PROVENANCE IMPLICATIONS OF SAND COMPOSITION FROM LEBO AND LOWER TONGUE RIVER MEMBERS, FORT UNION FORMATION (PALEOCENE), SOUTHWESTERN WILLISTON BASIN

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Introduction:

Sand composition of the Lebo and lower Tongue River Members (both Paleocene) was studied from a site north of Route 12, 25 miles east of Miles City. These data were compared with sands of the Lebo Member (Paleocene) and Hell Creek Formation (Late Cretaceous) south of Route 12 (Sloan, 1988), and also with strata of Lebo age in North Dakota where sand composition from the Ludlow and Tongue River Members has been studied by Velbel (1988a, 1988b). These three areas were analysed in my senior thesis (Wong, 1988) to decide whether tectonic setting (model of Dickinson and Suczek, 1979) or climate (model of Suttner, Basu, and Mack, 1981) most influenced sand composition.

This paper is more speculative. The regional implications of the differences in provenance of the stratigraphic units in the three study areas is examined because compositional changes ought to indicate the time when unroofing of plutonic and metamorphic rocks occurred. Previous literature shows the initiation of block mountains in the younger part of the Early Paleocene (Torrejonian). Once formed, they are thought to continue to be actively uplifted through the remainder of the Paleocene (RMAG, 1972, Figure 53, p. 227 and Figure 3, p. 237; Cherven and Jacob, 1985, figs 25 and 25B-H). The Bighorn Mountains and Black Hills are the nearest block mountains to the study area, and are therefore likely contenders sand sources, although other, more distant sources are possible. Neither the Bighorns nor the Black Hills were thought to have contributed sediment during the latest Cretaceous or the earliest part of the Paleocene (Puercan). Evidence in this paper implies that there was a pulse of the the Laramide Orogeny earlier (latest Maestrichtian) than previously thought, but that pulse died down and was renewed again after the Tiffanian stage.

The stratigraphic units studied are primarily the Lebo Member (Montana) and the Ludlow Member (North Dakota). The Tongue River Member which overlies both these units in the two states was also studied. All three members are Paleocene in age; upper Ludlow is the same age as Lebo and the boundary between the Lebo or Ludlow and the overlying Tongue River Member is reputedly a time-line throughout the western Williston Basin (Bluemle et al., 1981). The stratigraphic units reported here are of thus comparable age so that changes in sand composition should reflect some influence of source-area changes.

Results:

Both the Lebo and Tongue River Members consist of fine- to very fine-grained unconsolidated sand, mud, carbonaceous shale and lignitic coal. The Lebo Member locally shows medium-grained sand within channelbelt deposits. Lebo Member is characterized by smectite-dominated clay minerals that occur in the muds and as matrix in the sands (see Hayden report, this volume). Tongue River Member has essentially no smecitite clay (Belt et al., 1985; Belt and Rockwell, in press). Thus the sands from the early Paleocene strata in the district are solidified by smectite (Lebo case) or are entirely friable (Tongue River case) due to the dominance of kaolinite and illite.

Considering both Lebo and Tongue River Members of Montana together, point counts revealed a predominant composition of mono- and polycrystalline quartz (40-50lithic fragments (45-55cases of embayed volcanic quartz, quartz with recycled overgrowths, and brown chert. Both weathered and fresh feldspars are seen; varieties include microcline and perthite. Potassium feldspar is dominant over plagioclase. Major lithic fragments consist of limeclasts, shale-siltstone fragments, and quartz-mica aggregates. Minor lithic constituents include quartz-mica tectonites, mica, volcanic lithics, and indeterminate lithic fragments. Trace constituents include polycrystalline mica (metamorphic lithic?) and glauconite.

All constituents were plotted on various Dickinson-style ternary diagrams (Dickinson and Suczek, 1979; Dickinson et al., 1983). Figure 1 indicates some of these plots. They clearly show differences between the two formations in the three areas.

The constituents studied suggest significant contributions from extrabasinal sources, including Meso-

