Climatic Implications of Two Pollen Analyses from Newly Recognized Rocks of Latest Pliocene Age in the Washburn Range, Yellowstone National Park, Wyoming

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Pollen analyses suggest climate about 2 million years ago was broadly similar to that of today

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CLIMATIC IMPLICATIONS OF TWO POLLEN ANALYSES FROM ROCKS OF LATEST PLIOCENE AGE IN THE WASHBURN RANGE, YELLOWSTONE NATIONAL PARK, WYOMING

By GERALD M. RICHMOND, U.S. GEOLOGICAL SURVEY, and WILLIAM MULLENDERS and MADY COREMANS, INSTITUT DE BOTANIQUE, UNIVERSITÉ CATHOLIQUE DE LOUVAIN

ABSTRACT

Pollen analyses of siltstone beds in sedimentary rocks that overlie and closely resemble the basal sedimentary unit of the Eocene volcanic sequence in the Washburn Range, north-central Yellowstone National Park, have yielded pollen types and percentages indicative of an age no older than latest Pliocene. These sedimentary rocks are lithologically similar to others that lie conformably beneath the slightly more than 2.0-million-year-old Junction Butte Basalt and are therefore no younger than latest Pliocene in age. The geomorphic setting of the sediments in a north-trending paleovalley suggests that their source was an upland to the south in an area of central Yellowstone Park which has since foundered because of caldera collapse.

Comparison of the pollen analyses of the sediments at two localities and the altitudes of the localities with the modern pollen rain and altitude limits of present day forest associations suggests that the vegetation zones and climate in latest Pliocene time were broadly similar to present conditions. The sedimentary rocks are correlated with others in and near Yellowstone Park on the basis of their overall relation to the Huckleberry Ridge Tuff, which overlies the Junction Butte Basalt and is also pottasium-argon dated as slightly more than 2 million years old.

INTRODUCTION

The Washburn Range, in north-central Yellowstone National Park, is a westward projection of the north-trending Absaroka Range along the east boundary of the Park (fig. 1). The Washburn Range is underlain chiefly by andesitic lava flows, flow breccias, and epiclastic volcanic sedimentary rocks of early to middle Eocene age (Smedes and Prostka, 1972). In places, these rocks are disconformably overlain by the Junction Butte Basalt, Huckleberry Ridge Tuff, and Lava Creek Tuff (Christiansen and Blank, 1972; U.S. Geological Survey, 1972). The Junction Butte Basalt has been K-Ar dated as 2.01±0.05 and 2.15±0.05 million years (m.y.) old (J. D. Obradovich, written commun., 1978). The Huckleberry Ridge Tuff, which locally overlies the basalt, has been K-Ar dated as about 2.02±0.08 m.y. old and the Lava Creek Tuff as 0.616±0.08 m.y. old (J.D. Obradovich, written commun., 1978). The Junction Butte Basalt and Huckleberry Ridge Tuff are of particular significance to this paper. Christiansen and Blank (1972) assigned both units to the Pleistocene.

