Evaluation of Ar-Ar ages of Individual Mica Grains for Provenance Studies of Loess, Long Island, NY

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Introduction

Loess is ubiquitous over much of the North American mid-continent and forms some of the most productive agricultural soil. Loess also covers large areas of Long Island's surface, and is the basis of its agriculture (De Laguna, 1963, Sirkin, 1967, Newman, *et al*., 1968, Nieter, *et al*., 1975). Loess on Long Island is normally less than one meter thick, and is easily distinguished from the underlying stratigraphic units, which are mainly made up by till, sand, or gravel. We report here Ar/Ar ages of single mica grains in loess to study the provenance of Long Island loess.

The provenance of loess may indicate paleo-wind patterns. During the last glacial period, four major winds may have deposited the loess on Long Island: prevailing west wind, jet stream, glacial anticyclone, and katabatic winds from the north (a wind flowing down glacier, Cohmap, 1988). Ages of signal grains of mica in the loess may help to determine which were the dominant winds that carried the loess.

The provenance of loess has been studied by many people using various methods.

- Rutledge (1975) studied loess in Ohio using major element and mineralogical compositions;
- Tripathi and Rajamani (1999) studied loessic sediment in the New Delhi region, India and Ding *et al* (2001) studied Chinese Loess Plateau using trace element composition;
- Aleinikoff *et al* (1999) studied Colorado loess using Pb isotopes ratio of K-feldspar and single zircon U/Pb ages;
- Muhs and Bettis (2000) studied Iowa loess using geochemical and partical size;
- Nakai (1993) and Pettke *et al*. (2000) studied dust on Pacific Ocean floor using Nd and Sr isotope ratio;
- Ji *et al* (1999) studied loess in Luochuan, China using clay mineralogy;
- Fang *et al* (1999) studied loess in West Qinling, China using magnetic susceptibility;
- Cilek (2001) studied loess in the Czech Republic using heavy minerals; and
- Muhs *et al* (2001) studied Indiana and Iowa loess using major element composition.

These studies suggest that the bulk of loess has traveled only 100's of kilometers, while some traveled several thousand kilometers. Other than the single zircon U/Pb age method and single feldspar Pb isotope method, all the other methods used bulk samples, which may mask a small source by dominant local sources.

Here, we use single-step laser fusion Ar/Ar ages of single grains of muscovite and biotite in loess to see if it is possible to evaluate the relative importance of provenance sources, including distant sources. Mica grains were co-irradiated with hornblende monitor standard Mmhb (age = 525 Ma, Samson and Alexander, 1987) in the Cd-lined, in core facility (CLICIT) at the Oregon State reactor. Analyses were made in the Ar geochronology laboratory and Lamont-Doherty Earth Observatory. Individual grains were fused with a CO_2 laser, and ages were calculated from Ar isotope ratios corrected for mass discrimination, interfering nuclear reactions, procedural blanks and atmospheric Ar contamination. This method preserves the single grain information of U/Pb zircon ages, and may be better than zircon U/Pb ages because biotite is easily altered during weathering and in the sedimentary cycle and may provide more direct provenance information for a bed rock source that was being eroded by a contemporary glacier. Muscovite is a multi-cycle mineral in sedimentary environment, but it is much less robust than zircon. Furthermore, there is sufficient quantities of biotite and muscovite in our samples and Ar/Ar or K/Ar ages are available for these two minerals in bedrock throughout North America.

Long Island has a good geological setting to evaluate the use of single grain Ar/Ar ages of mica for a loess provenance study. The mica ages of the basement rock to the north of Long Island, the proposed sources of the loess, change continuously and laterally, from 200 Ma toward the east Massachusetts, Rhode Island and eastern Connecticut, 300 and 400 Ma in central and western Connecticut and western Massachusetts, about 800 Ma in New York and New Jersey, and older than 1000 Ma in the far west (Figure 1). As the glacier advanced to the south, it crushed and ground the basement rocks and deposited rock fragment of all sizes, especially silt, in the outwash at the front of glacier, which wind could move. Under such conditions and assuming most loess is local, *ca*. 200 Ma Ar-Ar ages for mica indicate a source to the east, 300 to 350 Ma ages indicate a source to the north. 500 to 800 Ma ages indicate a source to the west~~-~~, and ages over 1000 Ma mica may indicate a source further to the west.

