Debris flows' effect on Holocene alluvial fan formation and record of environmental instability, Corral Creek, Park County, Wyoming

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INTRODUCTION

The traditional alluvial fan facies model considers stream deposition to be an important influence on fan construction. New work suggests that traditional models do not put enough emphasis on the influence of debris flows. The purpose of this study was to gauge the relative influence of stream versus debris flow deposition on the formation of the Corral Creek fan. A secondary goal was to use fan facies to determine the record of the area's environmental instability.

Background. Recently workers have debated the worth of current fan facies models. For example, Blair and McPherson (1992-1995) have stated that many facies models have inaccurately interpreted fan sediments as stream deposits, misjudged the effect of climate change on deposition, and incorrectly de-emphasized the influence of debris flow deposition on fan construction. In response, some researchers have questioned the accuracy of Blair and McPherson's model of debris-flow-dominated fans (Hooke, 1993; Nemec and Postma, 1995). It is necessary to examine fans in the field in light of these issues, so we can build a more correct model.

Geography. Corral Creek heads near Windy Mountain and flows north to join Clarks Fork of the Yellowstone River near Cathedral Cliffs, in the cool, semi-arid, mountainous Clarks Fork valley near the northeast border of Yellowstone National Park, in northwest Wyoming. Its upper drainage (upstream of the fan) is about 4 km^2 in area. It has slopes greater than 25° for much of its area and a maximum basin relief of about 1000 m. The Clarks Fork valley was last glaciated about 13,000 BP (Pinedale glaciation), so the Clarks Fork ice up Corral Creek probably deglaciated at about the same time.

Above the fan head, the stream cascades down the carbonate cliff formers, and is confined for about 100 m in shale bedrock, slumped carbonate bedrock blocks, and colluvium before its flow becomes unconfined on the fan. The fan (about 1 km^2 in area) is bordered on the east by the Cathedral Cliffs colluvial apron, and on the west by the Oliver Gulch stream (see figure 1). High spring runoff rates, severe rain storms, and mass wasting that includes landslides, slumps, and debris flows, mobilizes a fan sediment supply of bedrock (Eocene volcanics, Paleozoic carbonates, Cambrian shales), colluvium, and glacial material.

METHODS

The extent of surface deposits on the fan was mapped from photographs and by pace and compass. The fan morphology was recorded with a radial profile and a cross fan profile, measured with pace, compass, and altimeter (accurate to within 0.2 m); the profile and cross section morphology of the active channel were recorded in the same way. Cobble sizes of surface deposits keyed to these profile and cross section lines were measured by point counts with a Gravilometer.

Stratigraphic sections exposed in natural channels were described in the upper, middle, and lower fan. Facies relationships along survey lines were described as well. Sediment samples were taken from the described deposits. Geochron Laboratories, Massachusetts, analyzed three samples for radiocarbon, and the ages were calibrated with CALIB rev3.0.3A (Pearson and Stuiver, 1993).

RESULTS

Sediment. Point counts of surface cobbles show that between 50-80% are carbonates, 10-20% of the cobbles are shales, and 10-30% are volcanics (although as much as 50% of the cobbles may be volcanics). It is not surprising that carbonates are in the majority, since most of the cobbles observed in the upper reaches of Corral Creek were carbonates, weathered from the exposed bedrock above. Shale cobbles quickly weather on the fan surface, so the point counts may underestimate the shale fraction of surface cobbles actually transported onto the fan.

Colluvium enters the transport system to the fan through overland flow, creep, and as sediment remobilized by minor streams from landslides and earth flows on the colluvial apron of Cathedral Cliffs. Fine grained sediment flood deposits along Clarks Fork. The meltwater channel extends upvalley across Gilbert Creek to Crazy Creek. A flood could have come from a subglacial lake high on the Beartooth Plateau southerly along the route of Gilbert and/or Crazy Creek, along the large ice-marginal meltwater channel, and finally into Clarks Fork.