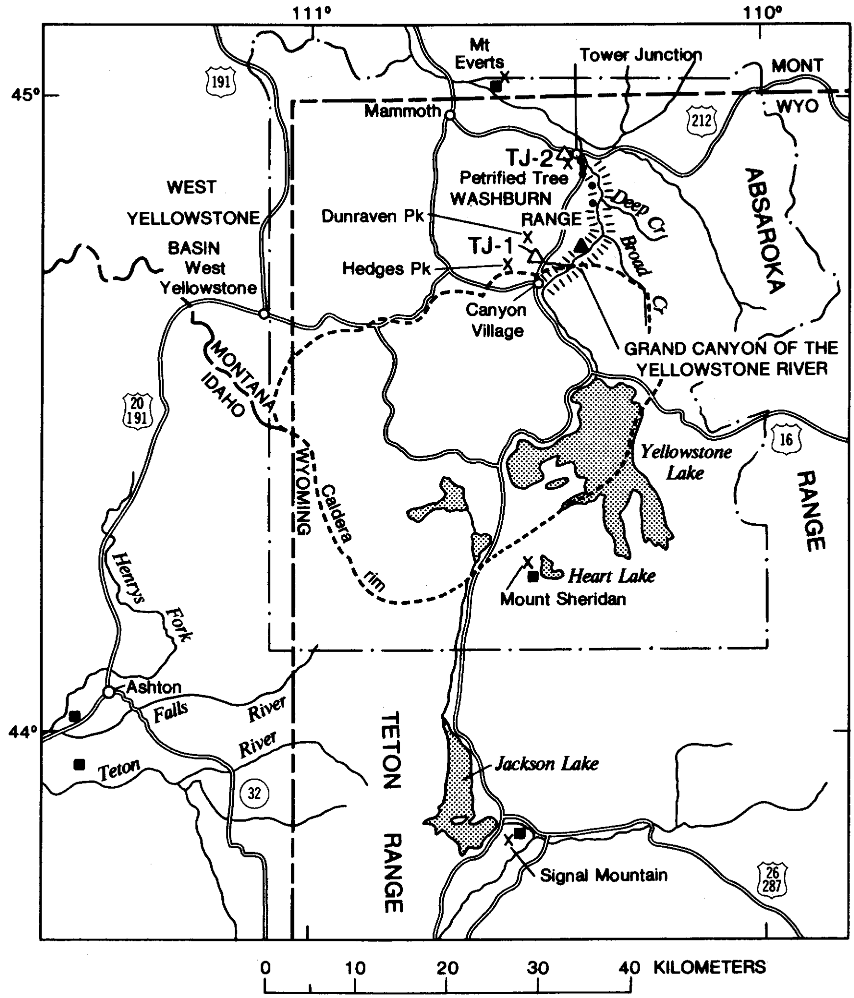

FIGURE 1.—Index map of Yellowstone National Park and adjacent areas showing known locations of sediments of latest Pliocene age. TJ-1 and TJ-2 are localities from which pollen analyses were made. Solid circles are localities where gravelly sediments underlie Junction Butte Basalt in paleovalley of Yellowstone River. Solid triangle is base of Huckleberry Ridge Tuff in same paleovalley. Solid squares are localities where sediments underlie Huckleberry Ridge Tuff.

Any change in this assignment is dependent on the age of the Pliocene-Pleistocene boundary at its stratotype section at Le Castella, Italy. Berggren (1972) estimated its age as 1.8 m.y. Subsequently, an age of 1.5 m.y. has been suggested (Haq and others, 1977). However, at Vrica, 16 km northeast of Le Castella, a continuous section of marine sediments ranging in age from middle Pliocene to lower Pleistocene contains a layer of volcanic ash in the zone of sediments that paleontologically records the deterioration of climate characterizing the Pliocene-Pleistocene transition (Selli and others, 1977). A preliminary age of 2.5±0.1 m.y. (fission track on glass) for the ash was determined by Boellstorf (1977). Subsequently, a K-Ar date of 2.2±0.2 m.y. on glass shards, a fission track date of 2.07±0.33 m.y. on glass, and a K-Ar date (whole rock) of 2.0±0.1 m.y. on a pumice block in sediments immediately above the ash have been determined (Selli and others, 1977). The age of the Pliocene-Pleistocene boundary is therefore probably about 2 million years. In any event, the Huckleberry Ridge Tuff and its correlative downwind ash bed, the type B Pearlette ash (Naeser and others, 1973), provide a time parallel marker that is essentially, if not actually, at the Pliocene-Pleistocene boundary.

The Eocene volcanic rocks in the Washburn Range include the Sepulcher (oldest), Lamar River, and Langford Formations of the Absaroka Volcanic Supergroup (Smedes and Prostka, 1972). Nonvolcanic conglomerate in the Washburn Range was first described by Shultz (1962, p. 43-57); it underlies or interfingers with the lower part of the Sepulcher Formation (Smedes and Prostka, 1972, p. C15) both in the Washburn Range and elsewhere (Prostka and others, 1975). In places, the nonvolcanic rocks clearly underlie the Eocene volcanic rocks (Shultz, 1962, p. 44; Smedes and Prostka, 1972, p. C16). In other places, they have been erosionally stripped and now occur at the surface.

