was found in at least sixteen different locations. Its thickness varies dependent on the depositional setting from 90 to 250 cm-thick. The most common total thickness of the Rockland tephra is approximately 100 cm, which is about the predicted thickness for the distance from the Brokeoff Volcano (Sarna-Wojcicki et al., 1985). In Mohawk Valley, the Rockland tephra is commonly underlain by soft sediment deformation due to loading on saturated sediments. In many locations layers of charred organic material several cms-thick underlie ash deposits. Similar observations were made in the Great Basin by Bell and House (2007) who proposed that large fires due to intense thunderstorm activity associated with volcanic eruptions may be the cause of common charred layers that underlie tephra deposits. In this setting, the charred vegetation may have washed into the basin and settled below the ash layers.

In most locations in Mohawk Valley the Rockland tephra deposit is composed of three major beds. The basal bed ranges in thickness from 30 to 175 cm and is composed of relatively pure silt and sand-sized tephra. The overlying beds range in thickness from 30 to 150 cm and are composed of a fine pebble and sand sized bed of mixed pumice and ash that is often overlain by a finer-grained silt and sand-sized ash. There are no indications of a hiatus during deposition of the Rockland tephra deposits in Mohawk Valley as might be evident from erosion, intervening deposits, or weathering within these packages. The multiple beds are likely from an initial airfall overlain by tephra washed off the surrounding landscape into the lacustrine-deltaic setting. In the Tulelake core #2, taken 160 km north of Brokeoff Volcano, the Rockland tephra was described as a 47 cm-thick deposit with four discrete beds that were also interpreted as one airfall deposit overlain by tephra re-worked in the basin (Rieck et al., 1992).

CONCLUSIONS

The twenty-six tephra beds found in Mohawk Valley consist of fifteen known tephras identified in prior studies and eleven tephras only recognized in Mohawk Valley. Tephrostratigraphic relations in Mohawk Valley provide age estimates for the eleven newly identified tephra beds (Table 5). The ages of three Clear Lake Ash beds were re-evaluated based on the revised age of the Rockland tephra (Table 6). The correlation of the tuffaceous interval of the Tulelake core to tephra beds in Mohawk Valley suggests these are not reworked or mixed tephra layers as initially interpreted, but instead may record volcanic eruptions, possibly from Medicine Lake Volcano as suggested by Rieck et al. (1992). The age estimate for the tuffaceous interval (~600-155 ka; Rieck et al., 1992) is supported by tephra correlations in the Mohawk Cliff section (< 610-570 ka through about 180 ka and younger) (Tables 5 and 6). In addition, we provide modified age estimates for the East McKay Butte tephra to 610-480 ka (Table 6).

When results of thermoluminescence dating of tephras were initially published there was an apparent discrepancy between those ages and the accepted ages of the Rockland tephra, the Thompkins Hill tephra bed, and the Dibekulewe ash bed (Berger, 1991). Since that time new age estimates have been published (Negrini et al., 2000; Lanphere et al., 2004), which suggest the thermoluminescence age estimates are not inaccurate and the dating technique may be better than initially considered.

Sixteen deposits of the Rockland tephra from the nearby Brokeoff Volcano 100 km to the northwest (Lanphere et al., 2004; Clynne and Muffler, 2010) were identified in the Mohawk Valley. These deposits generally consist of a basal airfall deposit overlain by a reworked deposit, the relative thicknesses of which varies by depositional setting and ranges in thickness from 90 to 250 cm.

This long tephrochronologic record is one of the most complete Pleistocene sections in the Western U.S and will aid tephrochronologic correlations in the mid to late Pleistocene. It complements the robust record in Summer Lake of 88 tephra beds that are mostly younger than those found in the Mohawk Lake sediments (Kuehn and Negrini, 2010). Together, the two locations host 119 tephra beds deposited over the past 740 ka. This Mohawk Valley tephrochronologic record provides most of the numerical age control for Quaternary deposits in Mohawk Valley. The numerous tephra beds were instrumental in the interpretation that a long-lived lake existed in Mohawk Valley and helped to document a detailed lacustrine and glacial record (Redwine, 2013). Furthermore, interpretations of the depositional environments and age of the Quaternary deposits in Mohawk Valley are important to understanding the age and style of faulting along the MVFZ throughout the Pleistocene.

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Figure Captions

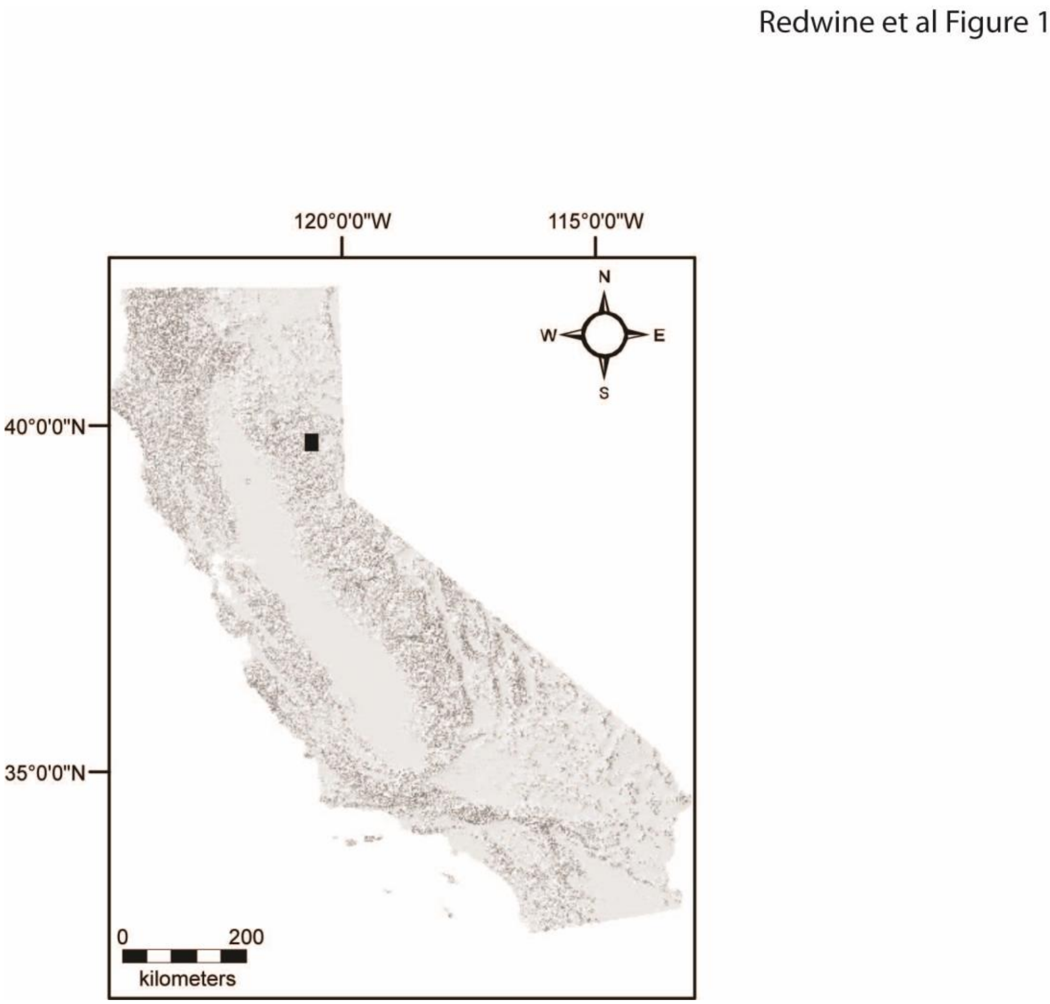

Figure 1. Location of study area in northeastern California. Small black box is area of Figure 2.

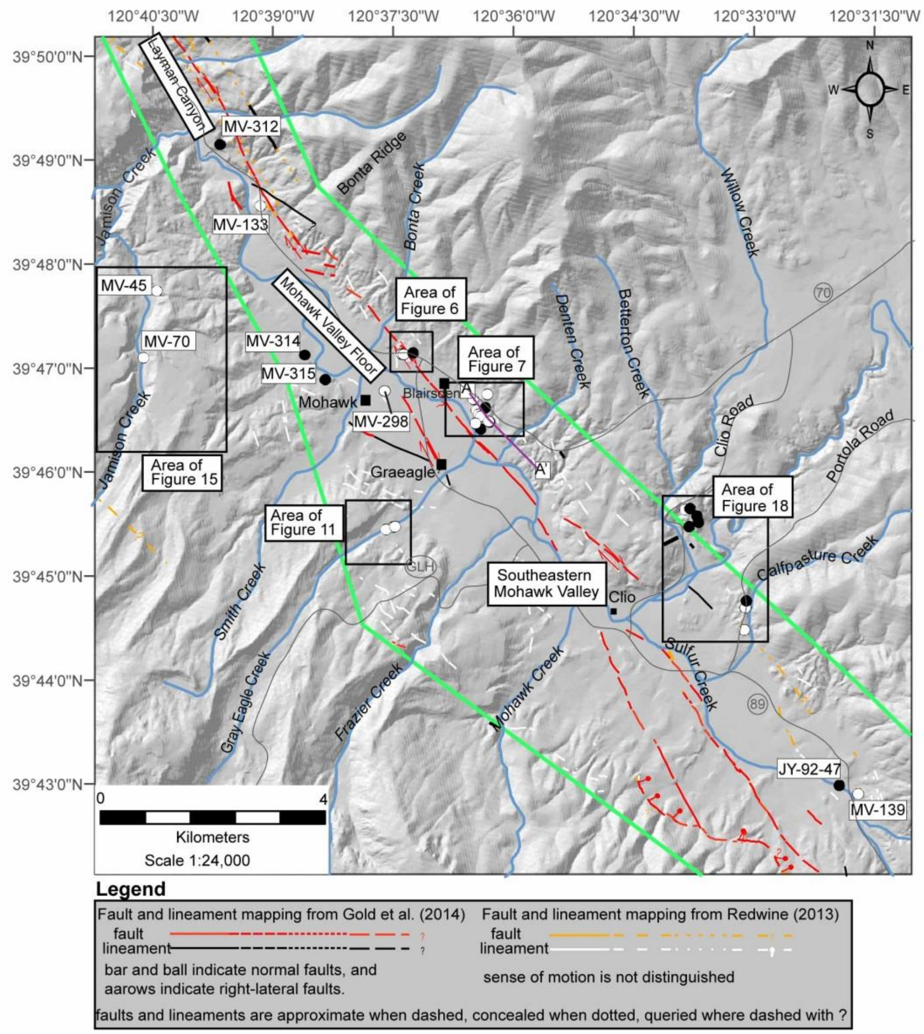

Figure 2. Location of sites where tephra beds have been found in Mohawk Valley, streams, faults and lineaments from mapping of Gold et al. (2014) and Redwine (2013), and limits of LiDAR imagery coverage (green lines). White circles designate sites in this current study only and black circles are sites from the prior and current studies. Purple line is location of cross section A-A’, also shown on Figures 7 and 9. Gray lines are major roads and highways, small black boxes designate nearby towns. GLH – Gold Lake Highway.

Redwine et al Figure 3

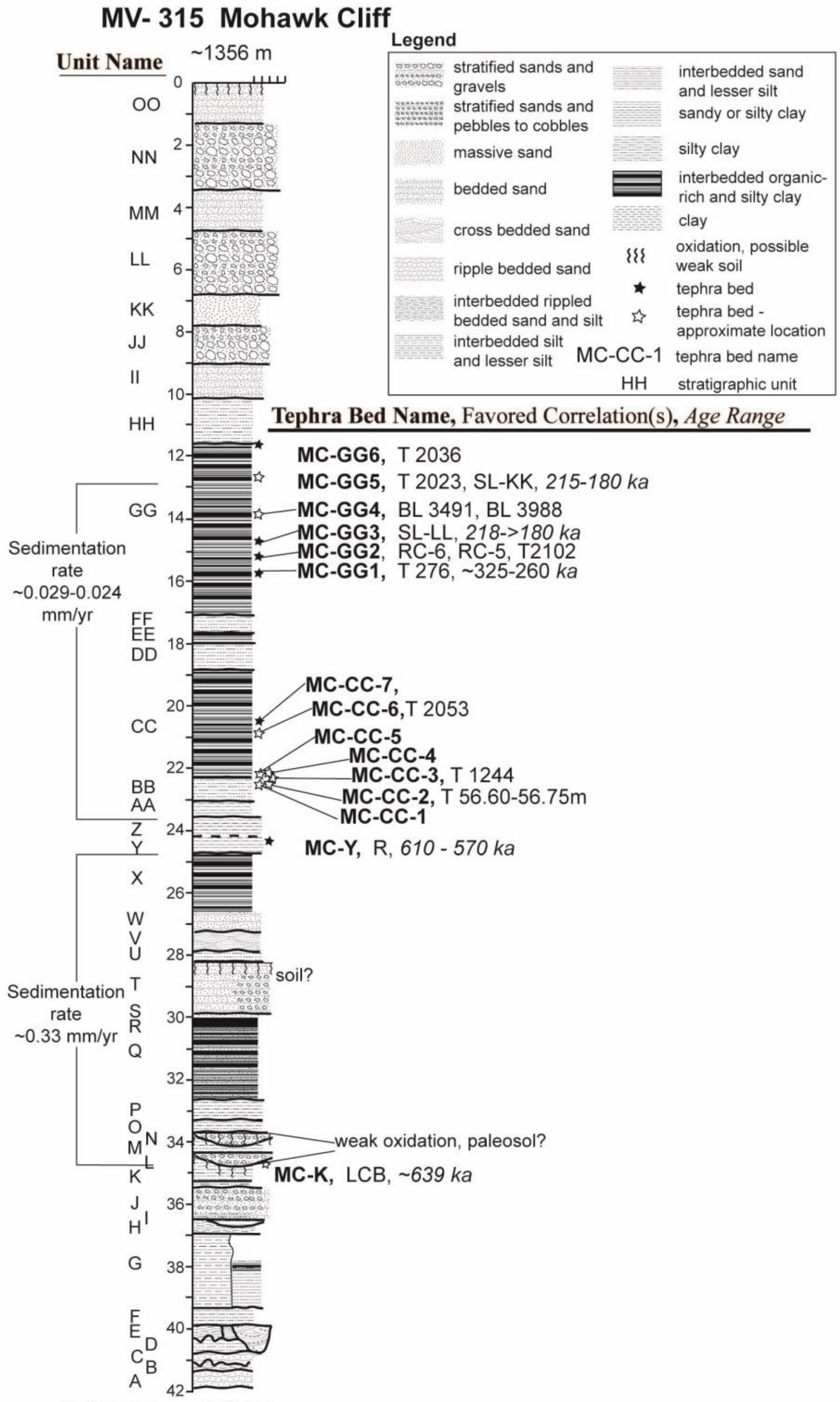

Figure 3. Stratigraphic column for site MV-315 (the Mohawk Cliff section) showing the location of 15 tephra beds and the stratigraphy of the sediments in which they were deposited. Favored tephra correlations and age estimates are also shown where they are available. This is a compilation of descriptions from the current study, a study by J. Davis in 1983, and by J. Yount, M. Reheis, S. Starratt, and M. McGuire in 1998. The stratigraphic positions of tephra beds are from measured sections and stratigraphic columns compiled by the prior studies. Letters on the left designate different stratigraphic units. Sedimentation rates are general estimates based on the age ranges and estimated elevations of the Summer Lake tephra bed KK tephra bed, the Rockland tephra, and the Lava Creek B ash.

