UNIVERSITY OF ALBERTA

FINE-GRAINED ALLUVIAL FANS OF DEADLODGE CANYON, DINOSAUR PROVINCIAL PARK, ALBERTA, CANADA

BY

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

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"At the dawn of day, we attacked the tents, and with our daggers and knives, cut through the tents and entered for the fight; but our war whoop instantly stopped, our eyes were appalled with terror; there was no one to fight but the dead and dying...the Bad Spirit had made himself master...and destroyed them."

- Saukampee, Peigan Chief (Symington 1969)

The Peigan tribe and the Blackfoot Nation, occupying territory north of the Red Deer River, were constantly at war with the Shoshoni to the south. The outbreak of small pox wreaked havoc on both tribes, killing thousands of people. The dead were buried aloft on the branches of the sturdy cottonwood trees that line the banks of the Red Deer River. The reach running through Dinosaur Provincial Park became known to the Blackfoot as the "Valley of Dead Lodges"; today, it is named "Deadlodge Canyon".

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Fine-Grained Alluvial Fans of Deadlodge Canyon, Dinosaur Provincial Park, Alberta, Canada submitted by Mark R. Seemann in partial fulfilment of the requirements for the degree of Master of Science.

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Dedicated to Diana and Harry Seemann,

my first teachers

ABSTRACT

Several relatively small, silt-dominated alluvial fans line the lower Red Deer River in Deadlodge Canyon, Dinosaur Provincial Park, Alberta. These features form extremely rapidly and their development is inextricably linked to the Red Deer River's cyclical pointbar replacement. Comparisons of estimated mean annual sediment supply rates to estimated fan volumes suggest a minimum fan age of about 150 years, while down-valley river migration rates suggest a maximum age of about 900 years. Eleven basal and within-fan radiocarbon dates confirm these minimum and maximum estimates and suggest a mean vertical accretion rate of 3.8 mm/year on the upper fan surface.

Vegetative cover on these rapidly aggrading fans was sampled to assess pattern and species-environment relationships. Both direct examination of the percent cover data and principle component analysis of the data show clear patterns of vegetation on the fan surfaces. The vegetative cover on the coarser-grained upper fan surfaces is characterized by the relative predominance of the grasses *Stipa comata, Calamovilfa longifolia, Koeleria cristata* and *Bouteloua gracilis*, while a *Symphoricarpos occidentalis* dominated shrub community is identified on the clayey lower fan surfaces. A less clearly defined mid-fan vegetative community is characterized by the predominance of *Artemisia cana* and *Agropyron smithii*. The three identified communities are found to vary along a xeric-mesic gradient largely established by variations in fan surface runoff. The observed vegetative pattern confirms and corroborates other grassland plant associations recognized on prairie hillslopes and in prairie coulees. An atypical floristic preference for fan slopes with a southerly aspect likely reflects the relatively efficient drainage characteristics of

the barren, steep-sided, south-facing basins which contribute runoff and sediment to the fans.

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1.0 INTRODUCTION

1.1 Context of the Study

Alluvial fans are arcuate-shaped depositional landforms prograding from the base of upland escarpments where feeder streams emerge from the confines of their catchment basins. Historically, the study of these distinctive features has been fragmented and sporadic, yet the trends in fan research have closely paralleled those of the larger field of geomorphology (Lecce 1988, 1990). Based on Kuhn's (1970) philosophies of scientific development, Lecce (1990) identified a series of research paradigms which provide a framework for evaluating the progressive evolution of fan research from a 'pre-paradigm' period, through a 'fan dynamics' period to the 'integrated fan dynamics' period which now prevails.

1.1.1 Pre-Paradigm Fan Research

The Pre-Paradigm period (pre-early 1960s) began slowly and was characterised by description, classification and the delineation of an acceptable nomenclature (Lecce 1988). Direct fan research was limited during this period but grew steadily with the exploration of the American Southwest. As in the broader field of geomorphology, this period was overshadowed by the Davisian concept of evolutionary stage. However, unlike other geomorphic studies, the concept of 'stage' and evolutionary cycles did not dominate fan research. By the mid 1950s fan research had become increasingly quantitative and process-oriented while, simultaneously, the parent discipline of geomorphology was beginning to feel constrained by Davis' evolutionary mold. A period of intellectual 'crisis' ensued and was not resolved until the introduction of systems theory and the concept of 'equilibrium states' in the early 1960s.

