# The sieve lobe paradigm: Observations of active deposition

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## ABSTRACT

**Sieve deposits were once considered to be one of the building blocks in alluvial fan stratigraphy. Later reinterpretation of sieve lobes as debris-flow deposits, favored because no visual records of active sieve deposition had been reported, undermined their significance, divided opinions, and left this issue unresolved. Here I document active deposition of sieve lobes in natural settings, in support of the original model. Sieve deposition can easily occur in natural settings such as proglacial outwash fans, small arid alluvial fans, or perennial streams when there is a scarcity of fine material, significant bedload, high slope, permeable ground, and discharges moderate enough to allow infiltration. The only hydrodynamic requirement for sieve deposition is a high rate of water loss promoted by permeable bed sediments. Under some circumstances alluvial fans can be built almost entirely of sieve deposits, as shown here. One effect of the rapid extraction of water is the creation of sigmoidal fan profiles. A gradation from sieve deposition to sheetflood occurs if sediment becomes progressively less permeable or if water flow increases, overcoming bed permeability. Sieve deposition is a universal depositional process based simply on infiltration, and it explains matrix-poor clast-supported gravels, while alternative hypotheses, such as matrix winnowing of debris flows used to dispute the sieve model, still need to be proven by observations in nature.**

## INTRODUCTION

The term "sieve deposition" has disappeared from the scientific literature of the past 10 yr due to a successful denial of this model, formally defined by Hooke (1967) after study and interpretation of modern natural deposits, based on an infiltration-forced accumulation concept that dates from 100 yr ago (Trowbridge, 1911, p. 738). Sieve lobes were originally interpreted to be produced by a loss of stream transport capacity caused by infiltration. As a result, a gravelly clast-supported, matrix-free, highly permeable, moderately sorted, lobe-shaped deposit was produced. This process was not observed in action in nature, but was replicated experimentally by Hooke (1967) and then by Milana and Tietze (2002).

Since 1992, this depositional model was been rejected in several papers by Blair and McPherson (1992, 1993, 1994, 1995), who "…recommend that the idea of 'sieve lobes' be viewed as hypothetical" (Blair and McPherson, 1993, p. 565). As no observations of natural active sieve lobes have been documented, they introduced an alternative interpretation of sieve lobes, creating a controversial mechanism requiring, first, deposition of a matrix-rich debris flow and subsequently, winnowing of the matrix by water flows. The evolution of a matrix-rich surface deposit into a matrix-free one was not observed, and is contrary to what most studies show, as alluvial surfaces tend to gain fine-grained material after deposition both by eolian dust addition and pedogenesis (cf. McFadden et al., 1987; Hooke, 1993).

Even though neither hypothesis was supported by real time observations in nature, after the denial of the sieve deposition model there has been almost no further mention of it in the alluvial fan literature.

In this contribution I show three natural examples of active sieve deposition, describe the processes observed, and discuss their appearance in outcrop and their potential for dominating entire alluvial fans, resulting in a sigmoidal slope profile due to the total decay of transport efficiency. This unique documentation of active natural sieve deposition concurs well with previous laboratory and field data, but suggests that some assumptions were not correct, i.e., their tendency to be formed at fan knickpoints or their formation by stream blockage. Sieve deposition is considered here to be a key depositional process in coarse alluvial settings (Hooke, 1967) and part of a continuum of processes with sheetfloods, controlled by factors such as discharge and sediment supply.

## ACTIVE PROCESS

Active sieve deposition was recorded in three different environments: on a fan built by a proglacial stream during a melt peak, on a small gravelly fan built by a rainstorm-induced flood over a dirt road, and on a steep permanent stream in a gorge.