Three cross-sections were surveyed across Clarks Fork and flood deposits. Paleoflood parameters were calculated using the Gauckler-Manning equation (Table 1). Paleodischarges are estimated to have been as high as 43 x 10^3 m^3/sec. There is much uncertainty with respect to each of the variables. The cross-section area does not accommodate eddies. The maximum height of flood deposits is in question. The slope was chosen for that of the present Clarks Fork because the flood deposits and terraces are not easily correlated. The roughness coefficient (0.1) was chosen from a table of various channel materials and configurations (Newson, 1994).

Flood Depth (m)	Slope	Roughness Coefficient	Discharge (1000 m^3/sec)	Velocity (m/s)
51	0.011	0.1	43	4.5
42	0.011	0.1	21	3.8
27	0.011	0.1	7	3.5

Table 1. Flood parameters for survey line C-C', using the Gauckler-Manning equation, $Q=AR^{2/3}S^{1/2}/n$ (Q = discharge in ft^3/sec, A = cross-sectional area in ft^2, R = hydraulic radius in ft, S = slope, n = Manning roughness coefficient) (Newson, 1994).

LAKE CREEK LINEAMENT

A lineament coincident with a mapped 1.8 km long fault cutting the Archean crystalline rock (Pierce and Nelson, 1971) is possible evidence for postglacial reactivation of the fault. The lineament goes through Lily Lake and strikes N 63° W. The lineament is most pronounced eastward from Lily Lake for 3.7 km, but may coincide with a meltwater channel as far as 4.7 km west of Lily Lake. East of Lake Creek, the lineament forms a 10-25 meter northeast facing scarp in till. Trees growing on the scarp exhibit curved trunks probably caused by creep of an over-steepened slope.

Minimum uplift for diversion of Lake Creek from old meltwater channels to its present course is only 1.5 m. These meltwater channels show miniature scabland topography. A reason for abandonment other than fault movement is unknown, but Lake, Muddy, and Beartooth Creeks all have segments which trend upvalley (abnormal for a glaciated area). Possible causes for late Quaternary fault movement include isostatic rebound upon deglaciation and the Yellowstone hot spot bow wave (Pierce and Morgan, 1992).

CONCLUSIONS

Ice flowed south into Clarks Fork valley from the Beartooth Plateau depositing many large till ridges, including till ramps, moraines, and possible drift drumlins. Although the moraines are likely to be left lateral, alternatives include terminal/recessional, interlobate, and medial. A radiocarbon age of 11,560 years for organic matter in the Corral Creek alluvial fan is the minimum date for deglaciation of the area. At some time during deglaciation one or more jökulhlaups occurred. A lineament near Lily Lake may be evidence for postglacial fault movement.

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from weathered carbonates, volcanics, shales, colluvium, and glacial drift is the probable source for the matrix of debris flows onto the fan.

Morphology. The Corral Creek fan has the concave up radial profile and the convex up cross fan profile that are typical of fan morphology (Blair and McPherson, 1994) (see figure 2). Slopes on the radial profile do not exceed 10°, average about 5° on the upper and middle fan, and decrease to 2° on the lower fan. Abandoned channels range from 0.4-1.2 m deep and up to 400 m long, with levees as much as 1 m high, 5 m wide, and 50 m long. At the head of the fan the relief between the bed of the stream channel and the top of the levees can be as much as 4 m. Abandoned channels incise the fan surface as far as 600 m down from the fan head (where a dirt road and drainage ditch cross the fan). Distributary scars extend 50 m farther down fan.

The most recent major depositional event constructed levees, and confined the stream between levees and colluvium on the western edge of the fan. Large (up to 1 m) boulders were deposited against logjams that built up against trees on the fan. The active stream flows in an aggradational channel, leaving adjacent and topographically lower channels abandoned.