In the course of a study of the Quaternary deposits south of the Washburn Range (Richmond, 1974, 1976a, 1976b, 1977), samples for pollen analysis were collected from glacial and interglacial lake sediments at a number of localities. Analyses of these samples by Mullenders and Coremans revealed suprisingly little contamination by Eocene pollen, despite the presence to the north and east of widespread Eocene rocks containing an abundant described megaflora (Knowlton, 1899; Dorf, 1960) and known Eocene pollen (Fisk and DeBord, 1974; Richard A. Scott, oral commun., 1975). To insure recognition of possible Eocene pollen contaminants, we collected samples of nonvolcanic siltstone and fine-grained sandstone interbedded in conglomerate at two readily accessible localities, shown as TJ-1 and TJ-2 in figure 1. The rocks at these localities have been mapped as Sepulcher Formation (U.S. Geological Survey, 1972; Prostka and others, 1975) and, based on their appearance, we had no reason to question their assumed Eocene age. At neither locality does the conglomerate contain clasts of Junction Butte Basalt or of Huckleberry Ridge Tuff but at neither locality is it overlain by Eocene volcanic rocks.

LOCALITY TJ-1

Locality TJ-1 (fig. 1) is just west of Grand Loop Road, 4.6 km northeast of Canyon Village, at a small dam along an unnamed creek that flows southeast from a saddle between Dunraven Peak and Hedges Peak. The sedimentary rocks crop out on a north-facing slope adjacent to the small dam at an altitude of 2,605 m. The outcrops are about 570 m above the Yellowstone River in its Grand Canyon to the east. The rocks consist of well-indurated, silicified, interbedded greenish-gray and greenish-brown conglomerate and sandstones, first described by Shultz (1962). The sandstone beds are 1-130 cm thick, hard, coarse to fine grained, and are locally weakly crossbedded. They include numerous thin lenses of hard siltstone. The conglomerate forms considerably thicker and commonly massive beds and lenses of well-rounded pebbles and small cobbles. The clasts are mostly 1-4 cm in diameter, but some are as much as 15 cm in diameter. They are chiefly of Precambrian granite, gneiss, and schist, but some are of porphyritic, medium-grained andesite and basalt of Eocene age and some are of dense varicolored quartzite like that of clasts in the Harebell Formation of Late Cretaceous age (Love, 1973) or the Pinyon Conglomerate of Late Cretaceous and Paleocene age (McKenna and Love, 1970). A small percentage are of siltstone, chert, and oolitic limestone. No clasts of rhyolite flows or tuffs were found. The matrix of the conglomerate is a silty coarse sand composed chiefly of quartz, feldspar, and muscovite. Shultz (1962, p. 49-51) has described its petrography. He (Shultz, 1962, p. 47-48) also reported that "coalified logs and plant fossils" were found in exposures, freshly opened at that time, but none of the fossil material could be identified. He stated (p. 49) that "some of the carbonaceous material has the appearance and texture of charcoal." Owing probably to slumping of the exposures, we did not find these organic deposits.

About 0.3 km southwest of locality TJ-1, in a small quarry along an abandoned section of Grand Loop Road, Shultz (1962 p. 52-53) found fossil leaves in fine- to medium-grained tuffaceous sandstone beds interlayered in a pebble conglomerate consisting wholly of andesitic volcanic material. The fossil leaves were identified by Erling Dorf (Shultz, 1962, p. 53) as:

Aralia notata Lesquereux (ginseng)
Carya culveri Knowlton (hickory)
(?)*Juglans crescentia* Knowlton (walnut(?))
Quercus weedi Knowlton (oak)
Quercus yanceyi Knowlton (oak)

All species are common to the Eocene volcanically derived sedimentary rocks in Yellowstone National Park (Dorf, 1960). Shultz (1962) recognized the lithologic difference between these rocks and those at locality TJ-1 but considered both to be of Eocene age.