Redwine et al Figure 4

Figure 4. Locations of other study areas mentioned in the text. M- Mohawk, BL- Buck Lake, CL- Clear Lake, NV- Newberry Volcano, TL- Tule Lake, MLV- Medicine Lake Volcano, SL- Summer Lake, CrL- Crater Lake (Mount Mazama), CaL- Carp Lake, PS- Puget Sound (Keton Island), PF- Palouse Formation, LP- Lassen Peak, MH- Mecca Hills (Thermal Canyon ash locality), OL- Owens Lake, Y- Yellowstone (Lava Creek B tephra locality), DV- Death Valley, P-Pyramid Lake, W-Wadsworth.

Redwine et al Figure 5.

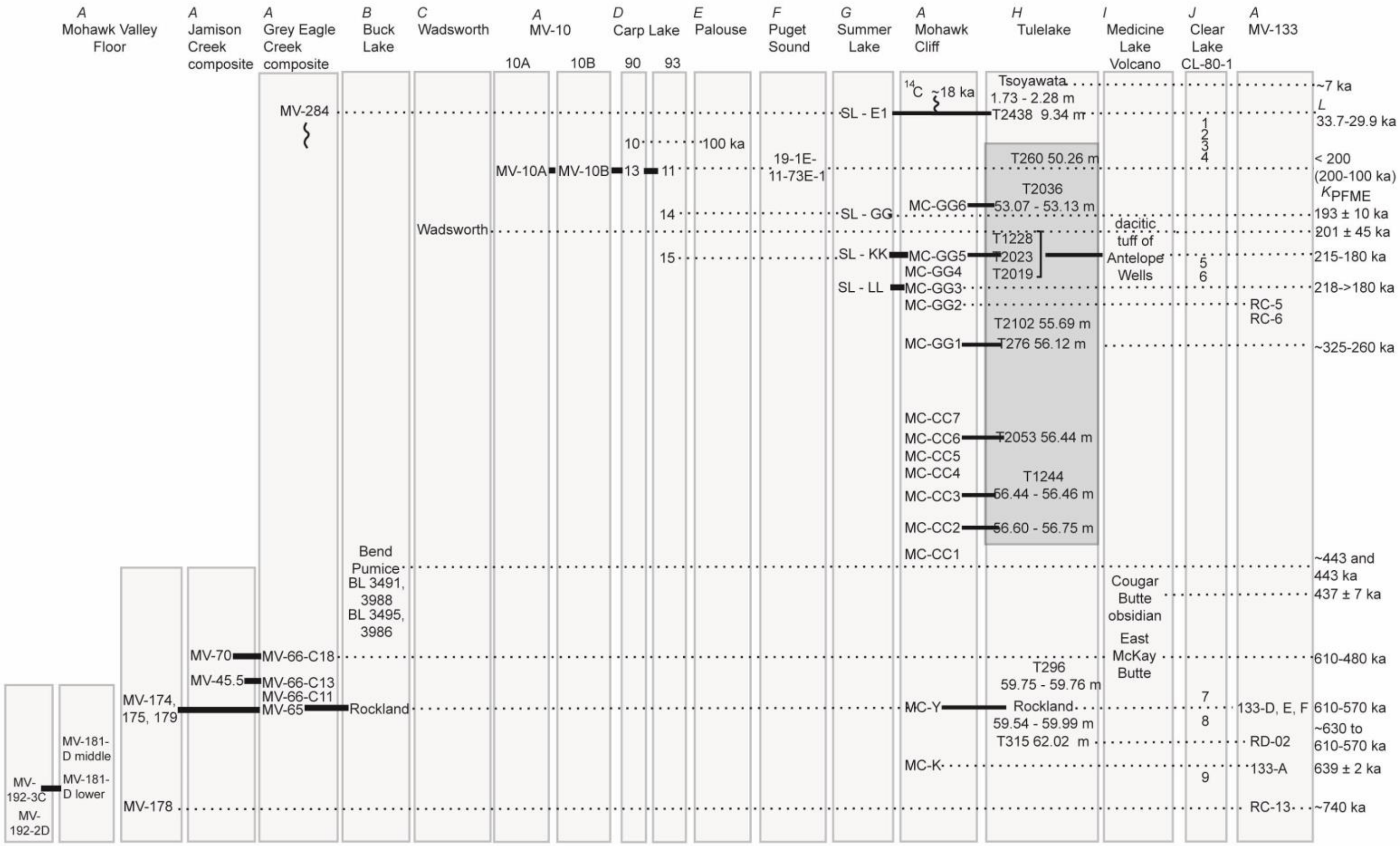

Figure 5. Correlation of tephra beds within and beyond Mohawk Valley. Only those sites in Mohawk Valley that help constrain ages of Mohawk Valley or elsewhere are included. Preferred age estimates are shown on the right. Solid lines show adjacent correlations, lines are dotted through areas without correlations. Darker gray box delineates the tuffaceous interval of the Tulelake core. Vertical wavy lines designate unconformities. Letters at top of columns correspond to these references. A-This study; B- Sarna-Wojcicki et al., 1991; Adam et al., 1994; C- Berger, 1991; D- Whitlock et al., 2000; E- Busacca et al., 1992; F- Walsh et al., 2003; G- Berger, 1991; Herrero-Bervera et al., 1994, Negrini, 1994; Negrini et al., 2000, 2002; Kuehn and Negrini, 2010; Donnelly-Nolan, 2010; H- Rieck et al., 1992; Sarna-Wojcicki et al., 1992; I- Herrero-Bervera et al., 1994; Donnelly Nolan and Lanphere, 2005; Donnelly-Nolan, 2010;

Redwine et al. Figure 6

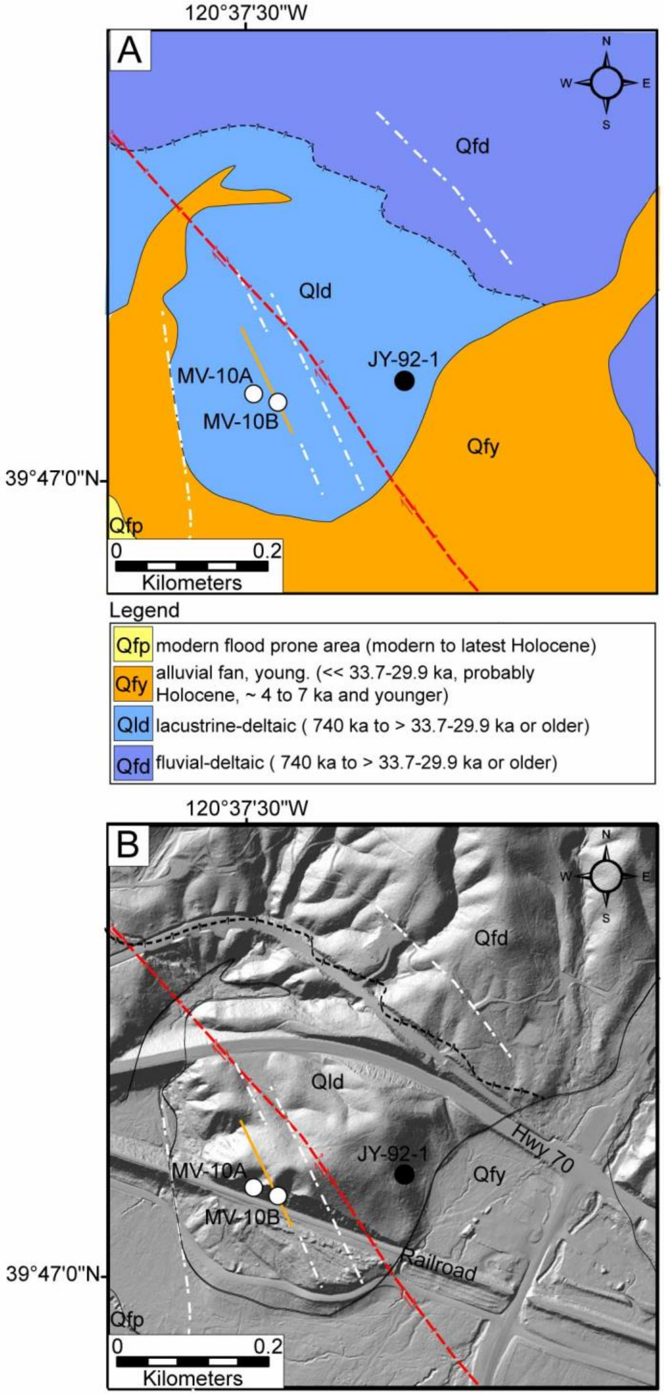

Figure 6. A) Geologic map of area just northwest of Blairsden (Figure 2) showing location of tephra beds MV-10-A, MV-10-B, and JY-92-1. Active faults cut through the lacustrine deltaic section (Qld) where the tephra beds lie. Red faults from Gold et al (2014) and orange faults and white lineaments from Redwine (2013) correlate to legend on Figure 2. Detailed unit descriptions are in Redwine (2013). B) LiDAR hillshade of the same area as above also showing location of tephra beds MV-10-A, MV-10-B, and JY-92-1 and mapped faults and lineaments.

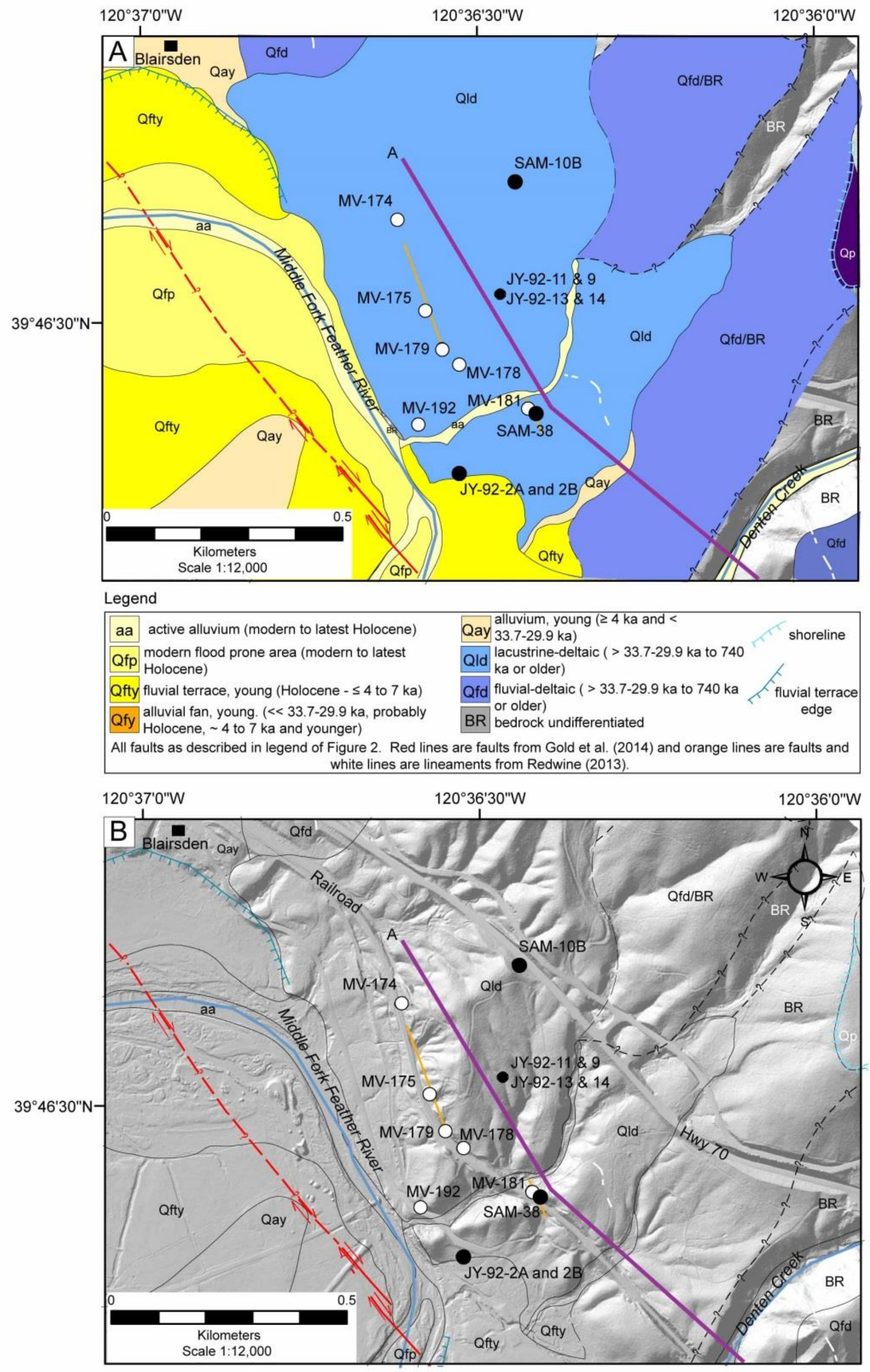

Figure 7. A) Geologic map of area just southeast of Blairsden showing location of tephra beds MV-174, MV-175, MV-178, MV-179, MV-181, MV-192, SAM-10B, SAM-38, and JY-92-2A, 2B, 9, 11, 13, and 14, and the location cross section A-A' (purple line) (Figure 9). The primary fault of the MVFZ has been mapped to the southwest of these sites, but additional faults are present and offset many of these tephra beds by small amounts. All of these tephra beds were deposited within lacustrine deltaic sediments of Mohawk Lake. White circles are tephra sites from this study, black circles are sites from previous studies. Detailed unit descriptions are in Redwine (2013). B) LiDAR hillshade of the same area as above also showing location of tephra beds and mapped faults and lineaments, and the location of cross section A-A'.