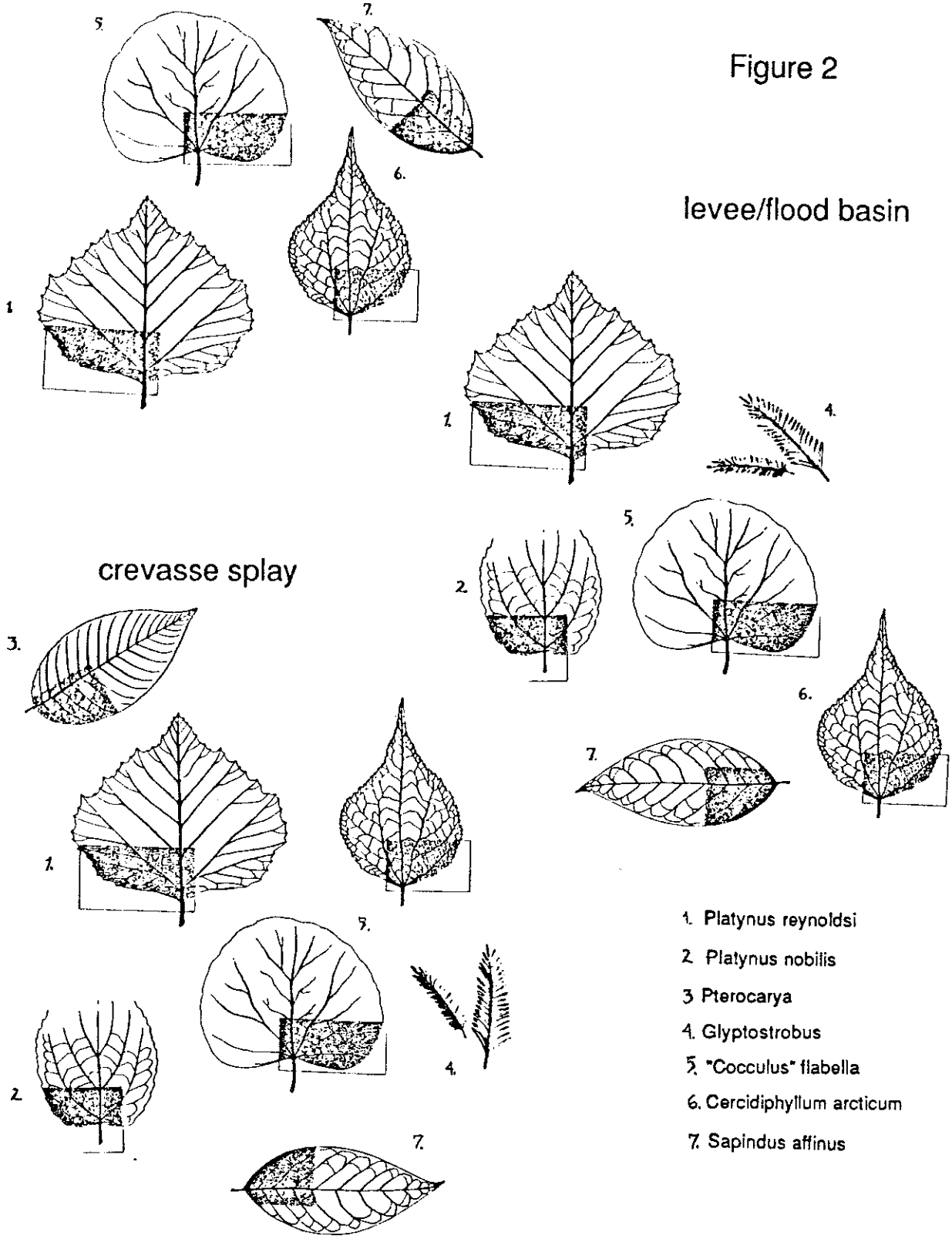
channel
levee/flood basin
crevasse splay
1. Platynus reynoldsi
2. Platynus nobilis
3 Pterocarya
4. Glyptostrobus
5. "Cocculus" flabella
6. Cercidiphyllum arcticum
7. Sapindus affinus

Figure 2

zoic and Paleozoic sedimentary rocks (stripping of basement cover during source uplift) and Precambrian granitic basement (exposed during unroofing). The intrabasinal sources (shale lithics, carbonates) are also significant, but subordinate to the extra-basinal contribution of sedimentary rock lithic fragments. The volcanic lithics form the smallest contribution, and their virtual absence differs considerably from the conclusions of Cherven and Jacob (1985, Figure 21).

Three sets of ternary diagrams were compared (Figure 1) : (a) my area, termed the Pine Hills (Lebo and Tongue River Members); (b) Laura Sloan's (1988) area, termed Mizpah (Lebo Member), and (c) the North Dakota area (Ludlow and Tongue River Members) of Mike Velbel (1988a, 1988b). T-tests were run on the Cyber system at the University of Minnesota Computing Center, using the SPSS software package. Compositional variation between the Lebo in the two Montana sites were compared with the Ludlow from North Dakota. The two Lebo sites in Montana were found to show little difference in composition. The variation seen might be due to operator differences or the fact that the Mizpah site included the entire Lebo section whereas the Pine Hills site included only the upper few tens of meters of the Lebo.