Pollen analysis[1] by Mullenders and Coremans of a sample of siltstone interbedded in the conglomerate at locality TJ-1 yielded the following distribution:

Arboreal pollen (AP)		*Nonarboreal pollen (NAP)*	
Type	*Percent*	*Type*	*Percent*
Pinus (pine)	84.9	*Artemisia* (sage)	5.1
Picea (spruce)	3.8	Chenopodiaceae-Amaranthaceae	.4
Abies (fir)	2.7	*Sarcobarus* (greasewood)	.1
Betula (birch)	0.1	Compositae (composites)	
		Tubuliflorae	1.3
Alnus (willow)	0.4	Gramineae (grasses)	.8
		Thalictrum (meadow rue)	.1
		Plantago (plantain)	.1
		Umbelliferae	.1
		Sphagnum (sphagnum moss)	.1
Total AP	91.9	Total NAP	8.1

Pollen sum: 957

The difference in taxa between the megaflora of Shultz and the pollen flora represented in our sample is obvious, and any attempt to equate the two on the basis of the absence of megafossils at locality TJ-1 is inadequate. The absence of leaves of *Betula* and *Alnus* in sample TJ-1 is not significant, for, if present, their pollen might have been transported from far upslope. The same explanation might apply also to the absence of megafossils of *Picea* and *Abies*. But such an explanation cannot apply to the presence of 85 percent *Pinus* pollen in our sample. Clearly, such an abundance of pollen indicates the presence of *Pinus* in the forest, as is further demonstrated by the pollen content of modern surface samples discussed below. A differential destruction of megafossils similar to that which takes place in bogs might explain the absence of megafossils of *Pinus* at the quarry, but this process is unlikely to have taken place in tuffaceous sandstone beds. Furthermore, the absence of pollen of *Quercus, Juglans,* and *Carya* in the sample from locality TJ-1, only 300 m from the megafossil site, seems impossible if the rocks at both localities are the same age. We therefore conclude that the contrast between the megaflora at the quarry and the pollen flora at locality TJ-1 indicates that deposition of the rocks at the two localities took place at different times and in very different environments. The contact between these two suites of rocks has not been found, but it probably is a disconformity in the form of a valley cut in the Eocene rocks. A fault zone recognized by Shultz (1962) at the quarry site appears to be restricted to the Eocene rocks.

[1]The samples from localities TJ-1 and TJ-2 were processed by the method of Frenzel (1964) as modified by Bastin and Couteaux (1966). The method combines the normal procedure for organic sediments with treatment by a liquid having a density of 2 (CdI+KI).

LOCALITY TJ-2

The exposures of siltstone at locality TJ-2 (fig. 1) are along the east side of the access road to Petrified Tree, 0.5 km south of its junction with Grand Loop Road west of Tower Falls. The rocks crop out on the steep west-facing valley wall at an altitude of about 2,025 m, about 210 m above the Yellowstone River in its canyon to the east. The deposits are only about 0.3 km from Petrified Tree, which stands upright in growth position in a tuffaceous unit of the Sepulcher Formation. Many specimens of Eocene wood and leaves have been collected from exposures in the slopes above the tree (Dorf, 1960).

The sedimentary rocks at locality TJ-2 consist of hard, buff, well-bedded siltstone and greenish-gray to buff, locally pebbly, coarse to fine, poorly sorted, weakly bedded sandstone derived from andesitic sources. Pollen analyses of a sample of the siltstone by Mullenders and Coremans yielded the following distribution:

Arboreal pollen (AP)		*Nonarboreal pollen (NAP)*	
Type	*Percent*	*Type*	*Percent*
Pinus (pine)	74.5	*Artemisia* (sage)	5.3
Picea (spruce)	5.3	Chenopodiaceae-Amaranthaceae	.7
Pseudotsuga (Douglas fir)	3.0	Compositae (composites)	
		Tubuliflorae	.3
		Liguliflorae	.7
Betula (birch)	.3	Graminae (grasses)	7.3
Alnus (willow)	.7	Polemoniaceae (polymonium)	.3
Fagus (beech)	.3		
Arceuthobium (dwarf mistletoe)	.3	*Selaginella* (selaginella)	.7
		Sphagnum (sphagum moss)	.3
Total AP	84.4	Total NAP	15.6