Facies. (see figure 3) Debris flow deposits make up about 50% of the described deposits, and are unambiguously identified everywhere but in the lower fan. Also, debris flow deposits are present in the upper drainage trunk stream. These deposits are matrix supported, poorly sorted, rich in fines, with up to 20% clasts (usually less than 15 cm in diameter). Other kinds of deposits in the upper fan that form levees and terraces are mostly poorly sorted, clast supported in a coarse grained to medium grained sandy matrix, crudely imbricated, with subangular to subrounded clasts less than 15 cm diameter. Surface cobble sizes can range from 5 cm to 1 m diameter.

Stratigraphic sections recorded in abandoned channels in the middle to upper fan show debris flow deposits from 0.3-0.5 m thick. Probable stream deposits of well sorted gravel fills are observed as lenses in the channel walls. The sediments in some exposures contain coarsening upward sequences (about 1 m thick), while other sections are capped with 5-10 cm of matrix supported layers of fine sandy-silt with clasts from 1-5 cm in diameter.

Thin (2-5 cm thick), wavy, discontinuous organic rich layers are present in the middle to upper fan exposures, and a thick (about 10 cm) organic rich layer at 10 cm depth commonly is present in some exposures in the middle to upper fan. The deepest exposures of organic-rich layers are in the more stable middle fan, particularly in the natural channel that the Oliver Gulch stream has cut on the western side of the Corral Creek fan. Three layers (av. 10 cm thick, up to 30 cm of organic rich layers interbedded with silt) were recorded at depths of 0.2, 2.0, and 2.5 m. These layers do not display well developed soil structure or distinct soil horizons. The layers bracket packages of massive silty-sand, matrix-supported sandy-silt, and lenticular units of poorly sorted, clast supported gravels.

In the middle to lower fan, 0.3-1.0 m thick debris flow deposits alternate with fine sands and silts, and lenticular gravel deposits. In the lower fan clast supported units with a sand matrix (0.5 m thick), silty-clay and fine sand-silt units (av. 0.2 m thick), and peaty organic rich layers are present. The land owner of the lower fan, Larry Luckinbill, stated that at about 1 m depth on some parts of the fan he digs up peaty, organic-rich material with woody debris, and in another part of the lower fan excavation (5-10 m depth?) reveals laminated fine silts and clays, with small (<1 mm) mollusk shells.

Radiocarbon dates. A pair of samples for dating were taken from two organic rich layers in the Oliver Gulch channel at depths of about 2.0 m (Geochron sample no. GX-22701) and 2.5 m (sample no. GX-22700), that bracketed a package of sediment. The layer at 2 m has a calibrated age of 3696 ± 135 BP. The layer at 2.5 m has a calibrated age of 4412 ± 95 BP.

A third sample was taken from a peat at 2.5 m depth (sample no. GX-22702), the base of a channel exposure in the lower fan, less than a meter above probable glacial drift. The calibrated age is 13,482 ± 180 BP.

DISCUSSION

Facies models. Study of the facies of the Corral Creek fan suggests that debris flows have a significant impact on fan construction. Much of the material that would compose debris flows (such as sediments from mass wasting) lies near the fan head, but debris flow deposits were observed well upstream (1.5 km) in the upper drainage. Cechovic and Schmitt (1993) found that debris-flow dominated alluvial fans in the Yellowstone area also have "extensive mudrock outcrops in the source area." There is not a lack of fine grained source material for the Corral Creek fan, but debris flow sediments make up only half of the deposits. Well sorted, clast-supported fluvial facies are not extensively present on the fan, so stream flow was not a significant mode of deposition either. The most recent deposits of the upper fan terraces and levees, which are matrix rich, usually clast supported, sandy to silty units, are mirrored in the sediments below the fan surface. These units were deposited in times of high flow rich in sediment, perhaps by hyperconcentrated flow, and possibly in association with debris flows.

Reworking by stream flow after these large depositional events was probably minimal. Units are mostly poorly sorted, crudely imbricated at best, and even if clast supported, they are matrix rich. Deposits would be better sorted, and less rich in fines if throughgoing flow had winnowed the upper parts of beds. No clear cross bedding was observed in any of the logged units. This evidence supports the idea that sediment-poor water flow is not a significant process on the fan.