Redwine et al Figure 8

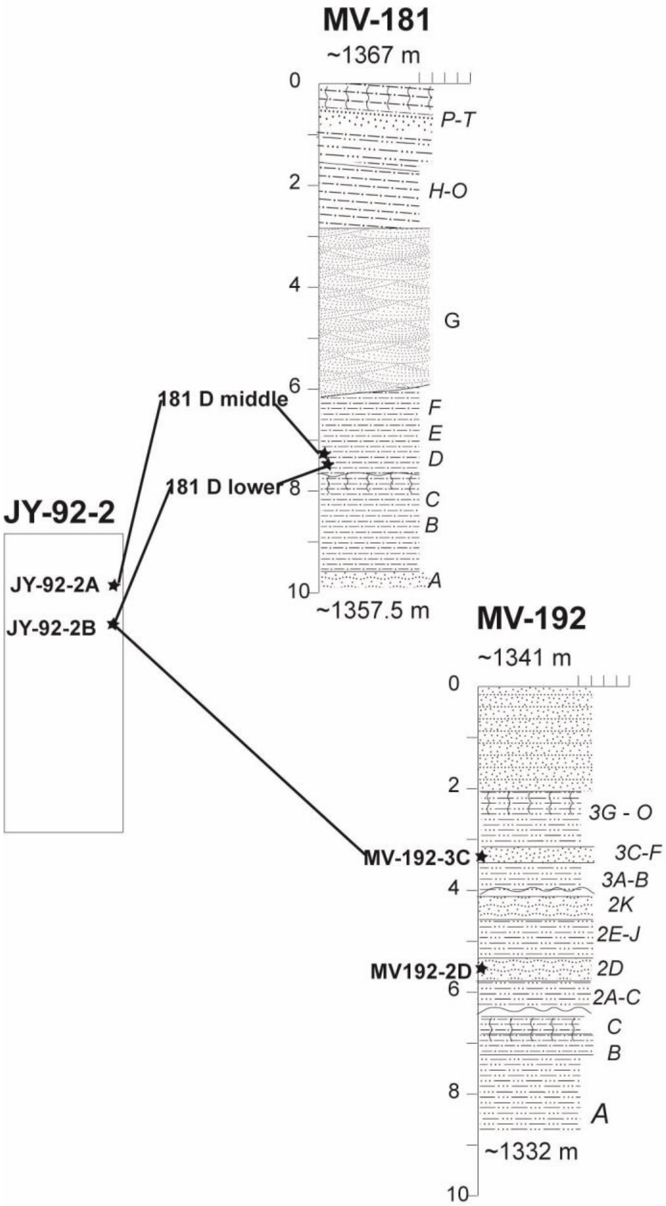

Figure 8. Correlation of tephra beds among three sites, MV-181, MV-192, and JY-92-2 (Figure 7). The exact location of JY-92-2 is uncertain, so elevation is not included and no stratigraphic descriptions are available. Site MV-181 lies more than 20 meters higher than site MV-191 and may be separated by a fault. Letters on the right of stratigraphic columns designate different stratigraphic units.

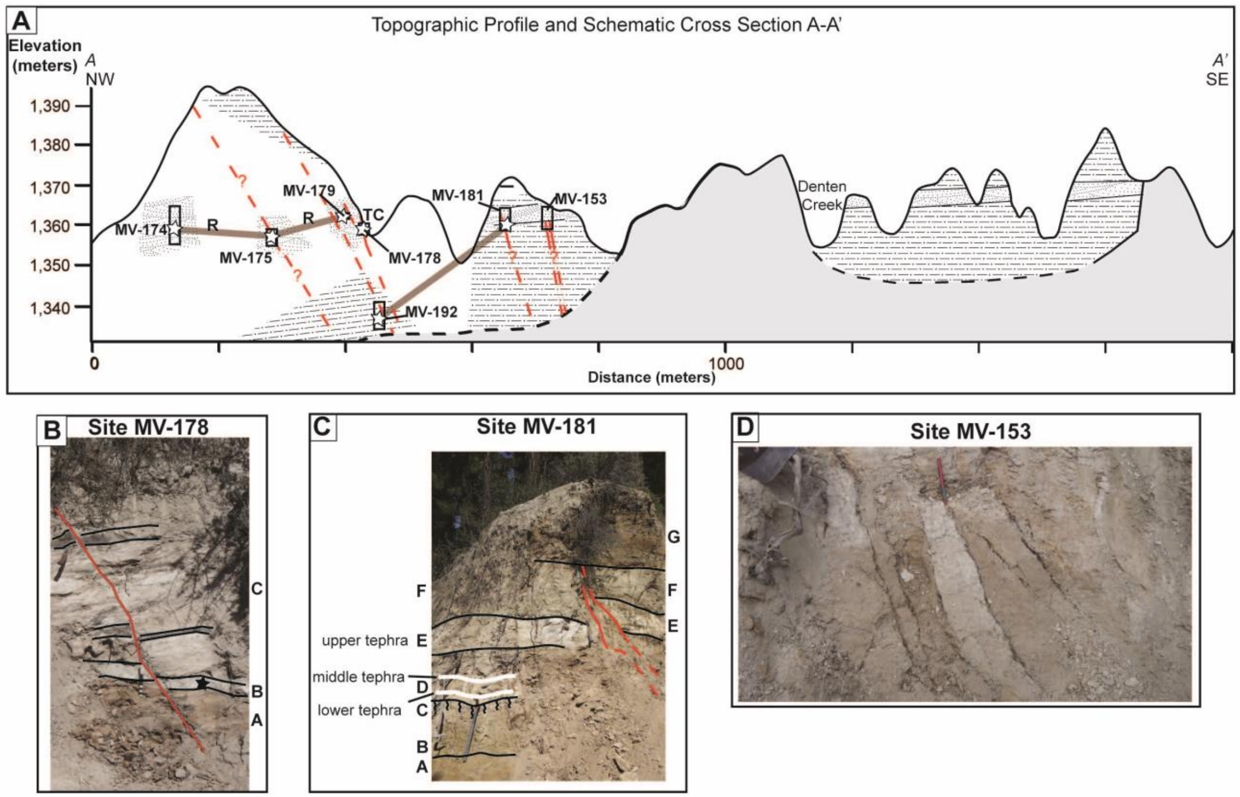

Figure 9. A). Schematic cross-section A-A' exposed along railroad and roads southeast of Blairsden (Figure 7). Topographic profile was extracted from LiDAR data. Patterns show silty clay (dash and dot) vs cross bedded sands (dots), gray is bedrock, and white represents areas not exposed. Gray tie lines connect correlated tephras. Three deposits of the Rockland tephra are at similar elevations exposed along the railroad (sites MV-174, MV-175, and MV-179). Thermal Canyon ash is lower, older, and exposed at site MV-178. Sites 181 and 192 have correlative tephra beds (Figure 8). Many small faults exposed in this area may indicate another splay of the MVFZ cuts through this section and may offset sites MV-181 and MV-192. The primary splay of the MVFZ is mapped to the southwest (Figure 7) (Gold et a, 2014). B). Photograph of site MV-178 - Thermal Canyon Ash with small (~ 7 cms) offset along a minor fault. Black and white measuring staff is 15-cm-high. Letters refer to stratigraphic units. C) Photograph of site MV181 - Three un-identified tephra beds are offset by a minor fault (~ 30 cm). The lowest tephra bed correlates with tephra 3C at site MV-192 (Figure 8). Pick axe is 85-cm-high. Letters refer to stratigraphic units. D). Photograph of site MV153- a zone of steeply dipping faults have facies changes across them. Fault planes are lined with dark clay films. Pencil is ~10-cm-long.

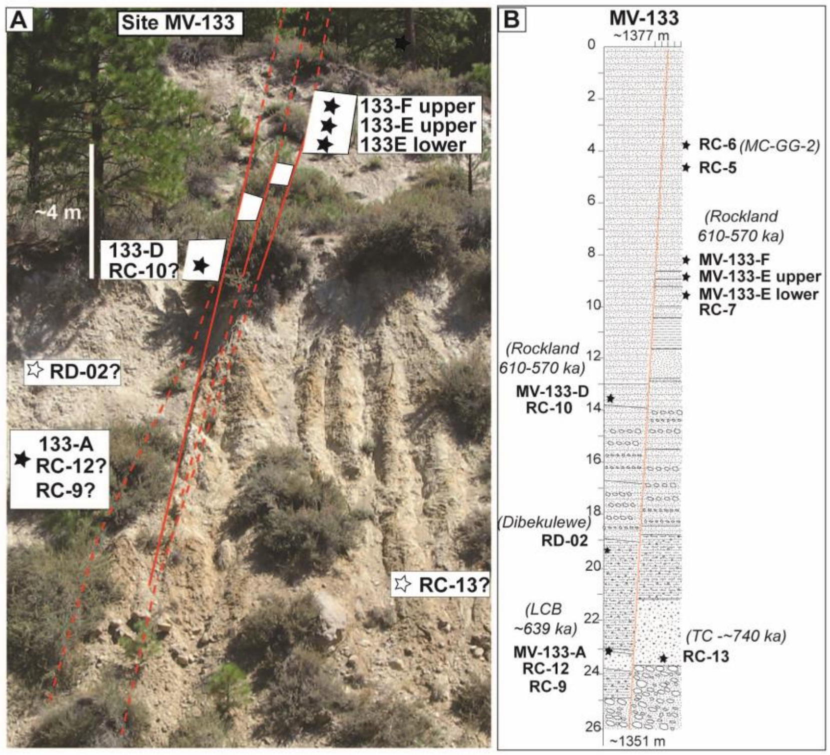

Figure 10. A). Photograph of Site MV-133, looking northeast. Tephra beds within this ~21 m-high exposure along Highway 70 were sampled and analyzed in all three studies. Locations of tephra beds sampled and analyzed in the present study are shown and those analyzed by prior studies are estimated. The Rockland tephra (MV-133-D, E, and F), sketched approximately as white boxes, is displaced north-side-down a total of about 4 m across several faults. B). Stratigraphic column of the same section with all tephra beds analyzed shown. Locations of tephra beds from prior studies within this section are only estimated, but the relative position of those tephra beds to one another is documented.

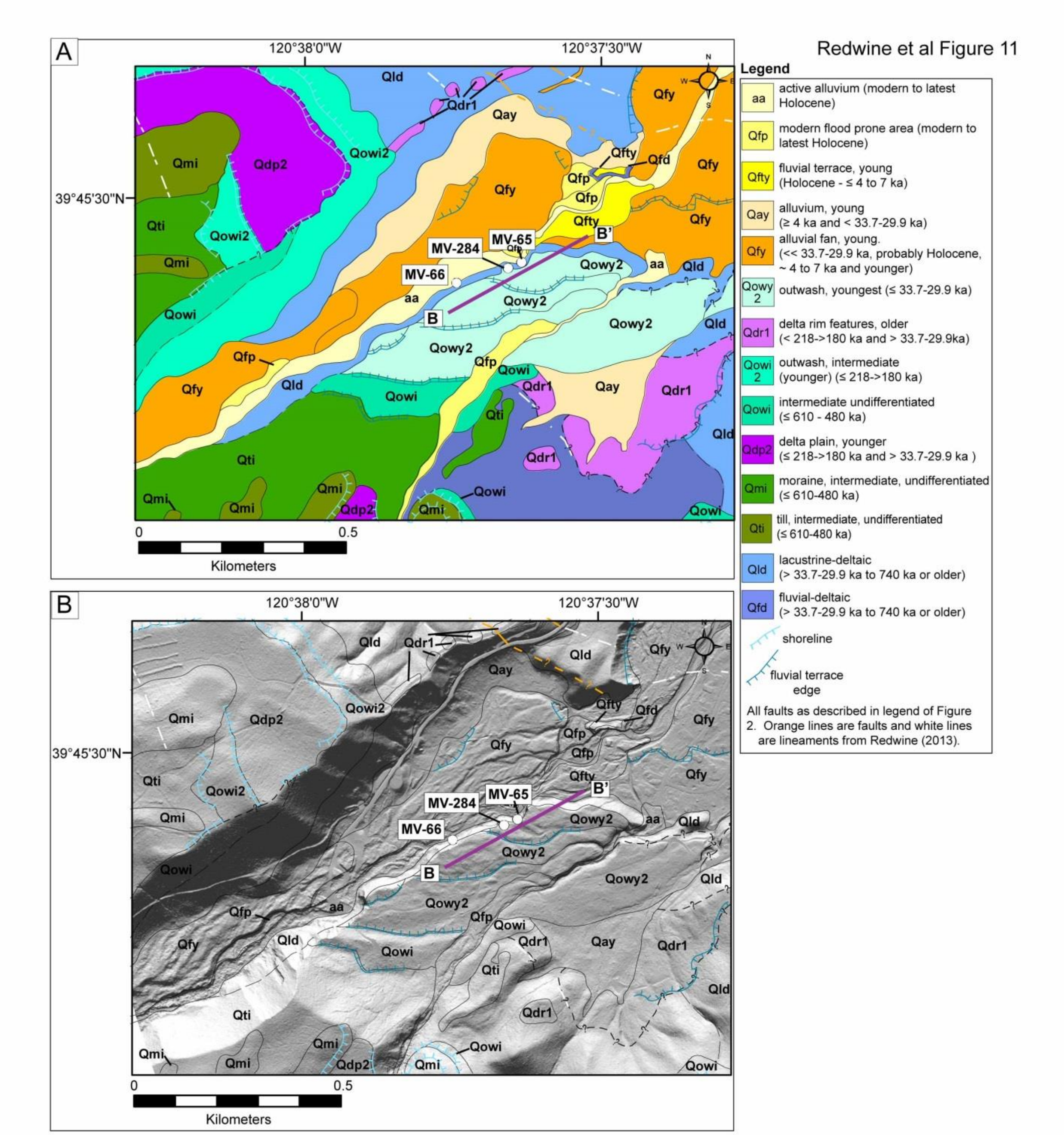

Figure 11. A). Geologic map of the Gray Eagle Creek area showing location of sites MV-66, MV-65, and MV-284 where tephra beds were found and the location of cross section B-B' (purple line) (Figure 12). Tephra beds were deposited within unit Qld, lacustrine deltaic sediments, in a complex depositional environment where ice from glacial streams repeatedly entered Mohawk Lake. Inset outwash and delta deposits eroded into, and were deposited onto Qld, as the lake level lowered. Detailed unit descriptions are in Redwine (2013). B) LiDAR hillshade of the same area as above also showing location of tephra beds, mapped faults and lineaments, and the location of cross section B-B' (purple line).