### Example 1

Example 1 (31°59′S, 70°10′W) involves several simultaneously active sieve lobes, activated by daily melt in a proglacial stream. The water was quite clear, with few fines in transport. Sieve deposition was not caused by a slope break or a boulder jam, mentioned as possible causes of initiation (Hooke, 1967; Nemec and Postma, 1995). The splitting of the stream into distributaries caused the discharge decrease needed to allow formation of several sieve lobes simultaneously (Fig. 1). Active sieve lobes, made of medium gravel, were 0.2–0.5 m high. The basic depositional mechanism was bedload dumping due to total decay of stream shear stress. Initial lobe deposition triggers a double negative-feedback mechanism, forcing more sedimentation due to (1) progressive loss of more water to the ground as the lobe enlarges, and (2) reduction in local depositional slope by lobe growth, forcing backfilling. The loss of stream capacity causes finer material to accumulate vertically and upslope in the upper plain and tail of the lobe (cf. Hooke, 1967). The lobe grows in a self-similar fashion (progradation and backstepping), backfilling the channel that was delivering the water and sediments until avulsion occurs. Avulsion occurred (spilling over levees) by the effect of transport capacity reduction due to lobe growth in two ways: (1) deposition of finer material, reducing bed permeability forcing water level to rise, and (2) distributary channel backfilling.

Due to infiltration, stream discharge decays progressively as it enters the lobe area until it

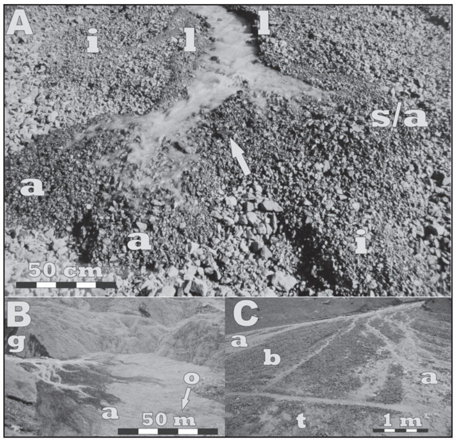

**Figure 1. Examples 1 and 2 (see text) of active sieve lobes. Abbreviations: a—active lobes, i—inactive lobes, s/a—semiactive lobes, l—levees. A: 30-cm-high sieve lobe accumulating sediment at end of infiltrating stream on proglacial fan (shown in B), which is 100 m in total length. Note finer sediment upstream from lobe front. B: Proglacial fan: g—glacier front, o—older lobes. C: Sieve lobe regraded into sheetflood lobe (b) as flood increased discharge and supply changed. Note car and foot tracks (t) filled by water, showing high permeability and water table at surface. Picture is of maximum discharge.**

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dies at the lobe edge. Thus, stream blockage within the lobe does not cause lobe avulsion, but may cause a miniavulsion, repositioning a sublobe, as explained for example 3. Lobe growth and avulsion occur slowly, not catastrophically, as indicated by partially buried plants (see following). Example 1 shows sieve lobes formed by steady discharges of ~1 $m^3$/s in distributary channels. This explains why they are sometimes related to intersection points, as this is where flow emerges out of an incised channel and becomes free to divide.

### Example 2

Example 2 (31°53´23´´S, 69°41´18´´W) demonstrates the transformation from sieve to sheetflood deposition as the initial lobe (~0.2 m high) received more water during a rising flood. This was observed on a small fan built by accumulation over a dirt road (Fig. 1C). An increase in discharge caused an increase of sand transport and pooling at the lobe front, raising the water table. The lobe was transformed into diamond-shaped bars as the original sheet-like distributary channel expanded over the entire lobe surface. This occurred because the lobe became saturated and the infiltration capacity was overwhelmed. The lobe front was unstable so irregular retrograde erosion occurred, followed by dissection, widening of the incision, reworking, and finally smoothing of the lobe as it was transformed into a sheet-flow complex composed of flat diamond-shaped bars (Fig. 1C).

### Example 3

Example 3 (31°36´S, 69°05´W) is an ~3-m-thick sieve lobe produced at Agua Clara ("clear water"), a permanent stream within a gorge, proving that the process is not restricted to fans. This steep creek (slope 16.2°) was visited before and after the rainy season, when lobes were active (Figs. 2A and 2B) and receiving a large supply of clean colluvial gravel. Due to the gravel obstruction, the stream (discharge ~50 L/s) infiltrates and reappears several times, and wherever it infiltrates sieve lobes are present.