Environmental record. The deglaciation of the Clarks Fork valley sets a maximum age for the Corral Creek fan at about 13,000 BP (Pierce, 1979), and the radiocarbon age of the peat layer just above glacial drift, 13,482 ± 180 BP, is in general agreement. It is not necessarily true that the fan began forming at this time, but deglaciation of the Corral Creek drainage would have provided abundant water and sediment (both drift, and sediment derived from mass wasting after retreating ice left steep, unstable slopes) for fan construction.

The two dates from the middle fan, 3696 ± 135 BP and 4412 ± 95 BP, may indicate periods when the sedimentation rate was high in the Corral Creek area. A high sedimentation rate suggests environmental instability. Factors that include forest fires and frequent storms can contribute to elevated sedimentation rates. On the modern fan, young grasses and small leafy vegetation grow on the stable surface, and are often covered by non-channelized deposition. Deposition due to high sedimentation rates would completely bury the vegetated surface. This material would decompose to form an organic rich layer, but not necessarily a well developed soil horizon. Radiocarbon dates of this layer would give an estimate for when it was buried. The two dates correlate well with data collected by Meyer *et al.* (1995) that suggest a major episode of increased fire related sedimentation in the Yellowstone area between 4000-4600 BP, and a minor episode around 3500 BP. However, Meyer *et al.* found easily visible concentrations of charcoal in debris flow deposits, whereas charcoal was relatively less visible in deposits on the Corral Creek fan. This makes it difficult to conclude if sedimentation on the fan related to these episodes was solely fire-related. Furthermore, modern day facies show that sediment can be eroded down to the ancient organic-rich layers (akin to exhumed paleosols), so deposits stratigraphically above organic rich layers do not have to be the deposits that originally buried those layers.

CONCLUSION

Radiocarbon ages support suggested periods for environmental instability, expressed through high sedimentation rates, in the Yellowstone area. Stream flow minimally reworks the majority of the fan sediments. New facies models probably are correct to de-emphasize the role of stream flow; hyperconcentrated flow deposits play as significant a role as debris flow deposits in fan formation.

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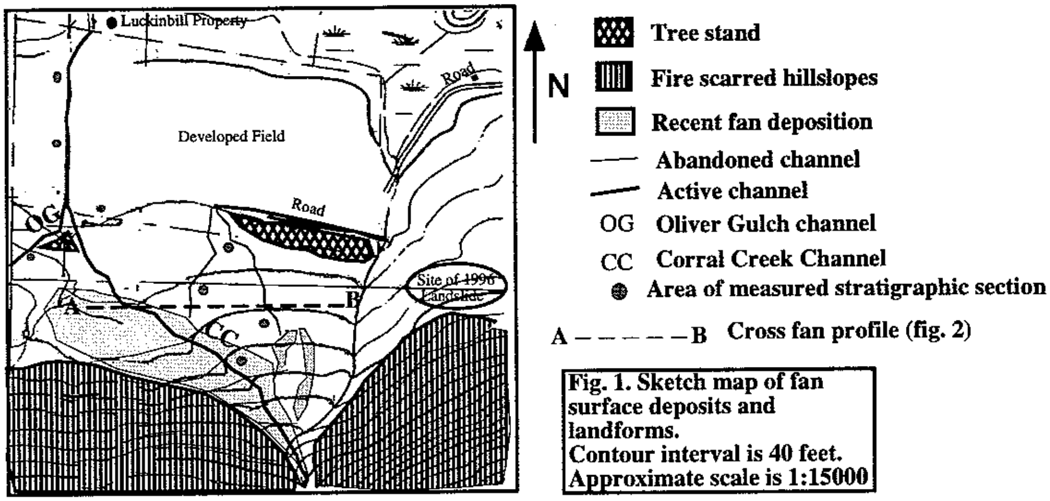