Pollen sum: 302

PALYNOLOGICAL EVIDENCE FOR AGE

The samples from both localities TJ-1 and TJ-2 are very rich in pollen and the pollen grains are well preserved. The notable lack of typical Eocene species, such as those represented by the leaves collected by Shultz (1962) or the flora listed by Dorf (1960), clearly indicate that the rocks from which we collected are not of Eocene age. Recent summaries of the evolution of flora during the Cenozoic (Leopold, 1969; Leopold and MacGinitie, 1972) show that evolutionary modernization of the early Tertiary vegetation in the Rocky Mountain region began in late Oligocene time and proceeded so rapidly that by middle Miocene time only a few species of trees that are not now present in the region remained. A few of these species persisted, in decreasing proportion to existing species, until the beginning of Quaternary time. For example, rare *Carya* and *Ulmus-Zelkova* occur in the Glenns Ferry Formation of western Idaho whose abundant molluscan fauna suggests a late Pliocene age, but whose rare vertebrate fauna suggests an early Pleistocene age (Malde and Powers, 1962). However, these trees are lacking in the overlying middle Pleistocene Bruneau Formation (Malde and Powers, 1962; Leopold, 1969; Leopold and MacGinitie, 1972). With the exception of a single grain of *Fagus,* all of the arboreal pollen in our samples represent species living in the area today. Of these species, *Abies cf. A. lasiocarpa* is reported from rocks as old as early Oligocene and *Picea cf. P. pungens* is reported from rocks as old as late Oligocene or early Miocene, both from localities in Colorado (Leopold and McGinitie, 1972, p. 195-196). *Pseudotsuga* is reported from beds as old as late Miocene in southern Idaho (Leopold and McGinitie, 1972, p. 197). Among the nonarboreal species, the most recent to appear were probably the Compositae, in Miocene time, and the Polemoniaceae, which occur in beds (Leopold and MacGinitie, 1972, p. 198) now assignable to the late Miocene on the basis of the recently revised age limits of that epoch (Berggren, 1972). However, the absence of relict early Tertiary species in our samples strongly suggests that the rocks at localities TJ-1 and TJ-2 are no older than latest Pliocene or earliest Pleistocene.

GEOLOGIC EVIDENCE FOR AGE

As indicated above, the conglomerate at locality TJ-1 does not contain clasts of rhyolite lava flow, or welded tuff, which are abundant in gravels of middle and late Pleistocene age (Pierce, 1974; Richmond, 1976a, b, 1977) in the Grand Canyon of the Yellowstone River. Such clasts were derived either from the Huckleberry Ridge Tuff, no younger than earliest Pleistocene in age, or from the Lava Creek Tuff of middle Pleistocene age (Christiansen and Blank, 1972). Both tuffs are present in the local bedrock. The absence of rhyolite tuff in the conglomerate at locality TJ-1 indicates that it is older than the Huckleberry Ridge Tuff and therefore no younger than latest Pliocene in age.

Support for such an age is provided by a similar sandy gravel containing lenses of sand and silt that is exposed at a number of localities in the walls of the Grand Canyon of the Yellowstone River from about 1.5 km southwest of the mouth of Deep Creek (fig. 1) downstream to Tower Junction (Christiansen and Blank, 1972; Pierce, 1974). This gravel is essentially identical to the conglomerate lithologically but is less indurated and less cemented. The clasts of the gravel, like those in the conglomerate at locality TJ-1, are chiefly of Precambrian granite, gneiss, and schist, Eocene andesite and basalt, and dense quartzite cobbles reworked from rocks of late Cretaceous or Paleocene age. An occasional pebble of Paleozoic limestone and fine-grained sandstone of unknown age may also be found. Christiansen and Blank (1972, p. B9) state that the gravel occurs in a paleovalley cut in Eocene rocks and that it is overlain by the Junction Butte Basalt which, on Mount Everts (fig. 1), directly underlies the Huckleberry Ridge Tuff. As indicated above, the Junction Butte Basalt is considered of Pleistocene age, but may approximate the Pliocene-Pleistocene boundary. The age of the underlying gravel, which contains no clasts of rhyolite tuff or Junction Butte Basalt, is therefore no younger than latest Pliocene.