The active lobe front suggested three growth stages: a dry lower third, predating the season's lobe growth (Fig. 2A); a moderately wet middle third; and a wet active upper third (Fig. 2B). A sharp slope break (lobe edge) separated the front from the upper plain. Active deposition was in two simultaneous sublobes, each being ~5% of the total lobe-front perimeter. As distributary streams reached the sublobe edge with clear water and minor bedload, the sublobe moved slowly but consistently, producing progradation of the entire lobe. The continuous input of fine to medium gravel to the lobe edge caused frequent minor avalanches along the wet front. Less frequent was the development of a steep channel using an avalanche scar, allowing sediment to advance further from the wet front and creating a protruding sublobe. Sublobes were also occasionally deposited en masse by fluidized grain flows cascading down a lobe front. Sublobes were formed by two main cycles (Figs. 2D and 2E), i.e., by superposition of gravel sheets and minor avalanching and by backstepping of gravel layers from the channel toe upward. Sublobe morphology was only observed on fresh wet deposits. On dry deposits it was smoothed. Deliberate obstruction of the distributary streams to enhance sublobe progradation did not produce significant changes, suggesting that the lobe dynamic is based on slow but permanent sediment input and not affected by moderate discharge changes.

## SIEVE LOBE–DOMINATED FANS

Two examples of sieve lobe–dominated fans are given, with the objective of showing (1) that entire fans can be built by sieve deposition; (2) how and why these fans differ from others, (3) how sieve lobes are distributed in a fan; (4) that they are a common element in incised channels being easy mistaken for bars; and (5) how modern aggradation occurs.

### Alluvial Fan Example 1

Alluvial fan example 1 is a small fan with sieve lobe complexes that completely filled an incised channel on a fan and progradationally spread out on the fan surface (Fig. 3A). Sediment from this range is largely gravel with little