Fig. 1. Sketch map of fan surface deposits and landforms. Contour interval is 40 feet. Approximate scale is 1:15000

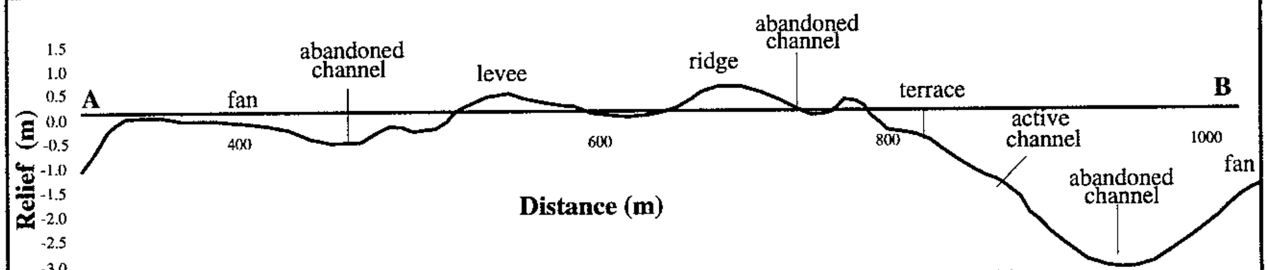

Fig 2. Section of cross fan profile (300-1120 m). Vertical exaggeration: 30x.