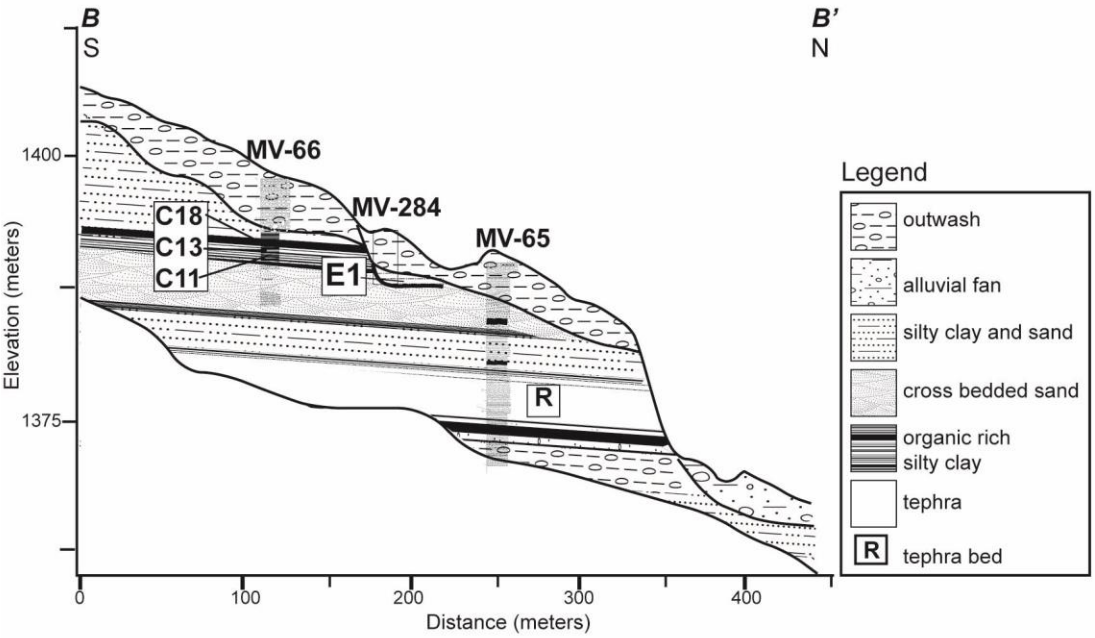

Figure 12. Schematic cross section B-B' (Figure 11) showing stratigraphic and topographic relations between the three sites where tephra beds were sampled. Compiled from intermittent exposures along Gray Eagle Creek. Stream and topographic profiles were extracted from LiDAR data.

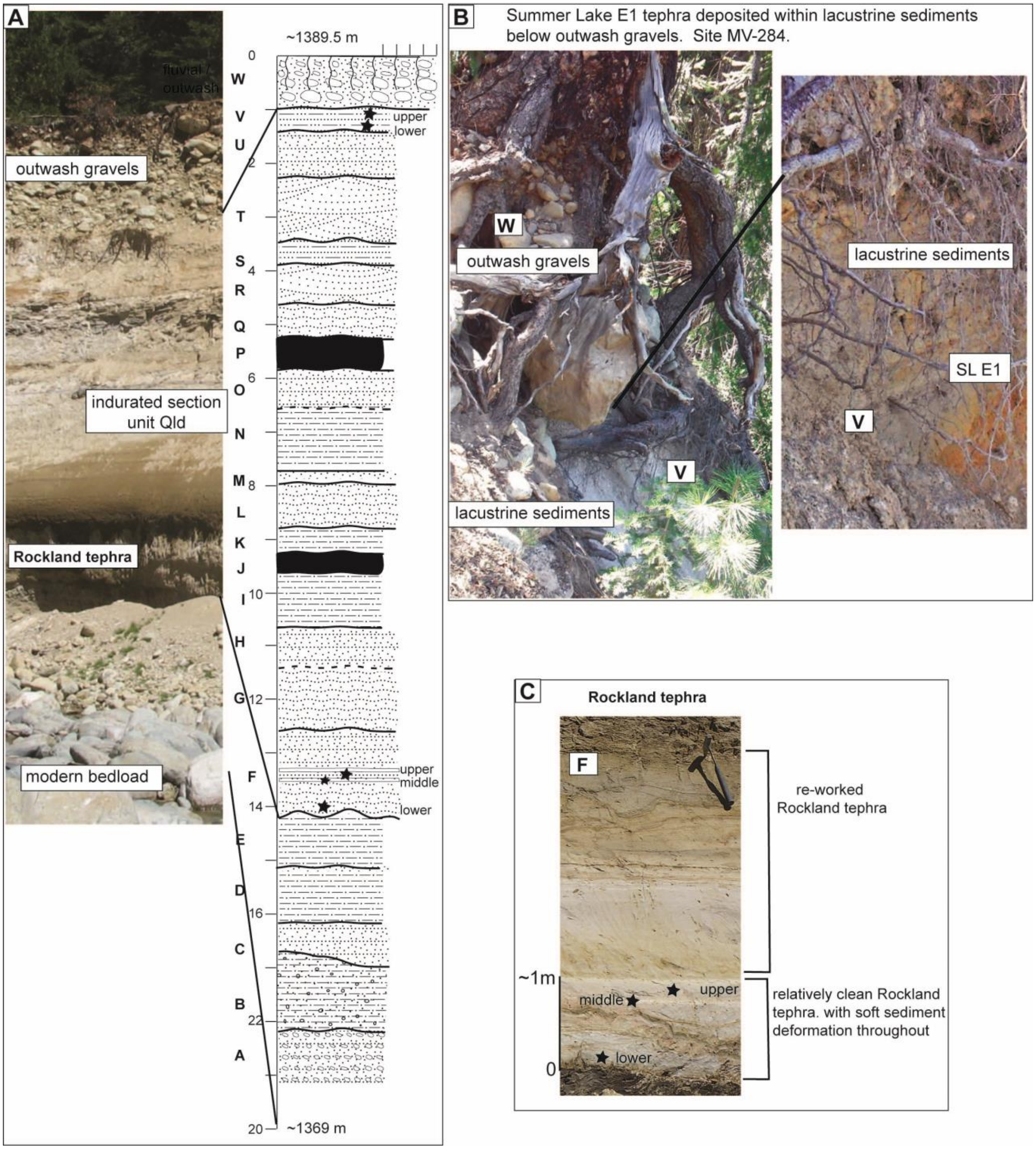

Figure 13. A) Photograph of site MV-65 and stratigraphic column compiled from sites MV-65 and MV-284 showing outwash gravels overlying the thick, indurated Mohawk Lake lacustrine deltaic section exposed at this location and location of tephra beds MV-284-V upper and MV-65-F lower. Tephra beds are indicated by stars. Patterns relate to the legend on Figure 12. B) Photographs of the upper part of this section, best exposed upstream at site MV-284 (Figures 11 and 12). The outwash gravels (unit W) overlie an approximately 50 cm-thick section of loose, lacustrine silt and sand that contain several diatom beds (Unit V). Tephra bed MV-284-V upper was sampled from within this section and the glass correlates with that from Summer Lake tephra bed E1 and Tulelake 2438. C) Photograph of tephra bed MV-65-F, correlative to the Rockland tephra. The bottom ~2 m is water-lain ash overlain by >1 m of cross bedded sand and re-worked ash. Site MV-65 is located downstream and stratigraphically below site MV-66.

Redwine et al Figure 15

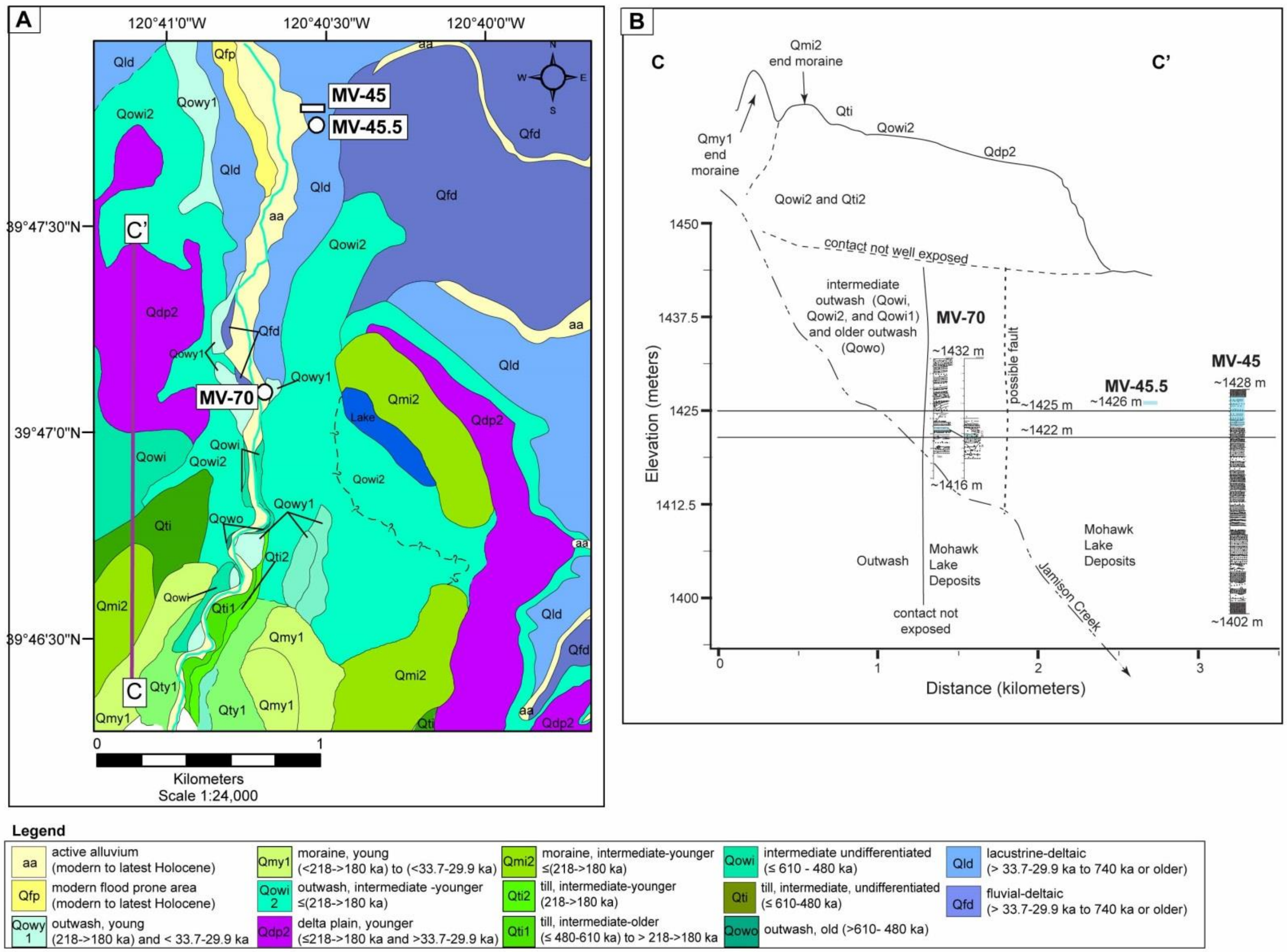

Figure 14. A) Photograph of site MV-66 and stratigraphic column showing outwash gravels overlying the thick, indurated Mohawk Lake lacustrine deltaic section exposed at this location and location of tephra beds MV-66-C18, C13, and C11. Tephra beds are indicated by stars. Patterns relate to the legend on Figure 12. Stratigraphic Unit C is shown at a larger scale in order to show the stratigraphic context of those three tephra beds. An unconformity is indicated between the upper and lower parts of Unit C because the two sections were describe about 1 meter apart.. No stratigraphic unconformities were observed. B) Photograph of the upper part of Unit C showing tephra bed MV-66-C18. C) Photograph of the lower part of Unit C showing tephra beds MV-66-C13 and MV-66-C11, stratigraphically below tephra bed C18.

Redwine et al Figure 17

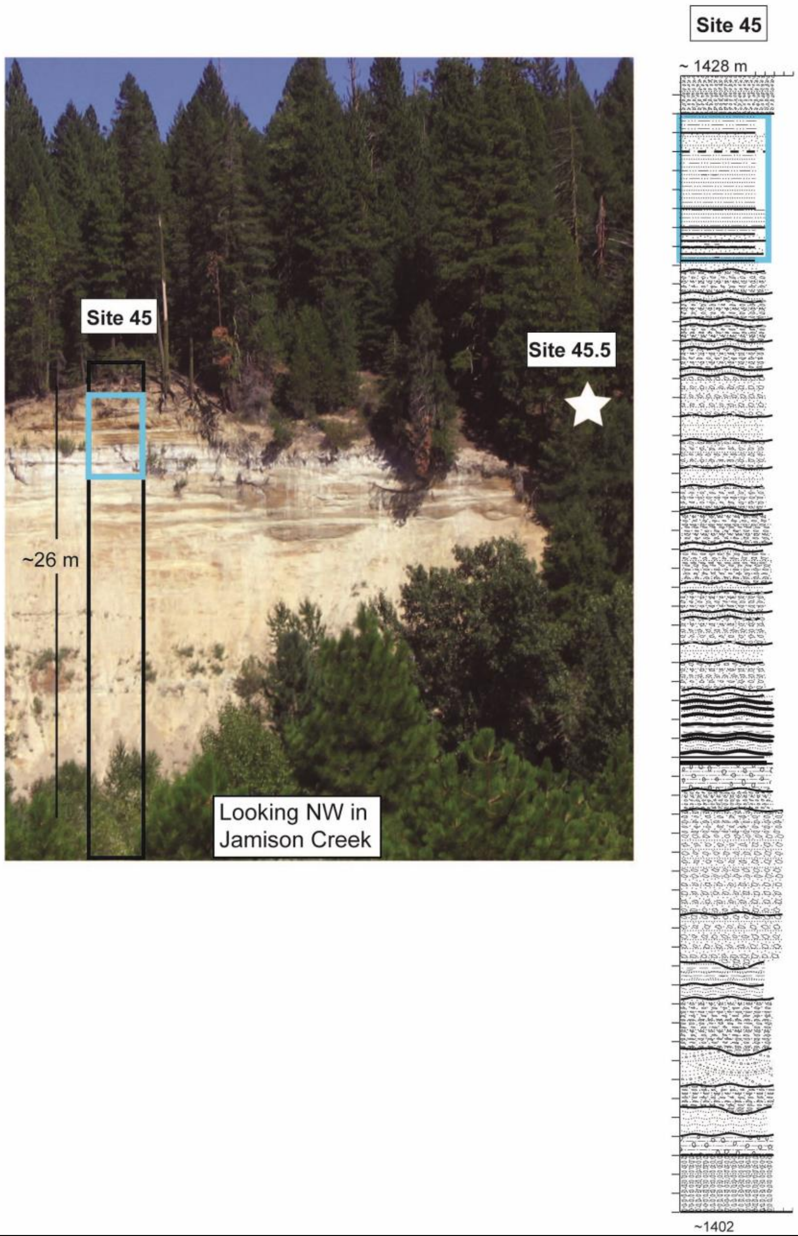

Figure 15. A) Geologic map along Jamison Creek showing locations of sites MV-70, MV-45.5, and MV-45 and schematic cross section C-C' (purple line). All three sites are sections of lacustrine deltaic sediments deposited within the Mohawk Lake delta. The tephra beds provide much of the age control for the overlying glacial deposits. Full unit descriptions are in (Redwine, 2013). B) Schematic cross section C-C' shows the complex geologic setting at sites MV-70, MV-45.5, and MV-45. Along Jamison Creek glaciers repeatedly flowed downstream depositing several generations of till and related outwash deposits that graded to the Mohawk Lake fluvial-deltaic section exposed from sites MV-70 through MV-45. Elevation control in this area is poor. Locations of the stratigraphic columns from sites MV-70 and MV-45 are shown as well as the sample location from site MV-45.5. Elevations of 1425 and 1422 m are shown to help compare the stratigraphic sections and elevations of tephra beds within them, highlighted in blue. Poorly exposed fractured lake sediments suggest a fault may be present between sites MV-70 and Mv-45.5 (Redwine, 2013). This further complicates the topographic relation among sites. The stream profile and topographic profile were extracted from 10 m DEM data.