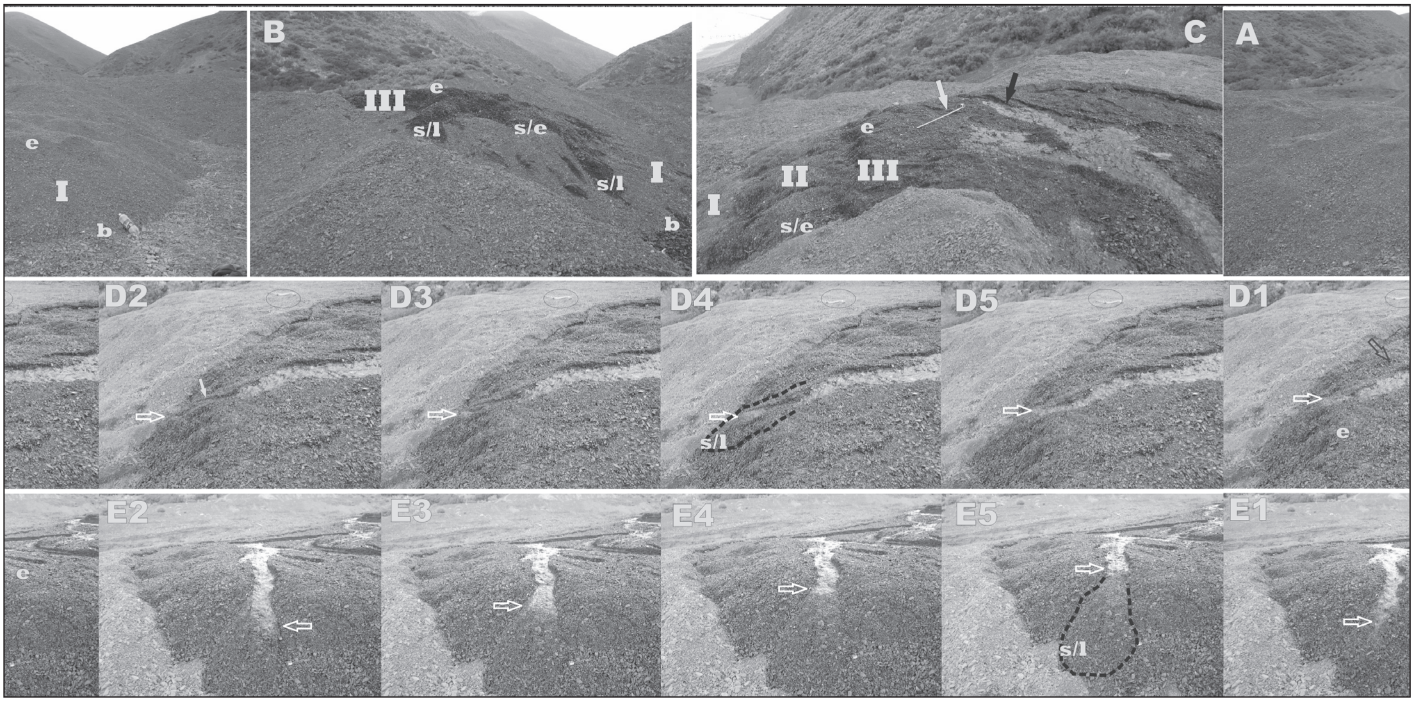

**Figure 2. Example 3 of active sieve lobe. Abbreviations: e—lobe edge, s/e—subedge (older), s/l—sublobe, b—lobe base; I, II, III—observed stages of lobe growth. A: Preview of active lobe before rainy season (December). B: Same view in April. C: View of upper lobe plain (tape extended 1 m, white arrow) and distributaries. D: Photo sequence (1–5) spanning ~30 s to show dynamic of sublobe growth by channeling and backstepping. E: As in D (30 s), showing growth by avalanching and sheet flow on head of distributary channel (black arrow in C).**

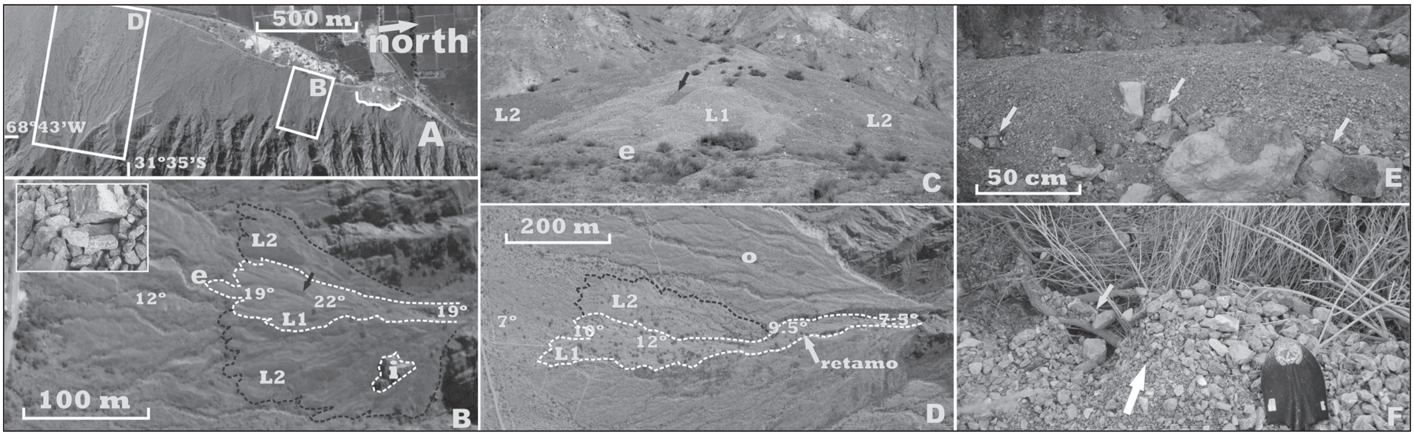

**Figure 3. A: Location of two sieve-dominated fans (b, d) described in text; white line is borrow pit exposure of Fig. 4). B, C: Image and ground view of smaller fan showing younger (L1) and older (L2) lobe complexes. Black arrows show patch of L2. Lobes grow up and downstream, drowning previously incised fan and mountain front (i—isolated outcrop). Inset in B shows perfectly clean and angular debris of L1, located in (e). D: Image of larger fan showing incised channel, and two recent sieve lobe complexes (L1, L2); o is older lobe. Angles indicate surface slope. E: Sieve lobe at upper incised channel drowning bouldery floor (arrows). F: Views of bush (retamo) located in D that effectively stopped advancing lobe. White arrow for flow sense. Note gravel on branches left by lobe-front advance and/or reworking and delicate branches that acted as sieves.**