Geological Background

~~Southern~~ The southern New England area, including southeast New York, Connecticut, Massachusetts and Rhode Island, has experienced a long and complex history (Figure 1). In general, this area was formed by four major ~~orogenic~~ events, Grenville, Taconian, Acadian, and Alleghanian orogenies, The older Grenville event occurred in the west, and ~~and~~ the later ones developed sequentially toward the east (Figure 1). Where a later metamorphism overlaps a previous one, the mica ages may be completely or partially reset. The closure temperature for mica Ar-Ar ages is about 300^{o} C.

The Grenville granulite grade rocks are exposed in the Hudson and New Jersey Highlands (Long and Kulp, 1962). Biotite in the Grenville rocks southwest of the Hudson River gives ages between 850 to 750 Ma. Biotite in the Grenville rocks east of the Hudson river gives ages from 750 to 700 Ma in the west to 500 to 400 Ma in the east (Dallmeyer and Sutter, 1976). Muscovite is not common in granulite-grade rocks.

Rocks affected by the Taconian orogeny are found in Taconic Mountains of eastern New York and western New England, they give biotite and muscovite K-Ar ages between 400 to 350 Ma (Long, 1962).

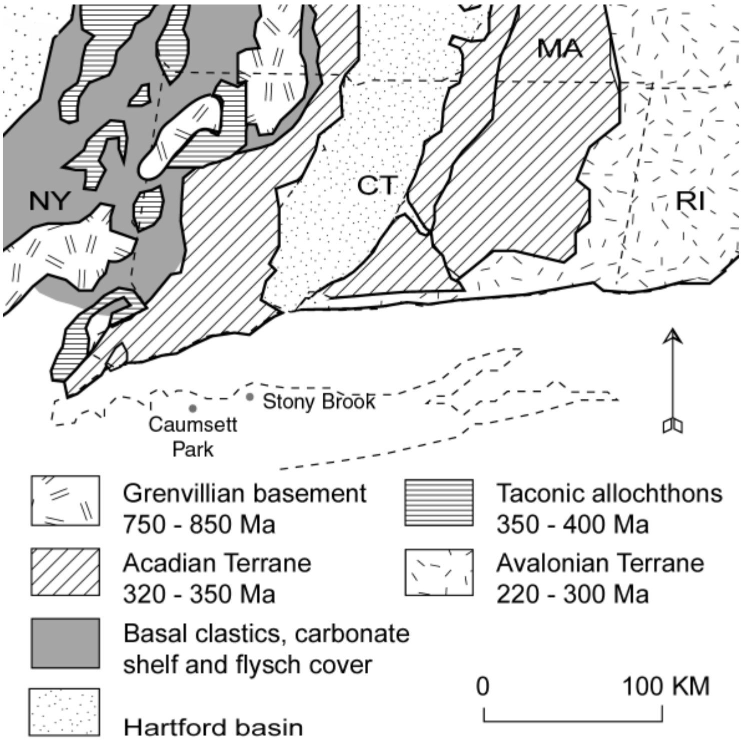

Figure 1. Regional Geology Map, the ages are K-Ar or Ar-Ar ages for biotite or muscovite.

The rocks affected by the Acadian orogeny ~~region are~~in western Connecticut~~,~~ have~~ing~~ biotite and muscovite ages between 320 to 350 Ma (Scott *et al*~~e~~. 1980, Seidemann, 1980;).

~~Biotite and muscovite from r~~The rocks affected by the Alleghanian Orogeny have mica ~~gave~~ ages between 220 to 300 Ma (Zartman etc, 1970, Scott *et al*~~e~~., 1980, Dallmeyer, 1982, Moecher *et al*. 1997), with older ages in the west and younger in the east.

During the Cretaceous, streams from the ~~remnanst~~ remnants of the Appalachian Mountains to the north and west carried sediment (mostly sand sized and smaller) and deposited them in flood plain, channels, and deltas in the vicinity of Long Island. These sedimentary layers underlie Long Island, and are known as the Lloyd Sand and the Raritan Clay of the Raritan Formation, and sands and clays of the Magothy Formation. The Cretaceous sediment is from a highly weathered source, dominated by quartz and muscovite, with no biotite. The sources of these sediments might be deeply weathered bedrock, or older sediments that were derived from the highlands to the west that formed during the Appalachian Orogenies. We have found no studies of the provenance of Cretaceous sediment in northeastern United States.