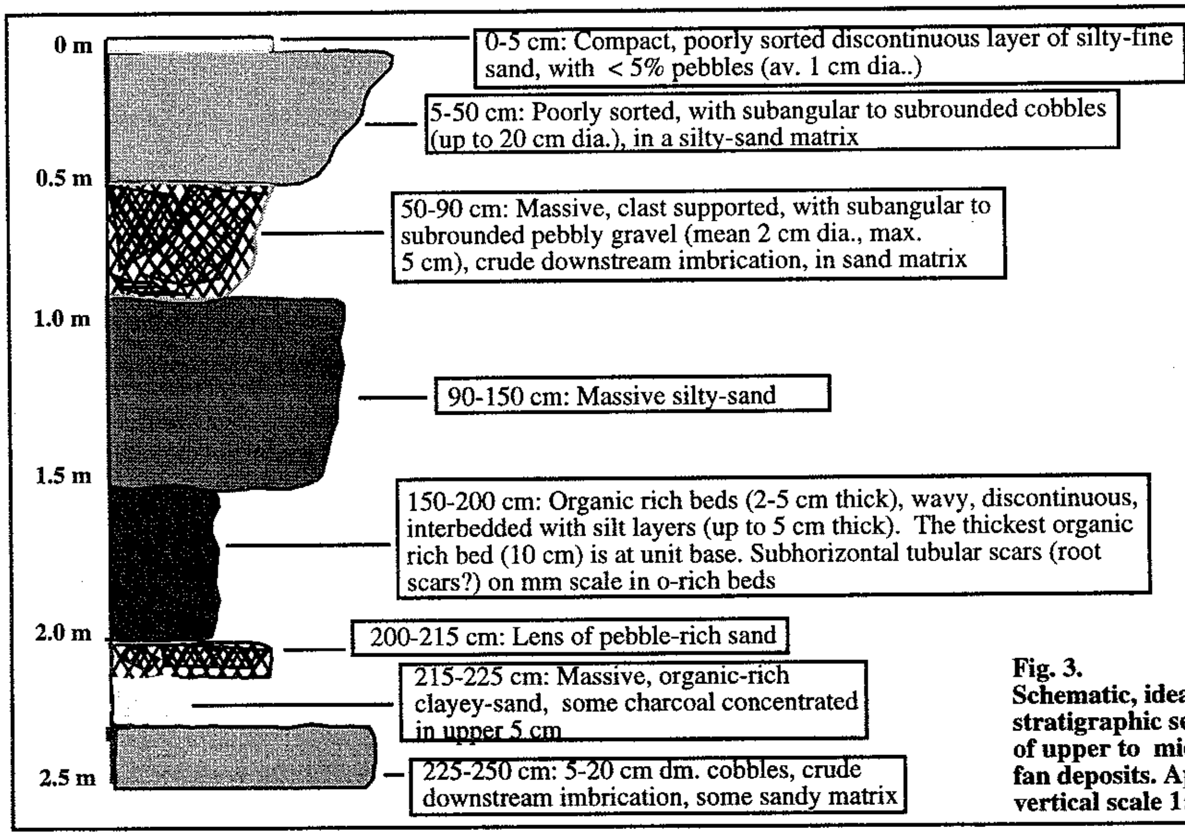

Fig. 3. Schematic, idealized stratigraphic section of upper to middle fan deposits. Approx. vertical scale 1:25

The Cathedral Cliffs Landslide, Park County, Wyoming

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INTRODUCTION

In May of 1995, a complex landslide occurred on the steep northwest-facing slopes below Cathedral Cliffs, in the Clarks Fork Valley of northwestern Wyoming. The slide had a maximum length of 550 m, a maximum width of 300 m, a relief of 190 m, and occurred in an area which was burned by the 1988 Yellowstone fires. The mechanics of slope failure and movement were diverse, ranging from slumping of intact blocks to earthflow. Bedrock stratigraphy of the slope suggests significant structural control on the landslide. Sedimentological evidence, in cores from a shallow lake below the slide, and geomorphological evidence show that the 1995 slide occurred at a site of earlier sliding. Personal accounts indicate that the slide occurred during the middle of the night and lasted several hours. It took weeks to settle and is still not completely stabilized. The purpose of this study is to describe and map the 1995 Cathedral Cliffs Landslide, study its kinematics, determine its major causes, and establish a perspective on mass-wasting events in the slope's history.

METHODS

The field area was surveyed with a tape measure, inclinometer, a Brunton compass, and a barometric altimeter. A base map was created from this survey, upon which I mapped the various geomorphic features. A core was extracted from Swamp Lake below the slope using a sediment corer and many strong backs. The core was split, measured and described in the field, and then wrapped in tin-foil for transportation back to the lab. There it was kept in cold storage before sampling for radiocarbon dating.

BEDROCK GEOLOGY

The slide occurred in bedrock consisting of two nearly flat-lying limestone units interbedded with shales. From the base to the top these layers are: Wolsey Shale, Meagher Limestone, Park Shale, and Pilgrim Limestone. Colluvium covers the lower part of the slope obscuring most of the bedrock below the Pilgrim Limestone. There are only a few small outcrops and benches of Meagher Limestone. The Pilgrim Limestone, however, outcrops as a continuous cliff up to 10 meters high. The only place along the cliffs where the Pilgrim Limestone is significantly fractured and slumped is directly above the landslide area.

DESCRIPTION

The landslide occurred mostly in the colluvium, but locally affected the shale bedrock. The slumped blocks of Pilgrim Limestone do not appear to have moved during the 1995 slide, and they appear to have limited the uphill extent of the slide. The landslide can be divided into five zones based on geomorphic features and type of failure: the first three are in the head of the slide; the fourth is the neck; and the fifth is the lower neck and toe (see figure 1).

Zone 1: This zone has four well-defined, steep scarps (each 2-5 m high), corresponding with slumped blocks of intact turf and standing trees. There are interesting relationships between compressional folds and tensional cracks in the slumped turf blocks.

Zone 2: This section has one well-defined head scarp (up to 8 m high), with a more broken up terrain below. This terrain consists of many small scarps (up to 1 m high) with thin strips of turf in-between, resulting in a "striped" appearance. There are also some debris flows, giving Zone 2 a more fluid appearance than Zone 1. There is a large, previously-slumped Pilgrim Limestone block above here that controls the position of the head scarp. There are only a few

Figure 1