sand and mud. This, coupled with low discharge and high slopes, creates a perfect scenario for sieve deposition. Formation of several lobes during the past decades has regraded the upper part of the fan, creating a slope break between this and the older incised fan (Fig. 3B). Gravels in the younger sieve complex are fresh and vegetation is absent, while those in the older lobes are varnished, although less so than on the older overlapped fan. Of these three fan-building stages, the last two were entirely produced by sieve lobes prograding over the older fan. Depositional processes on the oldest fan are not clear due to postdepositional alteration, mainly pedogenesis, vegetation, and fan toe gullying. Several pits showed that gravels on older surfaces have a fine matrix, suggesting that dust is actively deposited and infiltrated over the entire fan after alluvial deposition (cf. Hooke, 1993). The active fan has a sigmoidal profile with slopes of 19° at the head, then 22°, then 19° at the toe of the sieve complex, and finally 12° on the old fan. This fan shows that sieve lobe complexes grow in a self-similar fashion, i.e., backfilling the fan head climbing onto the mountain front and prograding over the older fan.

### Alluvial Fan Example 2

Alluvial fan example 2 is a larger fan, proximally incised with a well-defined intersection point, a sigmoidal profile, and slopes of 9° at the head, then 12°, 10° at the sieve complex toe, and 7.5° over the older fan. A survey of the recently deposited gravel in the incised stream and an associated depositional lobe below the intersection point (L1, Fig. 3C) suggests that it was formed by sieve deposition and associated facies (channels, levees). The last activation of this sieve lobe complex, which is composed of hundreds of sieve lobes, occurred during the last rains as bushes, partially buried by sieve lobes, were still green. A single bush could contribute to sieving (Fig. 3D), retaining clasts of 10 cm in its delicate branches. Less dense bushes did not affect sieving and were simply buried without any branch damage, suggesting ~1 m of vertical accumulation within the incised channel in a few decades. Sieve lobes present within the channel might be mistaken for braid bars but for their lobate morphology, their sediment grain size contrasting with coarser channel sediments, sediment sorting, and absence of fines. All sieve deposition took place without destroying any bushes, but rather burying them.

## STRATIGRAPHIC PRODUCT

After alluvial deposition, the original characteristics may be altered by weathering and other processes. The high surface roughness of sieve deposits acts as a trap for desert dust, subsequently washed downward into pore space by rain. Thus, it may be difficult to find the original matrix-free deposit; usually the bases of thick lobes remain clean while upper parts tend to be occluded by infiltrated fines. Inspection of artificial and natural exposures in gullies showed also that in some cases the latter passed laterally, within 2 m, into matrix-free deposits. This is ascribed to (1) early postdepositional dust trapping, (2) mud supplied by the gully's stream, and (3) dust trapping after incision. Thus, in modern alluvial deposits, natural exposures have to be analyzed with care, interstitial mud may be of diverse origin, and infiltrated mud is very common.

A gravel borrow pit offered a longitudinal exposure where sieve lobes were identified by matrix-free gravel in convex-upward, downstream-limited sediment bodies (Fig. 4). Two lobe fronts could be identified, related updip to gravel sheets produced on the upper plain of the lobe during growth. The two lobe fronts, made of coarse, reasonably sorted, sand-depleted