1.1.2 Fan Dynamics Paradigm

The paradigm of Fan Dynamics succeeded the Pre-Paradigm period and prevailed into the mid 1970s. Interest in the relationship between process and form dominated fan research under both laboratory (Hooke 1965, 1967, 1968) and field conditions (Bull 1961, 1963; Denny 1965). The central issue of the paradigm focused on the formulation of a general model for fan development, and two apparently conflicting approaches emerged: the evolutionary and equilibrium hypotheses.

The evolutionary hypothesis, originally proposed by Eckis (1928) and elaborated on by Lustig (1965), espoused fan growth from small, youthful fans to expansive, mature fans enveloping both their depositional basins and the surrounding uplands. Given the prevailing negative scientific attitude toward evolutionary hypotheses however, this approach received minimal attention and failed to explain the widely observed entrenchment and erosion of fan surfaces.

The 'equilibrium hypothesis' characterized fan development as existing in varying states of time-independent equilibrium. While Hooke (1968) regarded fans to be in a steady-state equilibrium, Denny (1965, 1967) suggested that a state of dynamic equilibrium best explained fan development. Neither equilibrium approach, however, fully resolved the paradigm's central question. The steady-state equilibrium approach failed to address long-term fan evolution and the dynamic equilibrium approach seemed limited to open systems (Hooke 1968).

Despite the renewed and focused research conducted throughout the 1960s, no universally applicable model of long-term fan evolution emerged and a second period of intellectual crisis developed.

1.1.3 Integrated Fan Dynamics Paradigm

When the geomorphic implications of Schumm and Lichty's (1965) landmark paper on the role of temporal scale had filtered through the geomorphic community, fan research began to emerge from its latest phase of crisis (Lecce 1990). By distinguishing between 'steady', 'graded' and 'cyclic' time, Schumm and Lichty (1965) demonstrated that evolutionary and equilibrium approaches could be seen as complementary; fans may evolve toward an equilibrium state. What this state could be, and under what conditions it could occur, highlighted the need for a comprehensive theory on fan development.

Although there is some debate as to whether the generation of such a theory is possible (Rachocki 1981), Wasson (1977) proposed some guidelines to focus and direct future fan research toward this objective. His plea to study both active and relic fans across a wide variety of environments was rewarded by increasingly widespread research beginning in the late 1970s and continuing through the 1980s (Australia: Wasson 1979; Japan: Suwa and Okuda 1983; Spain: Harvey 1984; Costa Rica: Kesel 1985; Canada: Leggett *et al.* 1966; Ryder 1971a, b; Kostaschuk *et al.* 1986; Rannie *et al.* 1989; England: Harvey and Renwick 1987; New Zealand: McArthur 1987; Somalia: Maizels 1990; Pakistan: Derbyshire and Owen 1990). Despite this trend, however, there still exists strong geographical biases within the literature, and research on fans in the American Southwest still dominates approximately twenty-five percent of published articles (Lecce 1990).

1.2 Alluvial Fans

Alluvial fans are morphologically distinct landforms with a unique role in long-term subaerial sediment storage (Harvey 1989). First identified by Surell (1841 - as cited in Bull 1977) and named by Drew (1873), alluvial fans have been defined in several ways over the last century (Fraser and Suttner 1986). Alluvial fans are arcuate-shaped stream deposits aggrading at the base of upland escarpments and extending into adjacent plains, valleys or basins (Bull 1977; Rachocki 1981). The sudden and progressive reduction in stream power as the confined channel emerges from its catchment basin causes sediment deposition (Bull 1979). This deposition ideally forms a segment of a cone with its apex located at the point the stream emerges from the upland region.