We correlate the conglomerate at locality TJ-1 with the gravel beneath the Junction Butte Basalt on the basis of their lithologic similarities. Both contain similar proportions of clasts of the same rock types, and both lack clasts of Huckleberry Ridge Tuff or Junction Butte Basalt. Figure 2 is a reconstruction of the profile of the floor of the paleovalley, controlled by altitudes at the base of the gravel (Pierce, 1974), the base of the Junction Butte Basalt, and the base of the Huckleberry Ridge Tuff (Prostka and others, 1975) in the paleovalley, and projected to the altitude of locality TJ-1. The reconstruction tends to support the above correlation, although a cover of middle Pleistocene rhyolite lava flows obliterates the paleovalley in places.

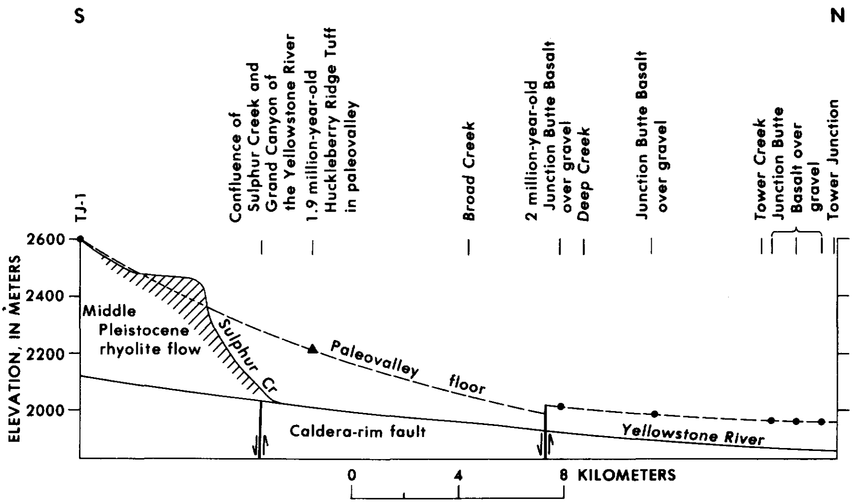

FIGURE 2.—Profile of floor of paleovalley of Yellowstone River between Tower Junction and locality TJ-1. Profile is drawn on altitudes at base of gravel beneath Junction Butte Basalt (from Pierce, 1974) and at base of Huckleberry Ridge Tuff in paleovalley (from Prostka and others, 1975), and is projected upstream, in part beneath younger middle Pleistocene rhyolite, to altitude of gravel at locality TJ-1. Solid circles and triangle correspond to those in figure 1.

Shultz (1962, p. 56) inferred that the source of the clasts of Precambrian rock in the conglomerate at locality TJ-1 was probably the Beartooth Mountains to the north. However, the similarity of this conglomerate to the gravel beneath the Junction Butte Basalt, and the north-sloping profile of the paleocanyon in which the basalt and underlying gravels were deposited, suggests to us that the source was a former upland to the south. The presently known southern limit of the conglomerate is just north of the rim of a large caldera complex which formed in the central area of Yellowstone National

Park during major eruptions of the Huckleberry Ridge and Lava Creek Tuffs (Christiansen and Blank, 1972), 2.02 ±0.08 million years ago and 616,000±8,000 years ago respectively. The inferred upland source of the conglomerate may have been present in this area before collapse of the caldera. The paleovalley downstream from locality TJ-1 is eroded in Eocene rocks north of the caldera rim and is probably cut by the caldera rim fault upstream to the southwest. Another paleovalley, tributary from the south, may have existed in about the position of the present Grand Canyon of the Yellowstone. If so, it was cut by the caldera rim fault about 0.5 km south of its confluence with the drainage from locality TJ-1.

The inferred upland source of the paleovalley drainage may have been continuous with the Basin Creek uplift, a domal structure truncated by the caldera rim fault along the south rim of the caldera in the south-central part of the park. Rejuvenation of the domal structure during the onset of volcanism in late Cenozoic time has been postulated by Love and Keefer (1969) The relatively steeper headward slope of the paleovalley profile (fig. 2) suggests that the gravels were deposited on the north slope of the inferred uplift immediately before volcanism began.

The precise age of the deposits at locality TJ-2 is more difficult to determine because they are unrelated to datable rocks. The sandy layers at TJ-2 are similar to sand in a gravel underlying the Huckleberry Ridge Tuff on Mount Everts (Pierce, 1973) in that both deposits are wholly of andesitic material. This implies that both deposits were formed in drainages that flowed northward from terrain underlain by andesitic rocks.