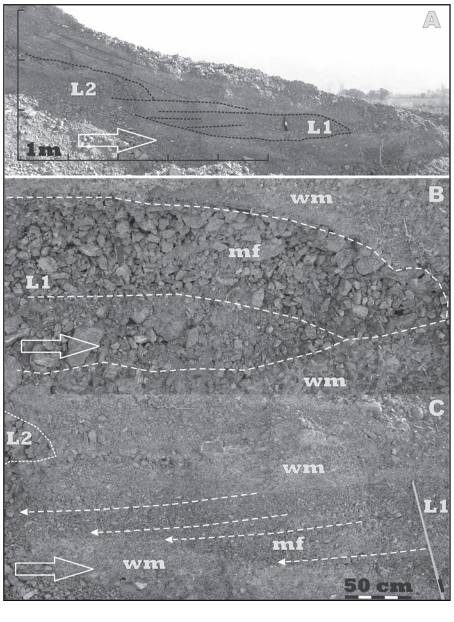

**Figure 4. Exposure of sieve lobe deposits. White arrow indicates sense of flow. A: View of two sieve lobes (L1 and L2) along depositional slope showing their convex-upward shape (scale divisions are 1 m; bottle for scale). B: Detail of L1 front, showing gravel with matrix (wm) and matrix free (mf). C: Detail of L1 tread showing onlap and finer material.**

gravel, did not show any layering or fabric, although crude foreset layering was observed in some modern lobe cuts. A meter upslope of the front, layering and tractive fabric was present in a much finer grained lobe tail, suggesting dilute sheet-flow action that died at the lobe front. Lobe-tail layers onlap a previous surface with higher mud content (Fig. 4C; cf. Hooke, 1967). Both lobes are capped by a dirtier and well-stratified clast-supported deposit, suggesting that sheet flow followed with long intervals of exposure. Lobe-front exposures are rare, as they are volumetrically small within the observed modern sieve lobe complexes.

The transverse exposure shows a lack of laterally persistent beds, with conspicuous wedges of clast-supported, matrix-free, moderately sorted, coarse-grained gravel. Almost 60% of the gravels exposed were interpreted to be sieve lobes and associated facies, yielding a model cycle that (1) starts with deposition over a nonerosive irregular base without lags, (2) follows with basal matrix-free gravel that is coarser and moderately sorted, and that (3) crudely fines upward with (4) an increase in matrix content, forming laterally restricted cycles. These units alternate with less-well-sorted, clast-supported, matrix-rich, bouldery gravels that suggest the action of small debris flows filling up the irregular topography of sieve lobes.

## CONCLUSIONS

The data presented herein suggest that clast-supported, matrix-free alluvial gravel is not deposited en masse. Almost all sedimentation witnessed was produced by deposition of single clasts, as a result of bed-shear stress decay. Observations suggest that sieve deposition is a universal process, and occurs at different scales, from thin sheets of a few centimeters to lobes 2–3 m high, although it is still not possible to define what controls lobe size. The only requirement for sieve lobe generation is an unsaturated, permeable ground associated with a low supply of fines to prevent pore occlusion and allow infiltration, a requisite that may occur worldwide. Present observations agree with Nemec and Postma (1995, p. 541), who wrote that the sieve deposition "…is not an alternative, specific process of sediment transport but a particular mode of bedload deposition." There are also no contradictions between laboratory and natural realms based on scale differences, as flow in natural fans splits, and an infiltrating distributary stream is replicable at laboratory scale.

Sieve deposition is not derived from, but may be aided by, an intersection point, boulder jamming or blocking brush, as the mechanism is a simple loss of flow shear stress due to infiltration, which occurs independently. Sieve lobes formed within channels can be mistaken for bars, but their characteristics are different as they (1) grow nonerosively in a self-similar fashion, downlapping and onlapping, (2) fine vertically and upstream, (3) show better sorting than neighboring alluvial deposits, and (4) show a change from disorganized fabric at the front to a tractive fabric at the tail. The associated channels and levees share characteristics with low-sediment concentration, high-slope, bedload-rich stream deposits.

Sieve deposition may build entire fans that commonly have sigmoidal profiles resulting from the complete decay of the transport capacity due to infiltration. Even large floods could infiltrate completely due to downstream bifurcation, as shown here. Given these facts, it is suggested that the twofold classification of fans that has become so popular (debris flow–dominated and sheetflood dominated; cf. Blair and McPherson, 1994) should be abandoned, as it was based on the denial of a natural depositional process well documented here. Sieve deposition suggests instead that the winnowed-matrix hypothesis used to deny sieving should be abandoned until it can be proven, as it is unlikely to occur in arid alluvial settings, given postdepositional processes.

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