Fans do not always take on this classic form, they are often limited by adjacent features and are a function of past conditions. For example, adjacent fans may coalesce to form a planar piedmont surface called an alluvial apron or bajada (Eckis 1928), which more closely resembles a pediment than a fan. Similarly, the shape of an isolated fan is a function of the sediments transported to the fan, the pattern of distributary channels on the fan, and the antecedent phases of entrenchment and aggradation.

Alluvial fans exist at one end of a 'fan-cone' continuum. Distinguishing between fans and cones may be difficult, especially in alpine environments, yet slope angle and primary depositional processes define the classification. The steeper (greater than twenty degrees) scree or talus cones are produced primarily by gravitational mass wasting, while alluvial fans are dominated by fluvial and debris flow events (Blackwelder 1928; Denny 1967; Beaty 1970; Bull 1977).

Cross-sectional transects running normal to the fan radius demonstrate convex-up profiles with slight asymmetry. Longitudinally, radial transects of the surface may range from a few meters to over 100 kilometres in length and typically maintain a classic concave-up profile (Hooke 1967; Bull 1977; Nilsen and Moore 1984). This latter profile frequently demonstrates the tripartite nature of fan surfaces. Recognizing this, Bull (1964) divided the fan surface into three dominant zones (the upper, middle and lower fan) each with decreasing gradients downslope.

A prominent feature of the upper fan is the 'fan-head trench' caused by the feeder stream's incision into the fan. This trench can be several tens of meters deep and may or may not be bounded by levee deposits. Entrenchment is usually deepest at the apex and becomes progressively shallower down-fan (Hooke 1967). The point at which the feeder stream emerges onto the fan surface has been called the intersection point (Hooke 1967; Wasson 1974). On fans with a mid-fan intersection point, active deposition and progradation are shifted away from the apex to more distal areas producing segmented accretion (Figure 1.1). Floods, debris flows and landslides are common on the upper fan and lead to the deposition of poorly sorted, coarse grained sediments (Bull 1963; Denny 1967). Within the upper zone the stream channel may be either meandering or braided, yet is most frequently in some transitional form. Slope angles in this zone vary greatly between fans (from three to twenty degrees) but angles between four and ten degrees are most common (Nilsen and Moore 1984).

The upper limit of the middle fan zone is approximately at the intersection point. This zone is characterised by sheetflow which may yield to shallow, braided distributary channels in more distal areas. Deposition consists predominantly of sands and pebbles, although coarser sediments consisting of reworked clasts from the upper fan may be found. Slope angles vary considerably in this zone yet usually exist at some intermediate angle between upper and lower fan.

The lower fan is characterized by braiding and rillflow along a network of distributary channels. Fine-grained sediments dominate the zone with some reworked larger clasts distributed from the upper areas (Packard 1974). This zone maintains the lowest slope angles found on the fan surface and seldom exceeds five degrees (Blissenbach 1954).

The tripartite concentric zonation model implies both a down-fan fining of sediments from apex to toe and simple, uniform progradation of the landform (Fraser and Suttner 1986). However, while the former may be true at a macroscale, both implications grossly oversimplify the depositional processes involved in fan formation. Neither discharge nor sediment deposition occur uniformly and the role of catastrophic events is neglected by this model.

1.3 Factors Influencing Fan Development

Ultimately, fan slopes are controlled by the stream(s) under which they lie and which give them sustenance. In turn, stream behaviour and dynamics are a function of several interacting and competing variables operating on and within fluvial systems (Schumm 1977). Alluvial fan slopes therefore exhibit a complex response to a myriad of intrinsic and extrinsic variables influencing stream slope, sediment supply and,