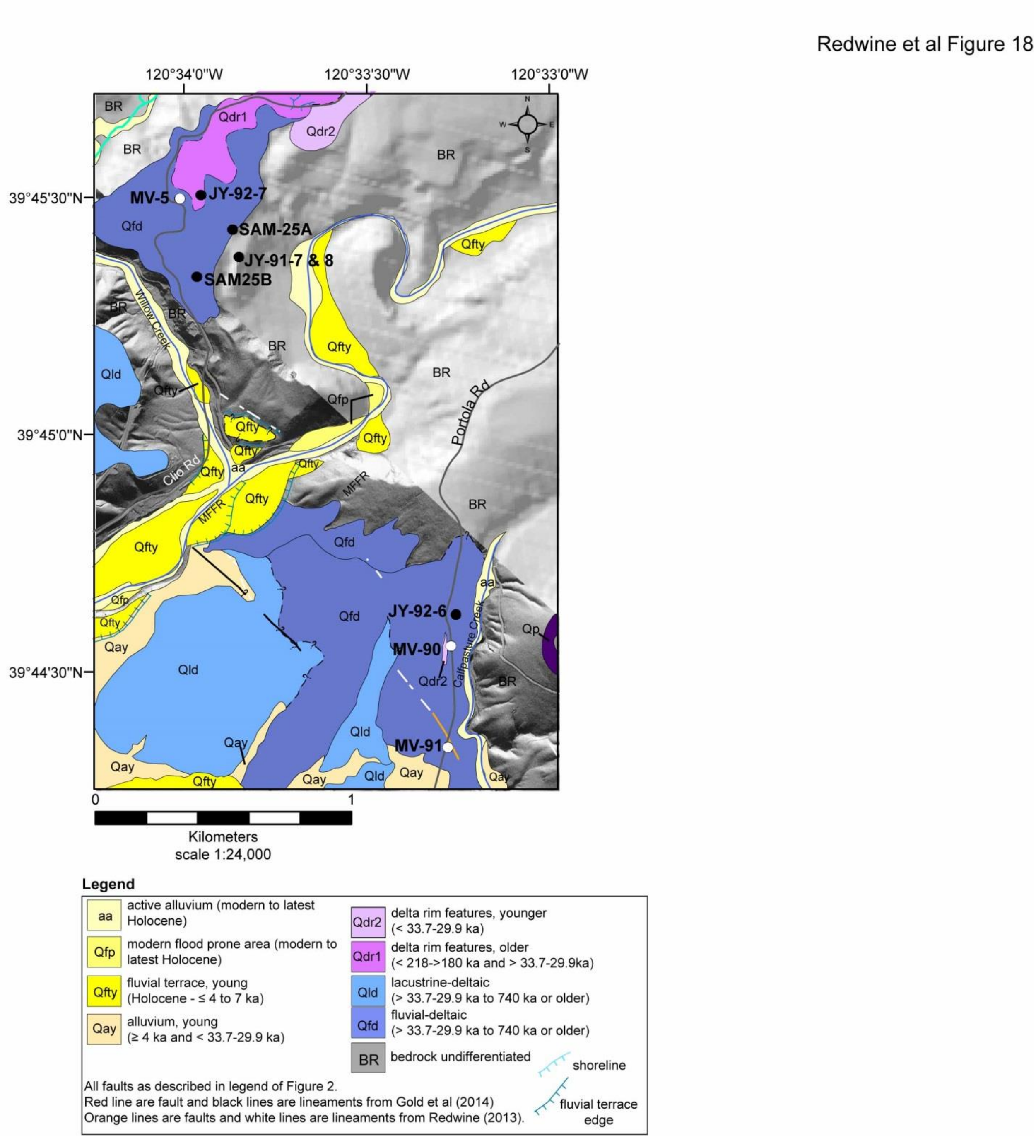

Figure 16. Photograph and stratigraphic columns from site MV-70. Two stratigraphic sections were described, labeled upstream and downstream. A tephra bed found within the downstream section, MV-70-downstream B, at between 1423-1422 m has been correlated to the East McKay Butte tephra (610-480 ka).

Redwine et al Figure 17

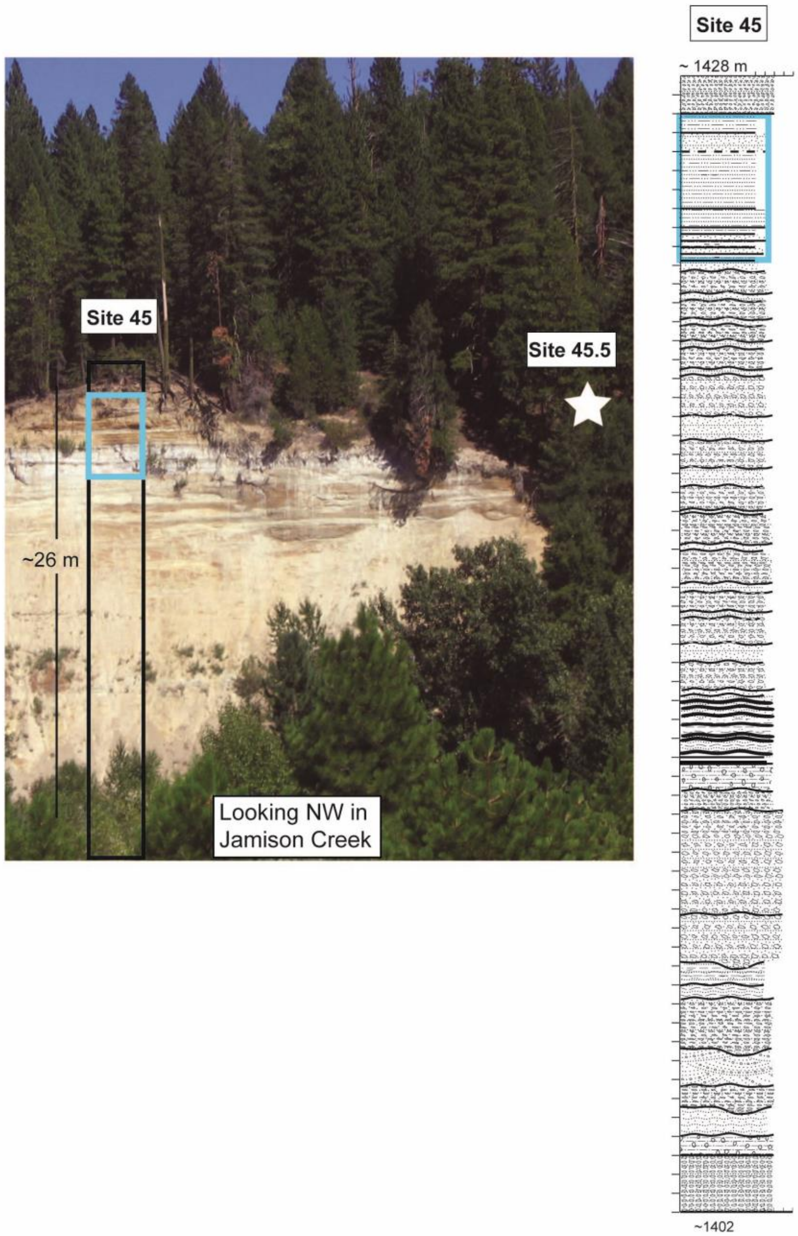

Figure 17. Photograph of sites MV-45 and MV45.5. Black box is the location of the stratigraphic column and is ~26 meters-high. White star is approximate location of tephra bed MV-45.5D. Elevation and stratigraphic location and context from tephra bed MV-45.5D, found on the forested hillslope at site MV-45.5, is approximate and might correlate to where other tephra beds were found within the adjacent stratigraphic section at site MV-45, highlighted in blue on the photograph and the stratigraphic column.

Redwine et al Figure 18

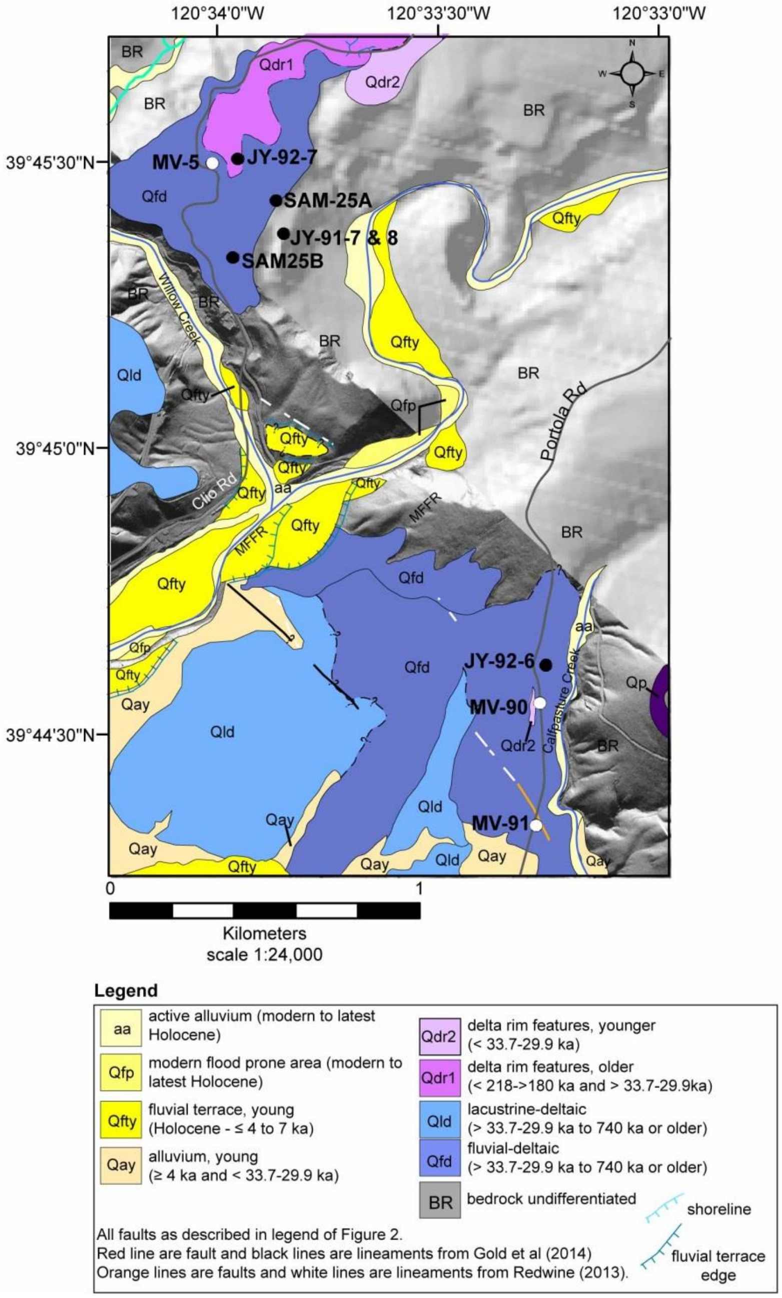

Figure 18. Geologic map of part of eastern Mohawk Valley showing locations of sites MV-5, JY-92-7, JY-91-7, JY-91-8, SAM25A, and SAM25B along Clio Road and MV-90, MV-91, and JY-2-6 along Portola Road. All sites are locations where tephra beds were located deposited within fluvial deltaic deposits. Detailed unit descriptions are in Redwine (2013). Darker gray hillshade is from LiDAR data. Lighter gray hillshade is from a 10-m-DEM.

Redwine et al Figure 19

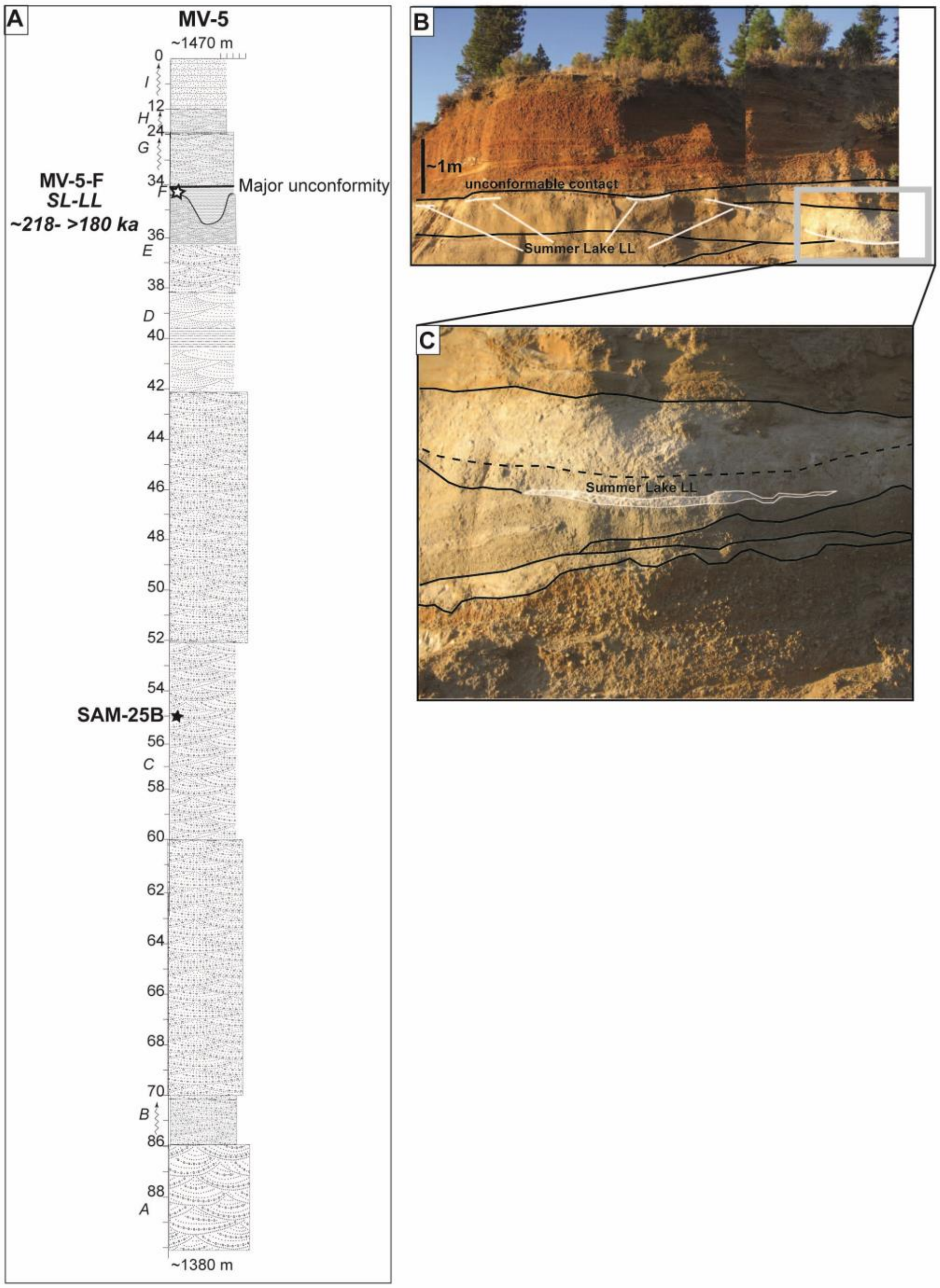

Figure 19. A) Stratigraphic column of about 90 meters of fluvial deltaic sediments exposed along Clio Road showing location of tephra bed MV-5-F. The location of tephra bed SAM25B is estimated from the mapped location on a topographic map in Mathieson (1981) compared with elevation extracted from LiDAR data. Tephra bed MV-5-F was deposited below a major unconformity within the section. B) Photograph of tephra bed MV-5-F and the sediments it was deposited within. Black lines show stratigraphic contacts. White line shows the laterally continuous tephra bed. Orange-stained gravels are above a major unconformity. Tephra bed MV-5-F was deposited within finer grained sediments below. C) Photograph of tephra bed MV-5-F deposited within indurated silts interbedded with sand and pebbles.