A seismic study (Lewis and Stone, 1991) shows that the pre-Pleistocene basement and sediments ~~-~~in Long Island Sound ~~basement is~~are covered by ~~glacier~~ glacial sediments. Under the ~~glacier~~ glacial sediments, the northern part of the Sound is Avalonian crystalline bedrock (Pacholik and Hanson 2001), while the southern part is a glacially modified, stream-carved surface of Cretaceous ~~Coastal~~coastal-~~Plain~~plain.

During the Pleistocene, the Sound may have been occupied by~~ a~~ glacial lakes several times as the glaciers advanced toward Long Island and retreated. The lakes formed because of the low eustatic sea level, the large quantity of meltwater from the glacier to the north, and the damming of the Sound by moraines.

Dreimanis and Vagners (1971) found that the size of glacial debris decreases progressively during transportion. Within 75 kilometers from the source, more than 70% of the particles are ground to smaller than 100 µm. So, the sediments larger than 100 µm in diameter carried by the glacier should be dominated by local components.

The bluffs on the north shore of Long Island at Caumsett State Park in Lloyd Harbor, New York contain Cretaceous sediment and glacial sediments including the remnants of a Gilbert delta. Sirkin (1996) suggested that the Gilbert delta was originally deposited some distance north of its present location in Long Island Sound during the last advance of the Wisconsinan glacier. After deposition, the Gilbert delta sequence and the underlying Cretaceous sediments were shoved southward by the advancing glacier.

The glacial sediments most likely consist of Cretaceous sands and local basement fragments. Biotite in the glacial sediment may be made up mainly of the biotite from the local basement rock in Long Island Sound and Connecticut because biotite is not present in the Cretaceous sediments.

Loess is commonly found on the surface above underlying glacial sediments. Most surficial loess in the United States was deposited during the last glacial period, when silt produced by glaciers was abundant. The loess we studied was deposited after the last glacier arrived on Long Island because there is no ~~overlaying~~ overlying outwash or till. The loess materials can potentially come from large distance, as wind distributes them so widely. Hence, Cretaceous sediment, glacial outwash, and far traveling dust carried by the wind may be sources of loess.

After the last glacier retreated from Long Island about 19 ka, Long Island Sound became a freshwater lake (Lewis and Stone, 1991). Under such conditions, the basement in the Sound was not exposed. The main source of the sediments in the lake would have been the bedrock to the north in Connecticut and Massachusetts. The glacial lake slowly lowered due to cutting of the Harbor Hill moraine in eastern Long Island Sound at the Race until about 15.5 ka when the lake was completely drained (Lewis and Stone, 1991). As the glacial sediments deposited in the lake were exposed, they became a potential local silt source of the loess. These sediments would have had their sources to the north in Connecticut and Massachusetts.

Mica Ages – Result and Discussion

Ar/Ar ages were obtained on about 100 muscovite and 400 biotite samples. Most muscovite grains contain greater than 90% radiogenic argon and give meaningful ages with uncertainty less than a few million years. Only 20% of the biotite grains have more than 10% radiogenic argon, the least amount necessary to give reliable ages. Uncertainties for muscovite ages are mostly below 0.5%, with a few between 0.5% and 1%. Uncertainties for the biotite ages are mostly below 5%, with a few between 5% and 10%. Histograms of the mica ages from Caumsett State Park are shown in figure 2 for muscovite from Cretaceous sand, muscovite and biotite from glacial sand, and muscovite from loess. Histograms of the mica ages of loess from SUNY Stony Brook campus are shown in Figure 4 for muscovite and biotite.