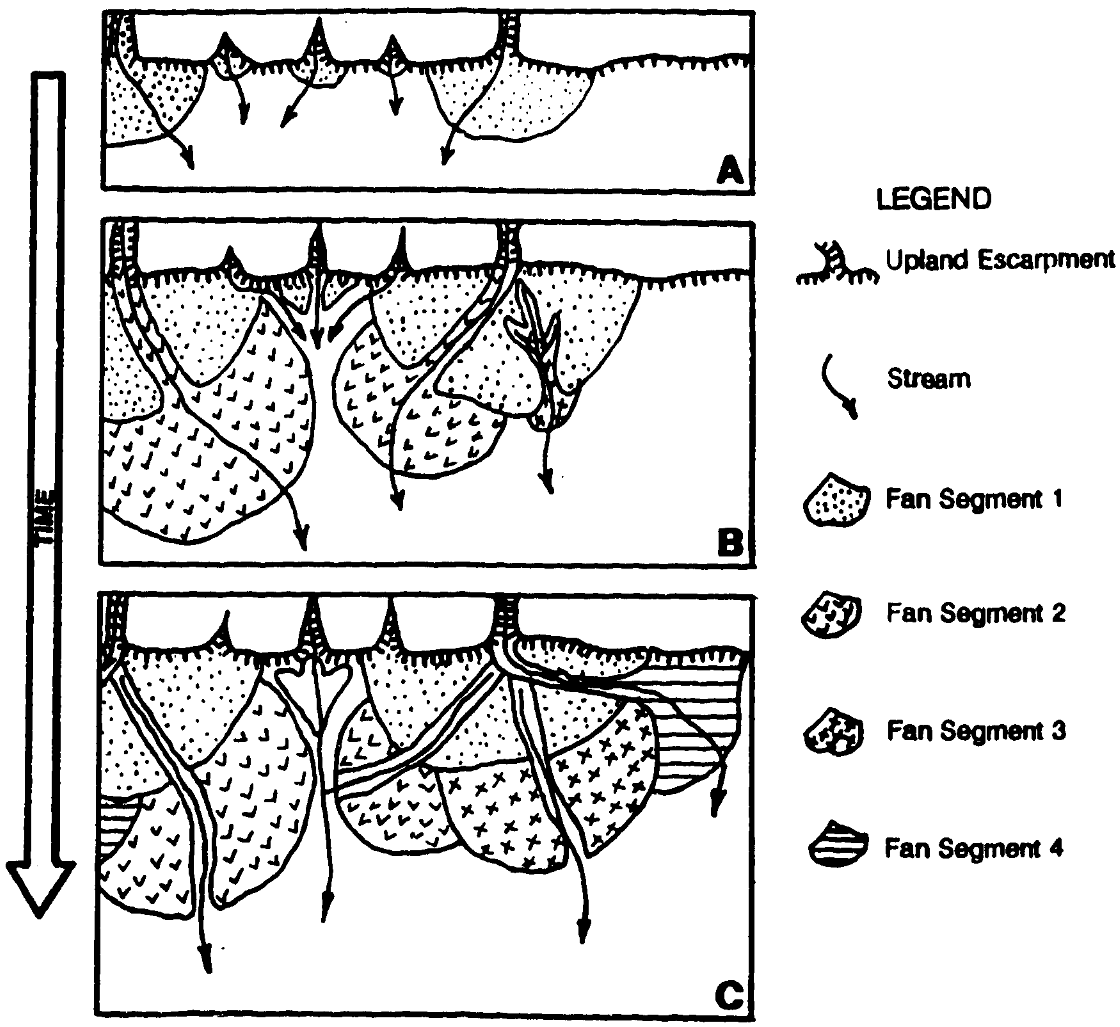


Figure 1.1 Model of segmented alluvial fan growth. Initial fan development is primarily accretionary (A), while subsequent dissection of the fan surface by stream piracy shifts deposition further down-fan (B and C) (after Denny 1967).

subsequently, fan morphology. Although numerous factors and combinations thereof influence fan morphology, these factors can generally be summarized within three broad areas: 1) tectonic and related base level controls, 2) climatic controls, and 3) lithologic factors.