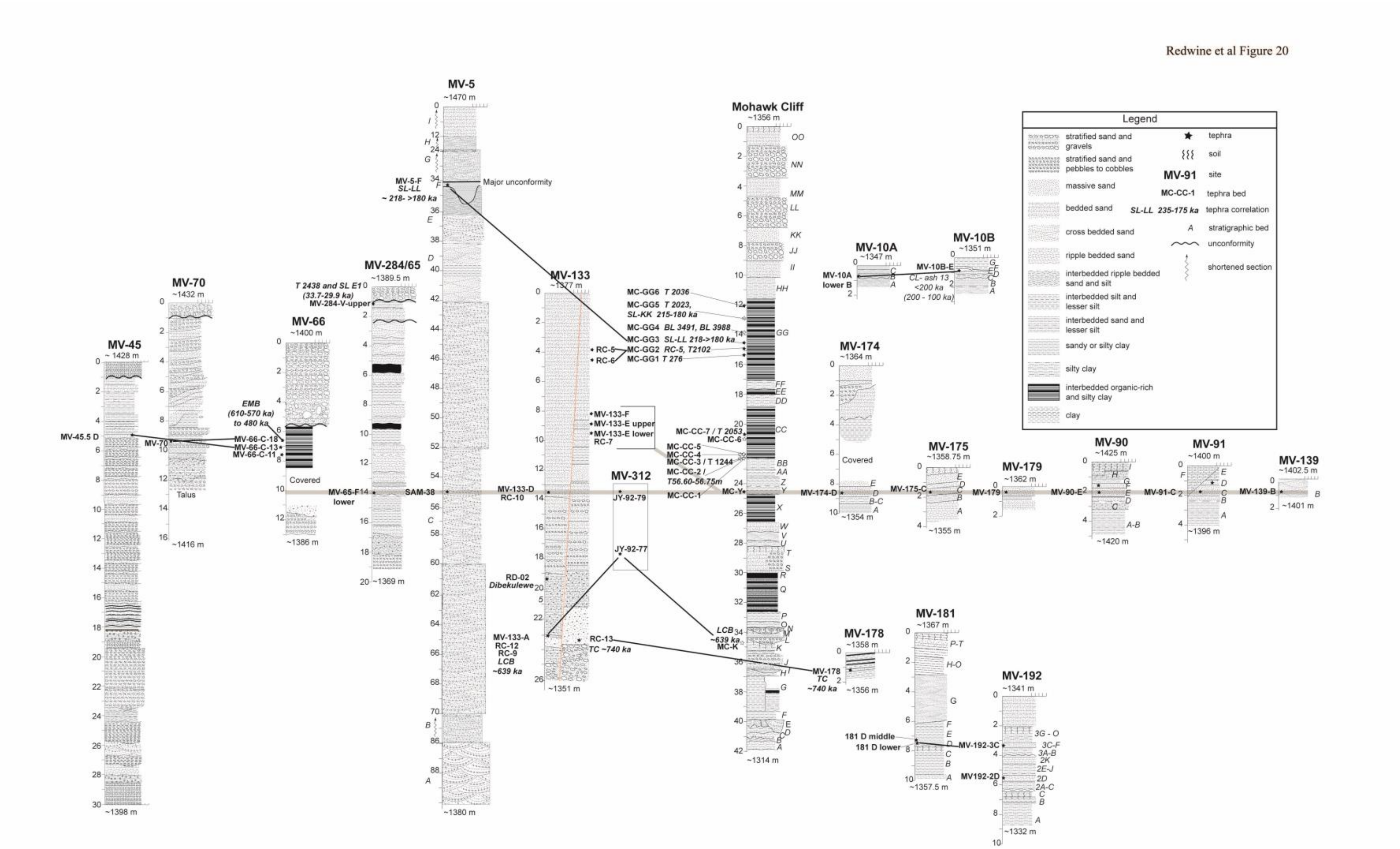

Figure 20. Correlation of nineteen stratigraphic columns within Mohawk Valley that have tephra beds deposited within the sediments. Site numbers/names are at the top of each stratigraphic column. Locations are shown in Figures 2. 6, 7, 11, 15, and 18. Letters along the stratigraphic columns denote different stratigraphic units. Gray tie lines connect the Rockland tephra. Thinner black lines show the correlations of other tephra beds. Red, diagonal line in section MV-133 represents a fault that cuts the tephra beds.

TABLE 1. GEOCHEMICAL ANALYSES OF MOHAWK VALLEY TEPHRA BEDS NORMALIZED TO 100 WEIGHT PERCENT.

Tephra bed	Sample No.(s)	Lab	USGS Lab correlation No.	Lab No.	Date Run	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Cl	Total	No. of shards analyzed
Site MV-315 (Mohawk Cliff)																	
MC-GG-6	JY-92-73	†USGS	3009	2964	5/7/93	75.18	13.86	1.24	0.09	0.04	0.61	0.13	4.33	4.52	§ND	100.0	ND
	RC-81		3342	4341	1983	75.55	13.54	1.20	0.09	0.05	0.59	0.14	4.21	4.62	ND	100.0	ND
	RC-82		3341	4342	1983	75.48	13.51	1.20	0.10	0.04	0.61	0.14	4.30	4.61	ND	100.0	ND
MC-GG-5	RC-80	USGS	3333	4340	1983	63.50	16.18	5.63	1.89	0.11	4.50	1.06	4.32	2.81	ND	100.0	ND
MC-GG-4	RC-83	USGS	3343	4343	1983	76.32	13.04	1.38	0.19	0.04	0.83	0.28	4.51	3.41	ND	100.0	ND
MC-GG-3	JY-92-72	USGS	3008	2963	5/7/93	66.78	16.57	3.94	1.20	0.06	3.67	0.67	4.55	2.58	ND	100.0	ND
	RC-84		3335	4344	1983	66.89	16.37	3.89	1.17	0.07	3.56	0.72	4.62	2.71	ND	100.0	ND
	RC-85		3337	4345	1983	66.89	16.37	3.89	1.17	0.07	3.56	0.72	4.62	2.71	ND	100.0	ND
MC-GG-2	JY-92-71	USGS	3010	2962	5/7/93	73.71	14.59	1.73	0.07	0.07	0.72	0.11	4.67	4.33	ND	100.0	ND
	RC-86		3344	4346	1983	73.88	14.35	1.76	0.07	0.06	0.71	0.13	4.62	4.42	ND	100.0	ND
MC-GG-1	JY-92-70	USGS	3007	2961	5/7/93	76.72	13.02	1.11	0.02	0.05	0.40	0.06	4.16	4.46	ND	100.0	ND
	RC-79		3345	4339	1983	76.37	12.93	1.14	0.03	0.06	0.40	0.05	4.41	4.61	ND	100.0	ND
MC-CC-7	JY-92-66 (major mode)	USGS	3043	ND	7/7/93	73.43	13.98	2.34	0.12	0.08	0.75	0.21	5.50	3.61	ND	100.0	ND
	JY-92-66 (mode 2)		3044	ND	7/7/93	73.57	14.23	1.88	0.28	0.01	1.58	0.31	3.77	4.36	ND	100.0	ND
	JY-92-66 (mode 3)		3045	ND	7/7/93	71.77	14.64	2.91	0.21	0.08	1.13	0.29	5.73	3.24	ND	100.0	ND
	RC-78		3346	4338	1983	73.53	14.25	2.44	0.14	0.07	0.79	0.25	5.22	3.31	ND	100.0	ND
MC-CC-6	RC-77	USGS	3347	4337	1983	76.98	12.81	1.18	0.00	0.04	0.41	0.07	4.10	4.40	ND	100.0	ND
MC-CC-5	RC-76	USGS	3336	4336	1983	73.53	14.24	2.15	0.35	0.05	1.33	0.41	4.92	3.01	ND	100.0	ND
MC-CC-4	RC-75	USGS	3338	4335	1983	73.82	14.24	2.05	0.31	0.06	1.21	0.38	4.91	3.01	ND	100.0	ND
MC-CC-3	RC-74	USGS	3348	4334	1983	76.96	12.83	1.18	0.01	0.06	0.47	0.07	4.11	4.31	ND	100.0	ND
MC-CC-2	JY-92-64 (minor mode)	USGS	3048	2959	7/7/93	74.81	13.37	1.69	0.01	0.08	0.46	0.10	4.74	4.75	ND	100.0	ND
	JY-92-64 (major mode)		3047	2958	10/4/93	76.66	12.86	1.12	0.01	0.04	0.44	0.05	4.49	4.34	ND	100.0	ND
MC-CC-1	RC-73	USGS	3339	4333	1983	65.58	16.17	5.08	1.35	0.10	3.70	0.90	4.62	2.51	ND	100.0	ND
MC-Y	JY-92-62	USGS	3006	2957	5/3/93	77.45	12.93	0.83	0.17	0.04	0.86	0.15	3.92	3.66	ND	100.0	ND
	JY-92-61		3005	2956	5/3/93	77.53	12.97	0.83	0.18	0.03	0.84	0.17	3.95	3.51	ND	100.0	ND
	RC-90		3340	4348	1983	77.52	12.84	0.91	0.17	0.03	0.84	0.17	3.91	3.61	ND	100.0	ND
MC-K	JY-92-50A	USGS	3046	2955	7/7/93	76.40	12.47	1.54	0.02	0.02	0.52	0.10	3.91	5.02	ND	100.0	ND
Fluvial terraces on floodplain of MFFR, near Mohawk Cliff site - Site MV-314																	
JY-92-74	JY-92-74	USGS	3353	2965	9/24/93	74.27	14.52	1.87	0.31	0.05	1.19	0.31	4.53	2.90	ND	100.0	ND
RC-92	RC-92		3334	4349	1994	73.20	14.64	1.92	0.32	0.06	1.30	0.34	5.21	3.01	ND	100.0	ND
Mohawk Valley Floor																	
MV-10A	10A (lower B)	**WSU	#NA	NA	2009	75.01 ††(0.16)	13.71 (0.09)	1.86 (0.05)	0.24 (0.02)	ND	1.48 (0.08)	0.19 (0.03)	3.64 (0.14)	3.70 (0.09)	0.17 (0.03)	100.0	17
MV-10B	10B-E	WSU	NA	NA	2011	74.77 (0.29)	13.87 (0.15)	1.85 (0.06)	0.23 (0.03)	ND	1.52 (0.09)	0.22 (0.03)	3.68 (0.10)	3.68 (0.07)	0.18 (0.03)	100.0	18
JY-92-1	JY-92-1 (minor mode)	USGS	2994	2943	5/3/93	76.63	13.44	1.07	0.10	0.05	0.74	0.12	4.12	3.73	ND	100.0	ND
	JY-92-1 (major mode)		2993	2942	5/3/93	74.20	14.12	1.90	0.22	0.03	1.51	0.19	4.15	3.70	ND	100.0	
MV-174	174-D	WSU	NA	NA	2011	77.98 (0.19)	12.67 (0.08)	0.86 (0.05)	0.17 (0.02)	ND	0.89 (0.05)	0.15 (0.04)	3.51 (0.09)	3.62 (0.14)	0.13 (0.02)	100	16