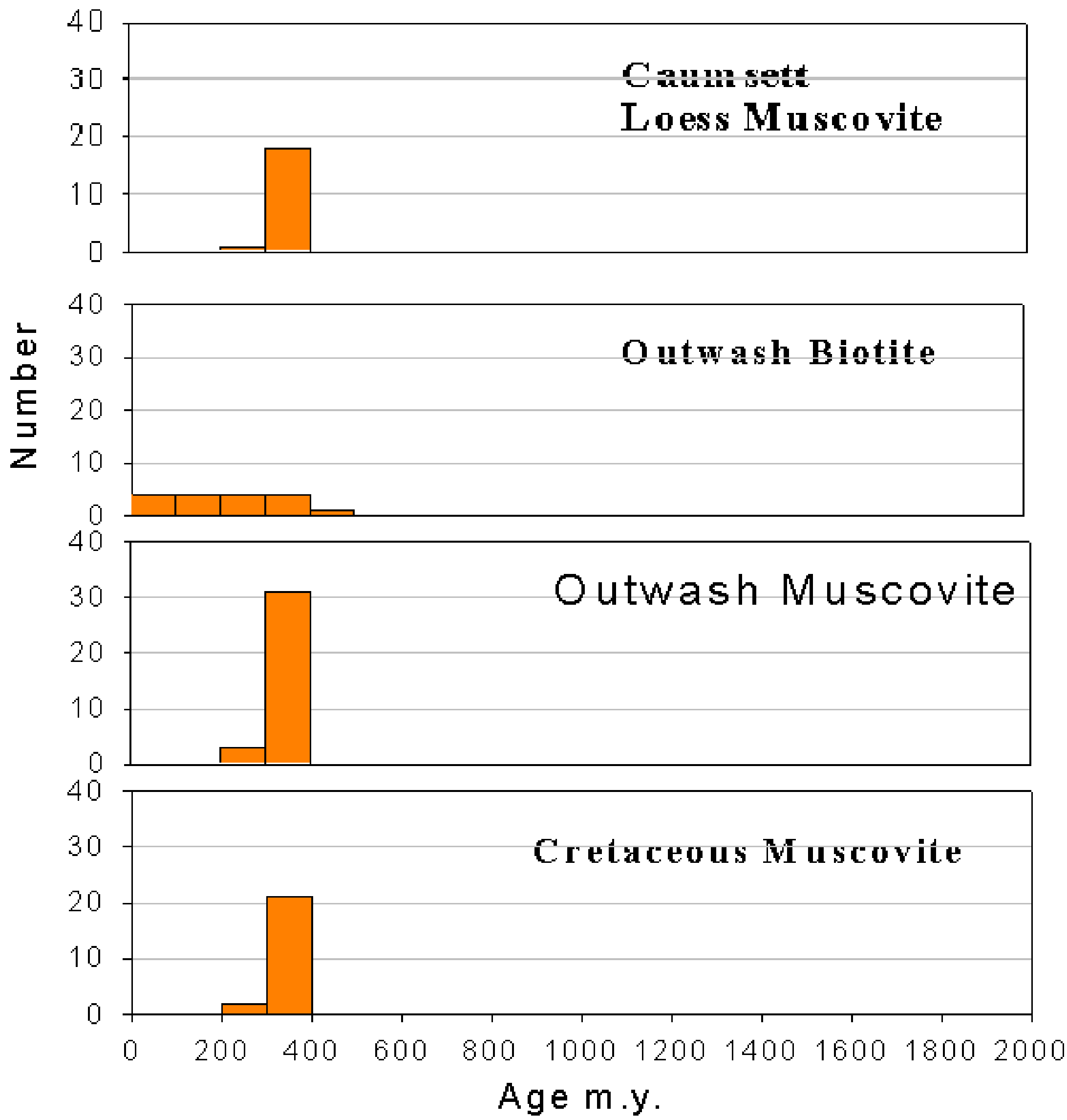

Figure 2. Mica ages from Caumsett State Park

Ar-Ar ages of single grains of muscovite from Cretaceous sand range from 275 to 400 Ma (Figure 2). All of the muscovite ages can be related to local sources to the north of Caumsett park in Connecticut (Figure 1), corresponding to a local derivation from a highly weathered basement. We also found that the quartz grains are angular, which also supports a local derivation of Cretaceous sand.

Muscovite from glacial sand has a similar age distribution ~~with~~ to those from Cretaceous sand: all ages are between 200 Ma and 400 Ma, with the majority between 300 Ma and 350 Ma (Figure 2). This result is expected because a large proportion of the glacial sediment may be Cretaceous sediment that was redeposited by the glacier. Comparing mica ages from glacier sand and Cretaceous sand with a 25 Ma group, shown in Figure 3, we see that the glacier sand has more 300 to 325 Ma muscovite ages, while muscovite from the Cretaceous sand has more 325 to 350 Ma ages.