The statistical difference between the Lebo Member in Montana and the Ludlow Member of North Dakota is significant, however. Pine Hills sandstones are 13higher in feldspars than the Ludlow in North Dakota. North Dakota samples are 25area Lebo also has higher quartz and feldspar percentages than is found in the Ludlow of North Dakota. Mizpah and Pine Hills samples are close enough in feldspar content that it is highly unlikely that there would be any significant source-area variation. North Dakota feldspars show a significantly higher percentage of weathered grains than Montana feldspars.

In southwestern North Dakota, the Tongue River Member does not differ significantly from the Ludlow in composition (Velbel, 1988b), and the Tongue River Member in both eastern Montana and in North Dakota are nearly identical in composition. The Tongue River shows significantly less feldspar than the Lebo in Montana (Figure 1). Thus the Tongue River in two states does not show as much feldspar as the Lebo in eastern Montana.

Discussion:

The carbonate and shale lithic grains are difficult to assign to either intra- or extra-basinal origin on the basis of the present information. Structures of the shale lithics suggest an intra-basinal origin, but further analysis needs to be done. Although direct evidence for recycled grains, such as rounded quartz overgrowths, siltstone lithics, and glauconite is relatively rare, a fairly large percent of all grains, could have been recycled from sedimentary rocks. The problem becomes what grains are evidence of first-cycle origin. The best candidates for first-cycle grains in the Lebo are, in the order of certainty: (1) unweathered feldspars, (2) volcanic lithics, (3) quartz-mica lithics (probably high-grade metamorphic source). Perthite suggests granitic plutons. The feldspars and volcanic lithics could have come from volcanics near the surface; feldspars and quartz-mica lithics could have came from unroofed basement rocks. Because unweathered microcline is present in nearly every thinsection, some basement ought to have been exposed.

Because the Lebo contains up to 20are considered first-cycle, the unroofing of basement should have been near the site of deposition. This would have happened during Torrejonian time, in agreement with Cherven and Jacob (1985) who show both the Bighorns and Black Hills contributing sediment.

Could some of the feldspars as well as the volcanics have come from the Black Hills? Early Paleocene volcanism has been recently reported from the Black Hills (Lisenbee 1985). However, because volcanic lithics are so rare, and because most feldspars are too large to have been blown by the wind, volcanics must have come from farther west of the Pine Hills and Mizpah field areas. It would be difficult to have sand-sized feldspar derived from the Black Hills. Those mountains lie 150 miles southeast of the study area, and the paleocurrent directions in the Lebo stream channels carrying the sand flowed east to northeast (Belt and Rockwell, in press; Metcalf report, this volume). The Bighorns, on the other hand become a likely, though perhaps not the only, source for the sands of the Lebo Member in both the Pine Hills and the Mizpah districts.

The Tongue River Member (in Montana as well as North Dakota) contains so much less feldspar than the Lebo and the Ludlow, that any source area was probably very subdued topographically at this time. This conclusion conforms with the sedimentological evidence previously presented by Belt and Rockwell (in press) and for North Dakota by Belt and others (1984). They propose a vast alluvial plain with high water table and anastomosed rivers in both states. Rivers flowed in a directions that vary from district to district. This concept also fits the low pH likely to have occurred in Tongue River time. Ponded-water

conditions were common. Smectite leaches to kaolinite under those conditions, and smectite is notably absent in Tongue River strata (Belt et al., 1985).

Hence Tongue River was a time of low-lying alluvial plains with source areas shedding little sediment, a scene that differs from the paleogeography of Cherven and Jacob (1985). Finally, the data from the Hell Creek Formation (late Cretaceous) relates to this study. Laura Sloan (1988) compared the Lebo in the Mizpah district with the Hell Creek near Ekalaka, Montana. She showed the same high concentration of feldspar in both. This suggests that the a nearby source area was also unroofed at that time, and because the paleocurrents in Hell Creek at that locality trend southeast (Murphy and Belt, in press), directly towards the Black Hills, it is unlikely the Black Hills were a source area then. Was it again the Bighorns, or some source area to the west or northwest? Further research on sand composition in all of these strata are needed to resolve these and many other issues.

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FIGURE 1

Lebo and Tongue River sands of Pine Hills all plot within Dickinson's (1970, 1979, 1983) "recycled orogen" field. North Dakota sands are richest in lithic fragments, Pine Hills are highest in feldspar, while Mizpah are intermediate.

QFL
Q = all Qm and Qp
F = all feldspars
L = all lithic fragments

North Dakota sands fall in the "recycled orogen" field. Pine Hills Tongue River sandstones are also "recycled orogen" while the feldspathic Lebo sands plot within the magmatic arc field of Dickinson (1970, 1979, 1983). Mizpah samples fall halfway between North Dakota and Pine Hills.

QmFLt
Qm = Monocrystalline quartz
F = all feldspars
Lt = all lithic fragments and Qp