MV-175	175-C	WSU	NA	NA	2009	77.97 (0.13)	12.50 (0.10)	0.87 (0.02)	0.18 (0.03)	ND	0.91 (0.05)	0.16 (0.03)	3.53 (0.11)	3.75 (0.11)	0.13 (0.02)	100.0	16
<u>Mohawk Valley Floor</u>																	
JY-92-11	JY-92-11	USGS	3001	2944	5/3/93	77.46	12.93	0.86	0.17	0.04	0.85	0.15	3.93	3.61	ND	100.0	ND
MV-179	179	WSU	NA	NA	2011	78.19 (0.24)	12.54 (0.19)	0.88 (0.03)	0.17 (0.02)	ND	0.87 (0.05)	0.16 (0.03)	3.44 (0.08)	3.62 (0.15)	0.13 (0.01)	100.0	19
JY-92-9	JY-92-9	USGS	3000	ND	5/3/93	77.36	12.97	0.86	0.17	0.03	0.85	0.16	3.93	3.68	ND	100.0	ND
§§ SAM-38	SAM-38	USGS	343	4563	1982	77.54	12.89	0.91	0.20	0.01	0.90	0.15	3.77	3.62	ND	100.0	ND
§§ SAM-10B	SAM-10B	USGS	340	4560	1982	77.80	12.74	0.88	0.16	0.02	0.82	0.15	3.91	3.52	ND	100.0	ND
MV-178	178-B	WSU	NA	NA	2009	75.28 (0.17)	13.57 (0.11)	1.33 (0.03)	0.17 (0.01)	ND	0.91 (0.03)	0.20 (0.04)	3.28 (0.19)	5.20 (0.19)	0.06 (0.02)	100.0	18
JY-92-13	JY-92-13	USGS	3002	2945	5/3/1993	74.44	14.14	1.32	0.17	0.04	0.88	0.20	3.71	5.11	ND	100.0	ND
JY-92-14	JY-92-14	USGS	3003	2946	5/3/1993	74.47	14.01	1.33	0.16	0.04	0.89	0.19	3.72	5.18	ND	100.0	ND
				bulk composition		67.85 (3.50)	16.33 (0.49)	4.10 (1.19)	1.12 (0.59)	ND	3.20 (1.12)	0.67 (0.23)	4.61 (0.54)	1.97 (0.30)	0.15 (0.07)	100	25
MV-181	181-D middle	WSU	NA	glass 1	2011	70.26 (1.05)	16.01 (0.26)	3.29 (0.21)	0.72 (0.11)	ND	2.44 (0.28)	0.51 (0.07)	4.45 (0.59)	2.17 (0.07)	0.16 (0.05)	100	16
				glass 2		63.25 (1.33)	16.91 (0.11)	5.69 (0.57)	1.91 (0.30)	ND	4.68 (0.54)	0.97 (0.06)	4.87 (0.27)	1.57 (0.13)	0.15 (0.10)	100	8
MV-181	181-D lower	WSU	NA	NA	2009	71.72 (0.35)	15.22 (0.23)	2.86 (0.07)	0.74 (0.04)	ND	2.68 (0.13)	0.40 (0.04)	4.06 (0.14)	2.19 (0.07)	0.13 (0.04)	100	20
	JY-92-2A (mode 3)		2997	2949	5/3/1993	74.21	14.80	1.68	0.16	0.09	0.98	0.12	5.24	2.72	ND	100.0	ND
JY-92-2A	JY-92-2A (mode 2)	USGS	2996	2948	5/3/1993	58.73	18.11	6.97	3.07	0.11	6.18	0.96	4.77	1.11	ND	100.0	ND
	JY-92-2A (mode 1)		2995	2947	5/3/1993	69.45	16.25	3.03	0.65	0.11	2.28	0.46	5.69	2.07	ND	100.0	ND
MV-192-3C	192-3C	WSU	NA	192 (strat# C)	2009	71.64 (0.30)	15.19 (0.13)	2.76 (0.05)	0.76 (0.03)	ND	2.81 (0.16)	0.43 (0.03	4.06 (0.20)	2.23 (0.06)	0.12 (0.02)	100.0	16
MV-192-2D	192-2D	WSU	NA	NA	2011	76.31 (0.59)	13.07 (0.33)	1.09 (0.32)	0.05 (0.03)	ND	0.60 (0.08)	0.11 (0.03)	2.85 (0.29)	5.74 (0.45)	0.18 (0.06)	100.0	16
JY-92-2B	JY-92-2B	USGS	2998	2950	5/3/1993	70.46	15.95	2.77	0.70	0.05	2.73	0.40	4.69	2.25	ND	100.0	ND
<u>Site MV-133</u>																	
RC-5	RC-5	USGS	986	4329	ND	74.16	14.23	1.76	0.08	0.05	0.69	0.11	4.61	4.31	ND	100.0	ND
RC-6	RC-6	USGS	987	4330	ND	74.30	14.24	1.71	0.07	0.05	0.69	0.11	4.51	4.31	ND	100.0	ND
RC-7	RC-7	USGS	988	4332	ND	77.94	12.74	0.88	0.17	0.03	0.87	0.15	3.81	3.41	ND	100.0	ND
RC-10	RC-10	USGS	990	ND	ND	77.78	12.83	0.89	0.17	0.03	0.83	0.16	3.81	3.51	ND	100.0	ND
133-D	133D	WSU	NA	133D	2009	78.47 (0.14)	12.37 (0.08)	0.91 (0.04)	0.18 (0.02)	ND	0.89 (0.06)	0.16 (0.03)	3.32 (0.10)	3.57 (0.18)	0.13 (0.02)	100.0	19
133-E	133E	WSU	NA	133E	2009	78.37 (0.22)	12.50 (0.11)	0.89 (0.03)	0.17 (0.02)	ND	0.87 (0.04)	0.16 (0.03)	3.31 (0.12)	3.60 (0.16)	0.13 (0.03)	100.0	19
133-F	133F	WSU	NA	133F	2009	78.37 (0.16)	12.43 (0.09)	0.90 (0.05)	0.17 (0.02)	ND	0.87 (0.04)	0.16 (0.04)	3.30 (0.15)	3.66 (0.26)	0.13 (0.02)	100.0	18
<u>Site MV-133</u>																	
RD-02	RD-02	USGS	3350	RD-02	10/3/1994	76.37	13.23	1.31	0.05	0.04	0.60	0.08	4.21	4.11	ND	100.0	ND
RC-12	RC-12	USGS	991	4311	1994?	76.67	12.53	1.59	0.03	0.03	0.52	0.11	3.61	4.91	ND	100.0	ND
RC-9	RC-9	USGS	989	4347	1994?	76.72	12.54	1.52	0.03	0.03	0.52	0.12	3.61	4.91	ND	100.0	ND
133-A	133-A	WSU	NA	NA	2009	76.77 (0.24)	12.21 (0.11)	1.54 (0.16)	0.02 (0.01)	ND	0.56 (0.05)	0.12 (0.03)	3.18 (0.28)	5.43 (0.41)	0.17 (0.04)	100.0	20
RC-13	RC-13	USGS	992	4312	1994?	75.28	13.63	1.31	0.17	0.04	0.86	0.19	3.71	4.81	ND	100.0	ND
<u>Site 312</u>																	
JY-92-79	JY-92-79	USGS	3139	2967	2/27/92	77.50	12.76	0.87	0.17	0.02	0.88	0.17	4.02	3.61	ND	100.0	ND
JY-92-77	JY-92-77	USGS	3138	2966	12/18/93	76.60	12.48	1.51	0.02	0.03	0.54	0.10	3.72	5.00	ND	100.0	ND

Gray Eagle Creek																	
MV-284-V	284-V-upper	WSU	NA	NA	2011	77.06 (0.33)	12.96 (0.19)	1.31 (0.11)	0.19 (0.03)	ND	0.81 (0.08)	0.25 (0.05)	3.89 (0.15)	3.34 (0.11)	0.19 (0.08)	100.0	16
MV-66-C18	66-C18	WSU	NA	68-C18	2011	76.18 (0.19)	13.35 (0.12)	1.20 (0.04)	0.09 (0.02)	ND	0.60 (0.03)	0.13 (0.03)	3.87 (0.12)	4.47 (0.09)	0.11 (0.01)	100.0	16
MV-66-C13	66-C13	WSU	NA	NA	2011	74.51 (0.34)	14.22 (0.21)	1.69 (0.11)	0.07 (0.02)	ND	0.70 (0.09)	0.11 (0.02)	4.13 (0.09)	4.44 (0.14)	0.13 (0.05)	100.0	17
MV-66-C11	66-lower	WSU	NA	66 - lower	2009	77.34 (0.27)	12.54 (0.13)	1.18 (0.06)	0.02 (0.01)	ND	0.38 (0.03)	0.05 (0.03)	3.67 (0.18)	4.69 (0.21)	0.13 (0.02)	100.0	20
MV-65-F	65-lower	WSU	NA	65-F (lower)	2009	78.06 (0.17)	12.46 (0.13)	0.86 (0.03)	0.16 (0.02)	ND	0.90 (0.05)	0.16 (0.03)	3.55 (0.15)	3.73 (0.17)	0.14 (0.03)	100.0	18
Jamison Creek																	
MV-70-B	70 - downstream B	WSU	NA	NA	2009	76.00 (0.16)	13.28 (0.12)	1.23 (0.03)	0.10 (0.02)	ND	0.65 (0.05)	0.12 (0.03)	3.91 (0.13)	4.59 (0.16)	0.12 (0.02)	100.0	16
MV-45.5-D	45.5-D	WSU	NA	NA	2011	74.80 (0.32)	14.05 (0.13)	1.68 (0.10)	0.09 (0.03)	ND	0.71 (0.07)	0.12 (0.03)	3.93 (0.25)	4.50 (0.18)	0.12 (0.03)	100.0	19
Site JY-92-47																	
JY-92-47	JY-92-47	USGS	3004	NA	5/3/1993	75.42	13.46	1.27	0.05	0.04	0.59	0.10	3.58	5.49	ND	100	ND
Site MV-139																	
MV-139-B	139-B	WSU	NA	139B	2009	78.33 (0.17)	12.44 (0.10)	0.88 (0.02)	0.16 (0.02)	ND	0.87 (0.06)	0.15 (0.03)	3.33 (0.17)	3.72 (0.20)	0.13 (0.02)	100.0	20
Portola Road / Calfpasture Creek																	
MV-90-E	90-E	WSU	NA	NA	2009	78.37 (0.18)	12.49 (0.08)	0.89 (0.02)	0.18 (0.02)	ND	0.88 (0.04)	0.16 (0.02)	3.34 (0.12)	3.59 (0.08)	0.12 (0.02)	100.0	18
MV-91-C	91-C	WSU	NA	NA	2009	78.14 (0.21)	12.49 (0.11)	0.88 (0.04)	0.18 (0.02)	ND	0.88 (0.04)	0.17 (0.03)	3.44 (0.15)	3.68 (0.15)	0.12 (0.02)	100.0	20
JY-92-6	JY-92-6	USGS	2939	3371	5/3/93	77.44	12.82	0.91	0.17	0.03	0.89	0.17	3.96	3.62	ND	100.01	ND
Clio Road / Willow and Betterton Creeks																	
MV-5-F	5	WSU	NA	5	2009	67.48 (0.18)	16.07 (0.07)	3.96 (0.10)	1.22 (0.05)	ND	3.61 (0.08)	0.68 (0.03)	4.24 (0.21)	2.58 (0.07)	0.15 (0.03)	100.0	18
JY-92-7	JY-92-7	USGS	2999	2960	5/3/93	66.38	16.76	3.88	1.19	0.05	3.58	0.67	4.80	2.69	ND	100.0	ND
JY-91-7	Underlies JY-92-7	USGS	2940	3373	ND	76.20	13.33	1.32	0.04	0.03	0.60	0.07	4.35	4.06	ND	100.00	ND
JY-91-8	Underlies JY-92-7	USGS	2941	3374	ND	73.76	14.29	1.77	0.07	0.08	0.72	0.13	4.75	4.43	ND	100.00	ND
Clio Road / Willow and Betterton Creeks																	
§§ SAM-25A	SAM-25A	USGS	341	4561	1982	76.50	13.30	1.30	0.06	0.01	0.59	0.07	4.12	4.05	ND	100.0	ND
§§ SAM25B	SAM25B	USGS	342	4562	1982	75.69	13.09	1.28	0.04	0.04	0.61	0.06	4.27	3.93	ND	99.0	ND

Notes: *SC Similarity Coefficient.

† Analyses by the Tephrochronology Laboratory of the U.S. Geological Survey in Menlo Park, Ca.

§ ND no data.

NA not applicable.

** Analyses by F. Foit in the Geo-Analytical Laboratory located in the Department of Geology at Washington State University.

†† Standard deviations of the analyses given in parentheses.

§§ from Mathieson (1981).

TABLE 2. TEPHRA CORRELATIONS AND AGE ESTIMATES FOR MOHAWK VALLEY TEPHRA BEDS.

Area / Site	Tephra bed	*SC	Tephra Name and possible Correlation	†Age Range (ka)	Elevation (m)	Thickness (cm) / Description	§Northing	Easting
Mohawk Valley Floor / MV-315 (Mohawk Cliff)	MC-GG-6	0.98	Tulelake 2036 at 53.14 m	<215-180	~1343.9	5	4406063	702008
		0.98	Tulelake 296	<610-570				
	MC-GG-5	0.95	Sample 68-16-1739, the andesitic dike at Medicine Lake Volcano (MLV), correlative to the andesitic tuff of the MLV, now referred to as the dacitic tuff of Antelope Well	215-180	~1343.05	2	4406063	702008
		0.94	Tulelake 2019, 2023, 1228 (53.07-53.13 m) - which is correlated to Summer Lake tephra bed KK and to the now dacite tuff of Antelope Wells					
	MC-GG-4	0.97	none	218-180	~1342.1	<5	4406063	702008
	MC-GG-3	0.97	Summer Lake tephra bed LL Wadsworth	218->180 200 ± 45	~1341.5	<5	4406063	702008
	MC-GG-2	0.99	Site MV-133-RC-5 and RC-6	(325-260) to (235-180)	~1341.05	<5	4406063	702008
	MC-GG-1	0.98	Tulelake 276 (56.12 m)	>325-260	~1340.7	<5	4406063	702008
	MC-CC-7	#NA	none	(610-570) to (325-260)	~1335.3	<5	4406063	702008
	MC-CC-6	0.99	Tulelake 2053 (56.44 m)		~1335	<5	4406063	702008
	MC-CC-5	NA	none		~1333.9	<5	4406063	702008
	MC-CC-4	NA	none		~1333.85	<5	4406063	702008
	MC-CC-3	0.98	Tulelake 1244 (56.44-56.46 m)		~1333.75	<5	4406063	702008
	MC-CC-2	**NR 0.98?	Tulelake (56.60 - 57.75 m)		~1333.73	<5	4406063	702008
	MC-CC-1	NA	none		~1333.7	<5	4406063	702008
	MC-Y	0.99	Rockland tephra	610-570	~1331.25	125 / lower 30 to 55 cm is primary deposition.	4406063	702008
	MC-K	0.98	Lava Creek B	639 ± 2	~1321.25	<5	4406063	702008
Mohawk Valley Floor / MV-314	JY-92-74	0.98	T-1163, Tsoyawata	7.014 ± .045	††ND	ND	4406062	701960
Mohawk Valley Floor / MV-10	10A-B	0.95	Puget Sound sample 19-1E-11-73E-1	No age known, likely correlates to Carp Lake, Ash 13	~1347	25	4406518	703366
		0.94	Carp Lake, Ash-13, core 93 from Carp Lake, OR	<200 (likely 200-100)	~1347		4406518	703366
	JY-92-1	ND	no correlation at time of analysis		ND	ND	4406536	703566
	10B-E	0.94	Carp Lake, Ash-13, core 93 from Carp Lake, OR	<200 (likely 200-100)	~1351	1 to 8 / burrowed, 1 to 2 mm fine sand sized tephra.	4406508	703400
		0.98	10A-B	<200 (likely 200-100)				
Mohawk Valley Floor / MV-174	174-D	0.98	Rockland tephra	610-570	~1355 to 1365	> 45 / airfall + reworked	4405715	704639