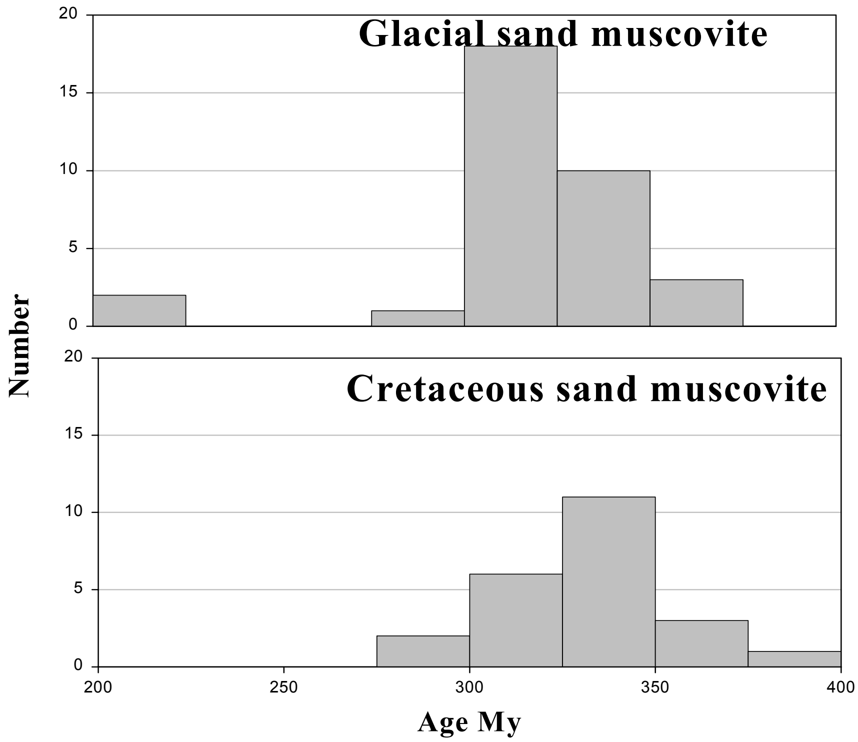

Figure 3. Muscovite from Cretaceous and Glacial sand ofCaumsett State Park by 25 Ma histogram

Biotite from the glacial sand gives a range of ages from 60 Ma to 500 Ma with no apparent mode (Figure 2). The biotite age distribution is broader from that of muscovite for two reasons:

1) the biotite grains are derived from bedrock and are from the glacial outwash because there is no biotite in Cretaceous sediments;

2) weathering may be responsible for biotite ages younger than 200 Ma.

Biotite may be weathering in both basement rock and after loess deposition. Hammerschmidt and Vonengelhardt (1995) found that partially weathered biotite from bedrock tends to give younger Ar/Ar ages. Basement underlying the Cretaceous sediment is weathered to a depth of 30 to 50 m. The present bedrock exposed in Connecticut is relatively unweathered. Thus, the glacier must have removed much of this weathered rock containing biotite. Blum and Erel (1997) found that the biotite weathers rapidly in a soil environment during the first 20 thousand years based on Rb/Sr isotope systematics of biotite from soils developed on terminal moraines. So, we are suspicious that at least some of the young ages may be due to the weathering.

Muscovite ages from Caumsett loess resemble those in glacial sand (Figure 2). None of the biotite grain gave reliable ages.