The physiographic setting of these deposits relative to the distribution and direction of flow of Pleistocene glaciers in the drainage of the Yellowstone River (Pierce, 1974) is such that all glacier-related deposits, and probably most interglacial deposits contain Precambrian plutonic and metamorphic rocks transported from sources to the northeast. Such material is abundantly present in nearby nonindurated ice-contact deposits of the last glaciation and scattered glacial erratics (Pierce, 1974).

Because the deposits at locality TJ-2 lack both rhyolitic and Precambrian crystalline material, we infer that they are probably preglacial and of latest Pliocene age.

PALEOECOLOGIC AND PALEOCLIMATIC INFERENCES

A comparison of the pollen analyses from localities TJ-1 and TJ-2 with the modern pollen rain and the present distribution of vegetation provides some clues for speculation as to the distribution of vegetation and climatic conditions slightly more than 2 m.y. ago in latest Pliocene time.

Baker (1976, p. E10-E12) has broadly defined the characteristics and altitude limits of five modern vegetation associations in Yellowstone National Park (table 1) and has described (p. E17-E20 and fig. 13) the modern pollen rain from surface samples collected in each.

TABLE 1.—*Vegetation associations and their altitude limits in Yellowstone National Park*

[Converted to meters from Baker (1976)]

Alpine association	2,800 m to 2,990-3,350 m (summits)
Picea-Abies-Pinus albicaulis forest association	2,590 m to 2,800-2,990 m
Pinus contorta forest association (mixed with *Picea* and *Abies* in upper part)	2,130 m to 2,590 m
Pseudotsuga association	1,820 m to 2,440 m
Artemisia steppe association	upper limit: approximate 2,075 m

Comparison of the pollen analyses from sample localities TJ-1 and TJ-2 with analyses of modern surface samples (table 2) reveals that the pollen types and percentages at locality TJ-1 are similar to those of both the *Pinus contorta* forest association (mixed with *Picea* and *Abies*) and the *Picea-Abies-Pinus albicaulis* forest association. We cannot distinguish between these associations because we have not differentiated species of *Pinus.*

TABLE 2.—*Comparison of major pollen types and percentages from localities TJ-1 and TJ-2 with those of modern surface samples*

[Two of the four surface samples representing the *Pseudotsuga* association were collected by William Mullenders from moss polsters. The other modern surface samples were collected by R. G. Baker (1976, and written commun., 1977) from pond muds, marshes, and organic-rich soils]

		Modern forest surface samples			
Pollen type	Fossil pollen locality TJ-1	*Pinus-Abies-Pinus albicaulis* forest association	*Pinus contorta* forest association with *Picea* and *Abies*	*Pseudotsuga* association	Fossil pollen locality TJ-2
Pinus	84.9	80.0-87.0	80.0-88.0	52.6-85.0	74.5
Picea	3.8	3.6- 3.8	0.5- 4.0	0.2- 1.7	5.3
Abies	2.7	1.5	0.6- 2.8	0 - 0.7	0
Juniperus	0	0 - 0.3	0 - 0.6	0.5- 2.3	0
Pseudotsuga	0	0 - 0.3	0 - 0.5	0.3- 2.8	3.0
Betula	0.1	0 - 0.3	0	0 - 0.6	0.3
Alnus	0.4	0	0 - 0.5	0 - 2.3	0.7
Ephedra	0	0	0	0 - 0.1	0
Artemisia	5.1	3 -10.6	4.5-12.5	4.8-29.7	5.3
Chenopodiaceae-Amaranthaceae	0.4	1.5	0.5- 2.3	0.3- 5.0	0.7
Sarcobatus	0.1	0 - 0.3	0 - 0.6	0 - 0.2	0
Compositae	1.3	0.5- 0.9	0 - 0.5	0 - 4.0	1.0
Gramineae	0.8	0 - 1.2	0.3- 4.5	0.5- 6.5	7.3
Number of samples	1	2	6	4	1
Pollen sum	302	[1]339	[1]228	[1]296	957

[1]Minimum pollen sum of all samples analyzed.