MV-174	174-D	0.98	Rockland tephra	610-570	~1355 to 1365	> 45 / airfall + reworked	4405715	704639
Mohawk Valley Floor / MV-175	175-C	0.98	Rockland tephra	610-570	~1357	>65 / >45 of well-sorted, sand-sized tephra with at least 10 to 20 cm of overlying reworked tephra	4405524	704700
	JY-92-11	0.99	Rockland tephra	610-570	ND	ND	4405560	704857
Mohawk Valley Floor / MV-179	179	0.98	Rockland tephra	610-570	1362	>>20	4405446	704734
	JY-92-9	0.99	Rockland tephra	610-570	ND	ND	4405560	704857
Mohawk Valley Floor / MV-178	178	0.959	Thermal Canyon Sample OL-92-1020 from Owen's Lake Core	740	1357L	5 / well-sorted, sparkly, gray, sand-sized tephra	4405409	704770
		0.964	Clear Lake Ash Bed 9, CL-0663	>660				
	JY-92-13	0.98	Thermal Canyon Sample OL-92-1020 from Owen's Lake Core or Clear Lake Ash Bed 9, CL-0663	740	ND	ND	4405560	704857
	JY-92-14	0.98						
Mohawk Valley Floor / MV-181	181-D middle	NA	none	>610-570	~1354.8	3	4405319	704917
Mohawk Valley Floor / MV-181	181-D lower	0.98	MV-192-3C		~1354.4	3	4405319	704917
	JY-92-2A		none (may be 181-D lower)		ND	ND	4405180	707769
Mohawk Valley Floor / MV-192	192-3C	0.98	Matches 181-D lower	>610-570	~1336	8 / massive, sand-sized, white tephra bed	4405285	704681
Mohawk Valley Floor / MV-192	192-2D	NA	none		~1333	2 to 5	4405285	704681
Mohawk Valley Floor / JY-92-2B	JY-92-2B	NA	none (may be 192-2D)		ND	ND	4405180	707769
Layman Canyon / MV-133	RC-5	NA	MC-GG-2	(325-260) to (235-180)	>1368	ND	4409158	700863
	RC-6	NA	none		>1368	ND	4409158	700863
	RC-7	ND	Rockland tephra	610-570	ND	ND	4409158	700863
	RC-10	ND	Rockland tephra	610-570	ND	ND	4409158	700863
	133-D	0.98	Rockland tephra	610-570	~1363	>25 / above that is removed.	4409158	700853
	133-E	0.979	Rockland tephra	610-570	~1367	80 / primary deposition.	4409158	700853
	133-F	0.976	Rockland tephra	610-570	~1368	25 / reworked Unit E	4409158	700853
	RD-02	ND	Dibekulewe	(639 ± 2) to (610-570)	ND	ND	4409158	700863
	RC-12	ND	Lava Creek B	639 ± 2	estimated ~<1354	ND	4409158	700863
	RC-9	ND						
	133-A	0.98	Lava Creek B	639 ± 2	~1354	5 to 10	4409158	700853
	RC-13	ND	Thermal Canyon	740	estimated ~<1354	ND	4409158	700863

Grey Eagle Creek / MV-284	284-V-upper	0.96	Summer Lake tephra bed E1 and Tulelake 2438	33.7-29.9	~1388	~10 to 30	4403434	703212
Grey Eagle Creek / MV-66	66-C18	0.96	Glass in the East McKay Butte obsidian	(610-570)-480	~1393.6	1 to 2 / Sand-sized tephra, white	4403399	703089
		0.97	70 Downstream B					
Grey Eagle Creek / MV-66	66-C13	0.97	MV-45.5-D	(610-570)-480	~1392.68 (~92 cm below 66-C18)	5 to 8 / Sand-sized tephra, white	4403399	703089
Grey Eagle Creek / MV-66	66-C11	NA	none	(610-570)-480	~1392.54 (14 cm below 66-C13)	1 to 3	4403399	703089
Grey Eagle Creek / MV-65	65- F-lower	0.98	Rockland tephra	610-570	~1375.5	250 / 50 cm primary deposition and 100+ cm reworked. Medium to coarse sand sized tephra with irregular lenses of pumice.	4403449	703245
Jamison Creek / MV-70	70-downstream B	0.97	MV-66-C18	(610-570)-480	~1422-1424	~5	4406449	698773
Jamison Creek / MV-45.5	45.5-D	0.97	MV-66-C13	(610-570)-480	~1426	up to ~400 / sand-sized tephra , white.	4407649	699006
Eastern Mohawk Valley / MV-139	139-B	0.98	Rockland tephra	610-570	1401	90+ / 18-20 cm primary deposition and ~70 cm reworked.	4398690	711483
Eastern Mohawk Valley / MV-90	90-E	0.98	Rockland tephra	610-570	1424	90+ / 20 cm primary deposition overlain by a 2 cm organic-rich layer and ~60-cm of reworked tephra, silt, and sand.	4402006	709476
Eastern Mohawk Valley / MV-91	91-C	0.979	Rockland tephra	610-570	1398	95+ / ~65 cm primary deposition overlain by >30 cm reworked tephra, silt, and sand.	4401609	709465
Eastern Mohawk Valley / MV-5	5-F	0.96	Summer Lake tephra bed LL	218->180	1436	~1 / Pink tint with coarse sand sized glass, quartz, and mica.	4403754	708416
		0.95	Wadsworth	201 ± 45	ND			
	JY-92-7	0.98	Summer Lake tephra bed LL	218->180	ND	ND	4403768	708498
		0.98	Wadsworth	201 ± 45	ND			

Eastern Mohawk Valley / JY-91-7		ND	no correlation, but there is chemical data in Table 1	ND	ND	ND	ND	ND
Eastern Mohawk Valley / JY-91-8		ND	no correlation, but there is chemical data in Table 1	ND	ND	ND	ND	ND
Layman Canyon / MV-312	JY-92-79	0.99	Rockland tephra	610-570	~1353	ND	4410248	700129
	JY-92-77	0.99	Lava Creek B	639 ± 2	~1353	ND	4410248	700129
§§Mohawk Valley Floor / SAM-10A	SAM-10A	ND	Rockland tephra	610-570	~1388	ND	4405800	704888
§§Mohawk Valley Floor / SAM-38	SAM-38	ND	Rockland tephra	610-570	~1358	ND	4405306	704931
§§ Eastern Mohawk Valley / SAM-25A	SAM-25A	ND	Rockland tephra	610-570	~1414	ND	4403633	708623
§§Eastern Mohawk Valley /SAM25B	SAM25B	ND	Rockland tephra	610-570	~1414	ND	4403448	708482

Notes. *SC= Similarity Coefficient.
†References in Table 3.
§NAD 83, Zone 10.
#NA not applicable.
**NR not recorded.
††ND no data.
§§from Mathieson (1981).

TABLE 3. AGE AND REFERENCES FOR TEPHRAS FOUND IN MOHAWK VALLEY.

Tephra Name (abbreviation)	Age range (ka)	References for age used
Tsoyawata (Ts)	7.014 ± 0.0045	Bacon and Lanphere, 2006
Summer Lake E1 (SL E1) = Tulelake 2438 (T-2438)	33.7-29.9	Negrini et al., 2000; Benson et al., 2013
Puget Sound sample 19-1E-11-73E-1	No age known, likely correlates to Carp Lake, Ash 13	Walsh et al., 2003
Carp Lake, Ash-13 (CL-13) = core 93 from Carp Lake, OR	<200 (likely 200-100)	Whitlock et al., 2000
Tulelake 2036 (T-2036)	<215-180	Reick et al.,1992; Kuehn and Negrini, 2010, Donnelly-Nolan, 2010
Tulelake 2019, 2023, 1228 (T-2019, T-2023, T-2019) Summer Lake KK (SL KK) andesitic tuff of Medicine Lake Volcano / dacitic tuff of Antelope Well	215-180	Berger, 1991; Herrero-Bervera, et al., 1994; Negrini et al., 2000; Donnelly-Nolan and Lanphere, 2005; Kuehn and Negrini, 2010; Donnelly-Nolan, 2010
Wadsworth	200 ± 45	Berger, 1991
Summer Lake LL (SL LL)	218->180	Berger, 1991; Negrini et al., 2000, Kuehn and Negrini, 2010; Donnelly-Nolan, 2010
MV-133-RC-5	(610-570) to (235-175)	stratigraphic position in Mohawk Valley
Tulelake 276 @ 56.12 m (T-276)	>325-260	Rieck et al., 1992; Herrero-Bervera, 1994
Cougar Butte obsidian	437 ± 7	Donnelly-Nolan and Lanphere, 2005; Donnelly-Nolan, 2010
MC-CC-7	(610-570) to (325-260)	stratigraphic position in Mohawk Valley
Tulelake 2053 @ 56.44 m (T-2053)		Rieck et al., 1992 and stratigraphic position in Mohawk Valley
MC-CC-5		stratigraphic position in Mohawk Valley
MC-CC-4		stratigraphic position in Mohawk Valley
Tulelake 1244 @ 56.44 - 56.46 m (T-1244)		Rieck et al., 1992; modified by stratigraphic position in Mohawk Valley
Tulelake @ 56.60 - 57.75 m (T- 56.60 - 57.75 m)		Rieck et al., 1992; modified by stratigraphic position in Mohawk Valley
MC-CC-1		stratigraphic position in Mohawk Valley
Glass in the East McKay Butte obsidian (EMB)	(610-570) to 480	McKee et al., 1976; modified by the stratigraphic position in Mohawk Valley
Rockland (R)	610-570	Meyer et al., 1980; 1991; Sarna-Wojcicki, et al., 1985; Alloway et al., 1992; Lanphere et al., 1999; Sarna-Wojcicki, 2000; Lanphere et al., 2000; Lanphere et al., 2004
MV-66-C11	(610-570) to >480	stratigraphic position in Mohawk Valley
Dibekulewe	(639 ± 2) to (610-570)	Rieck et al., 1992; Adams et al., 1994A; 1994B, 1995; Sarna-Wojcicki et al., 1997; Lanphere et al., 2002, 2004,
Lava Creek B (LCB)	639 ± 2	Lanphere et al., 2002
Clear Lake Ash Bed 9, CL-0663	>660	Sarna-Wojcicki et al., 1988 and revised in the current study
Thermal Canyon Sample OL-92-1020 from Owen's Lake Core (TC)	~740	Sarna-Wojcicki et al., 1993; Sarna-Wojcicki et al., 1997
MV-181-D middle MV-181-D lower MV-192-2D MV-192-3C	>610-570	stratigraphic position in Mohawk Valley. Could be older (>740 ka)

TABLE 4. ^{14}C ANALYSES OF FOUR SAMPLES WITHIN MOHAWK VALLEY.

Site	Sample Number	Material Dated	Site / UTM (NAD 83)	Date Analyzed	AMS ^{14}C date	$\delta^{13}C_{PDB}$	1-sigma calibrated date (68.2%)	2-sigma calibrated date (95.4%)	Depth below surface (cm)
297	PRI-11-123-297A	*Pinus* cone scale, charred	Site 297 - Floodplain Terrace of the MFFR / -4414561 694827	9/2011	*3665 ± 15	†N.D.	4080-4040; 4000-3970; 3950-3930	4090-4020; 4010-3920;	150-210 (bulk sample)
297	PRI-11-123-297B	*Pinus* charcoal, vitrified		9/2011	*3775 ± 15	N.D.	4220-4200; 4160-4140; 4130-4090	4230-4190; 4180-4080	
§JY	#GX-18471	Wood	Mohawk Cliff?	12/1992	**18,715 ± 235	-25.3	^{F}22,622.5 ± 368.5	††22,627 ± 764.5	N.D.
§JY	#GX-18472	Wood	Eureka Park Road to the SW?	12/1992	**36,000 ± 1,575	-27.6	^{F}40,429 ± 1,483	††39,850 ± 3,058	N.D.

Notes. *Analyses by PaleoResearch Institute, Golden, Co. Reported in radiocarbon years before present (B.P.) at 1 standard deviation measurement precision (68.2%), corrected for δ13C. Calibrated ages using OxCal3.10 (Bronk Ramsey, 2005)

†No Data.

§Material collected by J. Yount and exact location unknown.

#Material anaylyzed by Krueger Enterprises Inc.

**Ages are corrected for δ13C and are based upon the Libby half life (5570) years for 14C. Error stated is ±1σ as judged by the analytical data alone.

††Calibrated ages using Calib 7.0 (Stuiver et al., 2005) in conjunciton with Stuiver et al. (1993).

TABLE 5. SUMMARY OF AGE ESTIMATES FOR NEWLY IDENTIFIED TEPHRA BEDS IN MOHAWK VALLEY.

Tephra bed(s)	Site	Age (ka) based on over- and underlying tephra beds	General age estimate (ka) using *sedimentation rates from Mohawk Cliff minimum-maximum (mean)
MC-GG-4	Mohawk Cliff	218-180	287-180 (234)
MC-GG-2/ RC-5 and RC-6	Mohawk Cliff/MV-133	(~325-260) to (218-180)	323-224 (273)
MC-CC-7	Mohawk Cliff	(610-570) to (325-260)	522-463 (492)
MC-CC-5	Mohawk Cliff		570-522 (546)
MC-CC-4	Mohawk Cliff		572-524 (548)
MC-CC-1	Mohawk Cliff		577-530 (553)
MV-66-C13/ MV-45.5-D	MV-66 Gray Eagle Creek / MV-45 Jamison Creek	(610-570)-480	† NA
MV-66-C11	MV-66 Gray Eagle Creek	(610-570)-480	NA
MV-181-D middle	MV-181 Blairsden Section	>610-570 (may be >740 ka)	NA
MV-181-D lower / MV-192-3C	MV-181 and MV192 Blairsden Section	>610-570 (may be >740 ka)	NA
MV-192-2D	MV-192 Blairsden Section	>610-570 (may be >740 ka)	NA

Notes. Sedimentation rate (0.029-0.024 mm/yr) was calculated from the elevation difference of the Summer Lake KK (MC-GG-5) and the Rockland Ash (MC-Y) tephra beds in the Mohawk Cliff section and their estimated age ranges. These general age estimates used that sedimentation rate range and the range of the age estimates for the Rockand Ash with the distance above the Rockland Ash in the Mohawk Cliff section.

† NA Not Applicable

TABLE 6. SUMMARY OF NEW OR UPDATED AGE ESTIMATES FOR NINE TEPHRAS OUTSIDE OF MOHAWK VALLEY.

Tephra name	Mohawk Valley tephra bed / Site	Age (ka)	General age estimate (ka) using *sedimentation rates from Mohawk Cliff maximum-minimum (mean)
Clear Lake Ash beds			
Ash bed 7	*NA	<610-570 ka (~600 ka)	
Ash bed 8	NA	>610-570 ka (~625 ka)	
Ash bed 9	NA	>610-570 ka (~660 ka)	
East McKay Butte tephra	MV-66-C13/ Gray Eagle Creek MV-45.5-D / Jamison Creek	†610-480 ka	
Dibukelewe	RD-02 / Layman Canyon MV-133	§<(639 ± 2) and >(610-570)	
Tuffaceous Interval of the Tulelake Core (Rieck et al., 1992)			
T276	MC-GG-1/ Mohawk Cliff	~325-260 ka §	335-238 (287)
T205	MC-CC-6/ Mohawk Cliff	(610-570 ka) to (~325-260 ka) §#	532-476 (504)
T1244	MC-CC-3/ Mohawk Cliff	(610-570 ka) to (~325-260 ka) §#	575-528 (551)
unnamed tephra from 56.60 to 59.76 m	MC-CC-2/ Mohawk Cliff	(610-570 ka) to (~325-260 ka) §#	576-529 (552)

**Notes.* Sedimentation rate (0.029-0.024 mm/yr) was calculated from the elevation difference of the Summer Lake KK (MC-GG-5) and the Rockland Ash (MC-Y) tephra beds in the Mohawk Cliff section and their estimated age ranges. These general age estimates used that sedimentation rate range and the range of the age estimates for the Rockand Ash with the distance above the Rockland Ash in the Mohawk Cliff section.

†NA- Not Applicable.

§ from this study.

from Rieck et al. (1992).