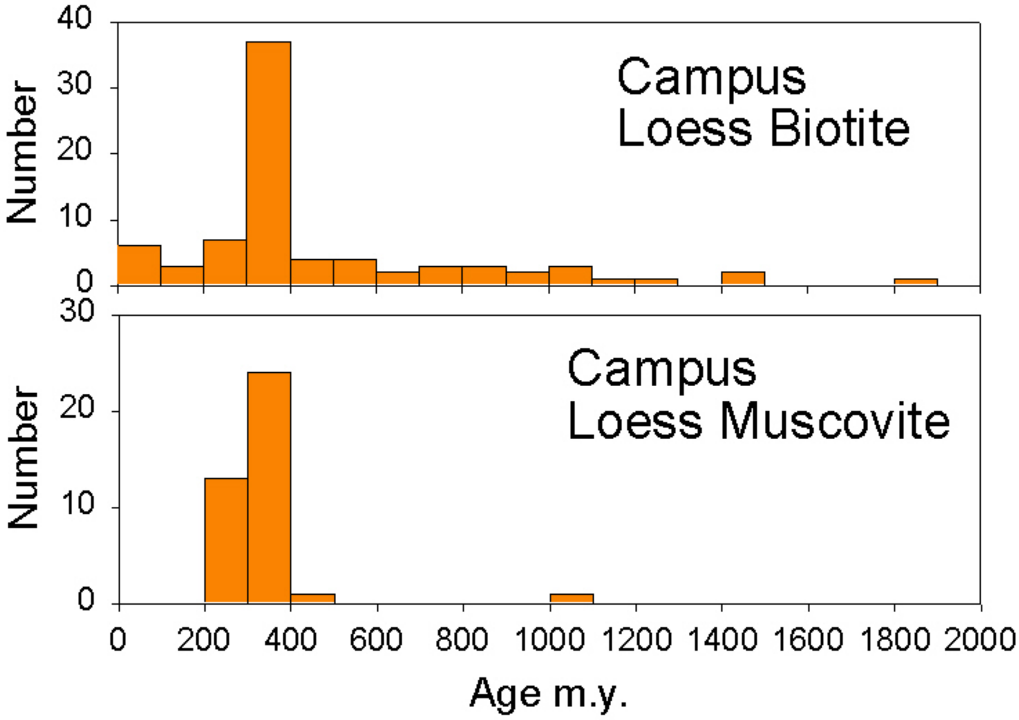

Figure 4. Muscovite and biotite of campus loess

Muscovite from the loess on the Stony Brook campus has a mode between 300 to 400 Ma (Figure 4), as does the muscovite from the loess, glacial sand and Cretaceous sand from Caumsett State ark. However, two differences are observed. First, there is a larger percentage of muscovite ages between 250 and 300 Ma on campus than at Caumsett. The higher percent of Avalonian muscovite may be the result of bedrock type changes in Connecticut to the north of the two sample sites, consistent with the Avalonian bedrock character found by Pacholik and Hanson (2001). Avalonian muscovite might also be carried by anticyclone winds from the east of sample site. However, the possibility of an eastern source is low because the muscovite age distribution in Caumsett Park is very similar to the age distribution of Caumsett Park glacial outwash. If we knew the age distribution of the muscovite of glacial sediment to the north of Stony Brook Campus in the Long Island Sound, we could evaluate the data better. Second, three muscovite grains give ages of 436, 509, and 1002 Ma. The 436 and 509 Ma muscovite may come from rocks affected by the Taconian orogeny in western Connecticut or Massachusetts and eastern New York. The 1002 Ma muscovite can only come from the west or northwest of these areas because muscovite at or east of the highlands was reset to younger ages.

Biotite ages of loess on the Stony Brook campus range from 70 to 1800 Ma (Figure 4). The mode between 200 to 400 Ma suggests local sources to the north in Connecticuit. The majority of the biotite might come from the drained glacial lake bottom.

Some biotite grains from glacial sand are also younger than 200 Ma. Some of these younger ages may due to alteration by weathering, but some of them may be giving the provenance age. Still, no evidence of an eastern source suggestive of glacial anticyclone was found.

Biotite that gives ages from 400 to 900 Ma may be mainly related to Greenville terrane. Those ages between 400 and 700 Ma are consistent with biotite ages found in Hudson Highlands, while those between 700 and 900 Ma could come from the New Jersey Highlands. The Grenville age biotite is consistent with the westerly prevailing wind.

Biotite Ar ages older than 900 Ma can only be found further west (data complied from National Geochronological and Natural Radioelement Databases, 1995). There is the possibility that some of the older ages could be the result of excess argon. Cosca *et al*, (1992) found that some chloritized biotite near the Grenville Front has excess argon and gives somewhat older ages. We are considering saving the mica remains from the Ar/Ar dating for Pb isotope analysis. This would give us one more provenance tool to evaluate the source. If a western US source is confirmed, the jet stream or the westerly prevailing winds would be ~~is~~ suggested for the transporting agent to this region.

Conclusion

Single grain mica Ar/Ar dating is a promising method for the provenance study of loess, especially if combined with other isotope methods. The method gives age for each individual grain. While muscovite ages are more robust, biotite does have the advantage of representing contemporaneous bedrock erosion by glaciers.

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