All three pollen assemblages contain 80 percent or more *Pinus* pollen, as much as 4 or 5 percent *Picea* pollen, and as much as about 3 percent *Abies* pollen. The percentage of *Artemisia* pollen is lower in our sample from locality TJ-1 (5 percent) than in some of Baker's (3-12 percent). The percentages for Gramineae and Chenopodiaceae-Ameranthaceae are also lower in our sample; but that for Compositae is higher. These variances do not appear sufficient to suggest major differences in vegetational environment; in fact, the overall similarity is great enough to strongly suggest that the local forest during deposition of the rocks at locality TJ-1 was probably either the *Pinus contorta* forest association mixed with *Picea* and *Abies* or the *Picea-Abies-Pinus albicaulis* forest association. The altitude of locality TJ-1 is about that of the modern boundary between the *Pinus contorta* forest association and the *Picea-Abies-Pinus contorta* forest association (table 1).

A similarity is apparent also between the pollen types and percentages in the sample from locality TJ-2 and those of surface samples from the modern *Pseudotsuga* forest (table 2) near and east of Mammoth (fig. 1). Pollen counts for individual species in the sample from locality TJ-2 are mostly within the range displayed by the surface samples. The percentage of pollen of *Picea* (5.3) at locality TJ-2 is greater than in these surface samples but less than in a surface sample (8.3 percent) from open *Pseudotsuga* forest in Jackson Hole, south of Yellowstone National Park. *Juniperus* pollen is more abundant in one surface sample collected near Mammoth where *Juniperus scopulorum* is a major component of the association. *Artemisia* pollen is also more abundant in one surface sample collected east of Mammoth where the association is a very open *Pseudotsuga* forest with widespread *Artemisia tridentata*. *Pseudotsuga* pollen is slightly more abundant in the sample from locality TJ-2 than in any of the surface samples (table 2), all of which are from very open to moderately open *Pseudotsuga* forest. Two samples from dense *Pseudotsuga* forest, one from Jakcson Hole to the south and the other from West Yellowstone Basin, west of Yellowstone Park, contained respectively 17.1 percent and 14.6 percent *Pseudotsuga* pollen. We infer therefore that the pollen assemblage from locality TJ-2 reflects the presence, at the time of deposition of the rocks, of a moderately open *Pseudotsuga* association, possibly with nearby *Picea*. Locality TJ-2 is presently in moderately open *Pseudotsuga* forest with nearby *Picea engelmanni* on north-facing slopes, and its altitude (2,025 m) is in the middle part of the present altitude range of *Pseudotsuga* forest (table 1).

The similarities of the pollen assemblages from the rocks at localities TJ-1 and TJ-2 to those of surface samples of modern forest associations, together with the relationship of the altitudes of localities TJ-1 and TJ-2 to the altitude ranges of modern forest associations, suggest that the forest associations and their altitude limits during deposition of the rocks at localities TJ-1 and TJ-2 did not differ greatly from those of the present. If true, the climate in Yellowstone National Park about 2 million years ago in latest Pliocene time was broadly similar to that of today.

Other deposits which we correlate with the rocks at localities TJ-1 and TJ-2 on the basis that all conformably underlie the Huckleberry Ridge Tuff include: (1) the Heart Lake Conglomerate (Love and Keefer, 1969) which underlies the Huckleberry Ridge Tuff in the south-central part of Yellowstone National Park; (2) the upper gravel unit of the Bivouac Formation (Love, 1956, 1973), which overlies a tuff unit dated as Pliocene (Christiansen and Love, 1977) and underlies the Huckleberry Ridge Tuff on Signal Mountain in Jackson Hole; and (3) widespread deposits of alluvial gravel and lacustrine diatomite, silt, and sand that conformably underlie the Huckleberry Ridge Tuff in the area drained by the Teton River and Falls River in Idaho, southwest of Yellowstone National Park.

The Heart Lake Conglomerate was formerly estimated to be of Pliocene or Pleistocene age (Love and Keefer, 1969) as was the Bivouac Formation (Love, 1956, 1973). The Glenns Ferry Formation in Idaho, considered to be of Pliocene and Pleistocene(?) age by Malde and Powers (1962), is probably mostly older than the rocks at localities TJ-1 and TJ-2 because it contains a small relict early Tertiary flora.

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