1.3.1 Tectonism and Base Level Changes

Tectonism influences fan morphology by vertically displacing the feeder stream at the fan apex (Bull 1961, 1964). This differential movement of the uplands relative to the depositional basin or plain can lead to either entrenchment of the fan head or upper fan deposition (Figure 1.2). Similarly, deposition and truncation at the fan toe are effected by both vertical and horizontal changes in the local base level to which fan streams grade (Figure 1.3).

Fan progradation due to tectonic uplift continues until the rate of basin erosion and fan deposition do not exceed that of uplift (Bull 1977). Deposition may occur at any location on the fan surface depending on relative rates of uplift (Bull 1961). Rapid uplift of the drainage basin produces primary deposition in the upper to middle fan whereas slow, gradual rise, if exceeded by rate of channel incision, leads to fan head entrenchment and the transport of sediments farther downslope. In the former situation, rapid uplift deposits younger sediments on the proximal fan, whereas in the latter case deposition of younger beds is shifted down-fan.

Fluctuations in the base level to which fan streams locally grade affect fan morphology by altering stream gradient. Steepening of the hydraulic gradient on fan

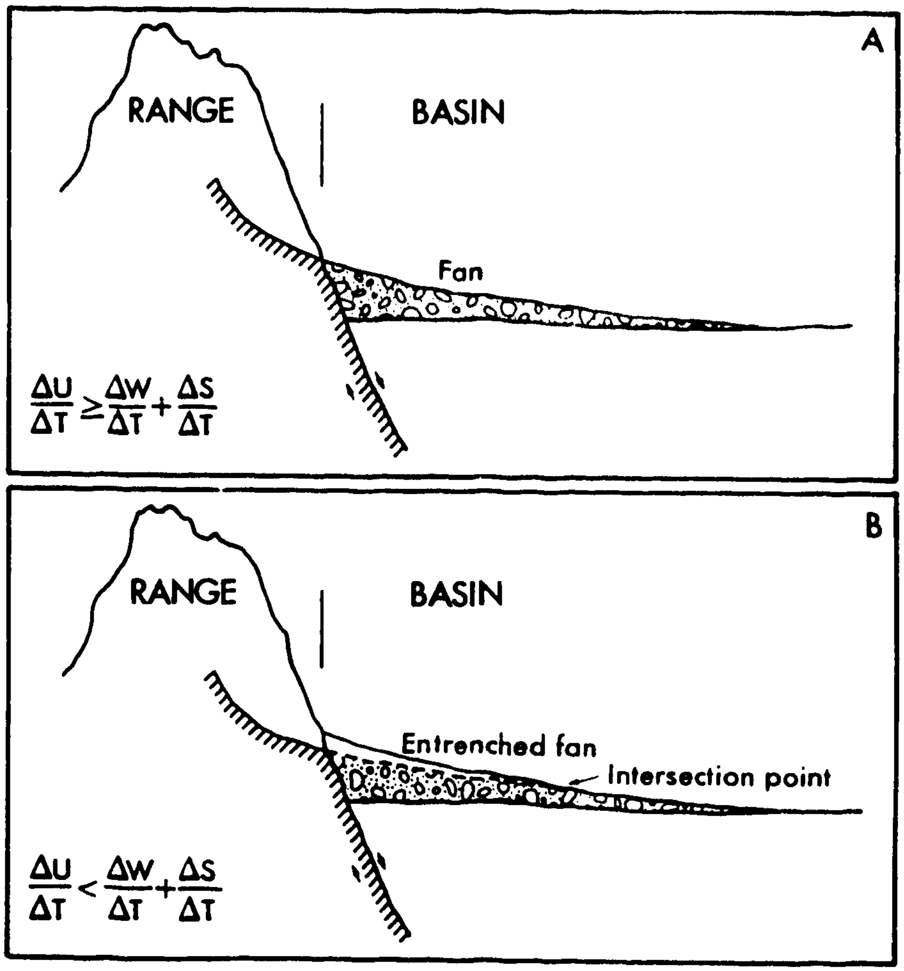


Figure 1.2 Schematic long profile showing the relationship between uplift (U), source area incision (W), and fan deposition (S) through time (T) (after Bull 1977)

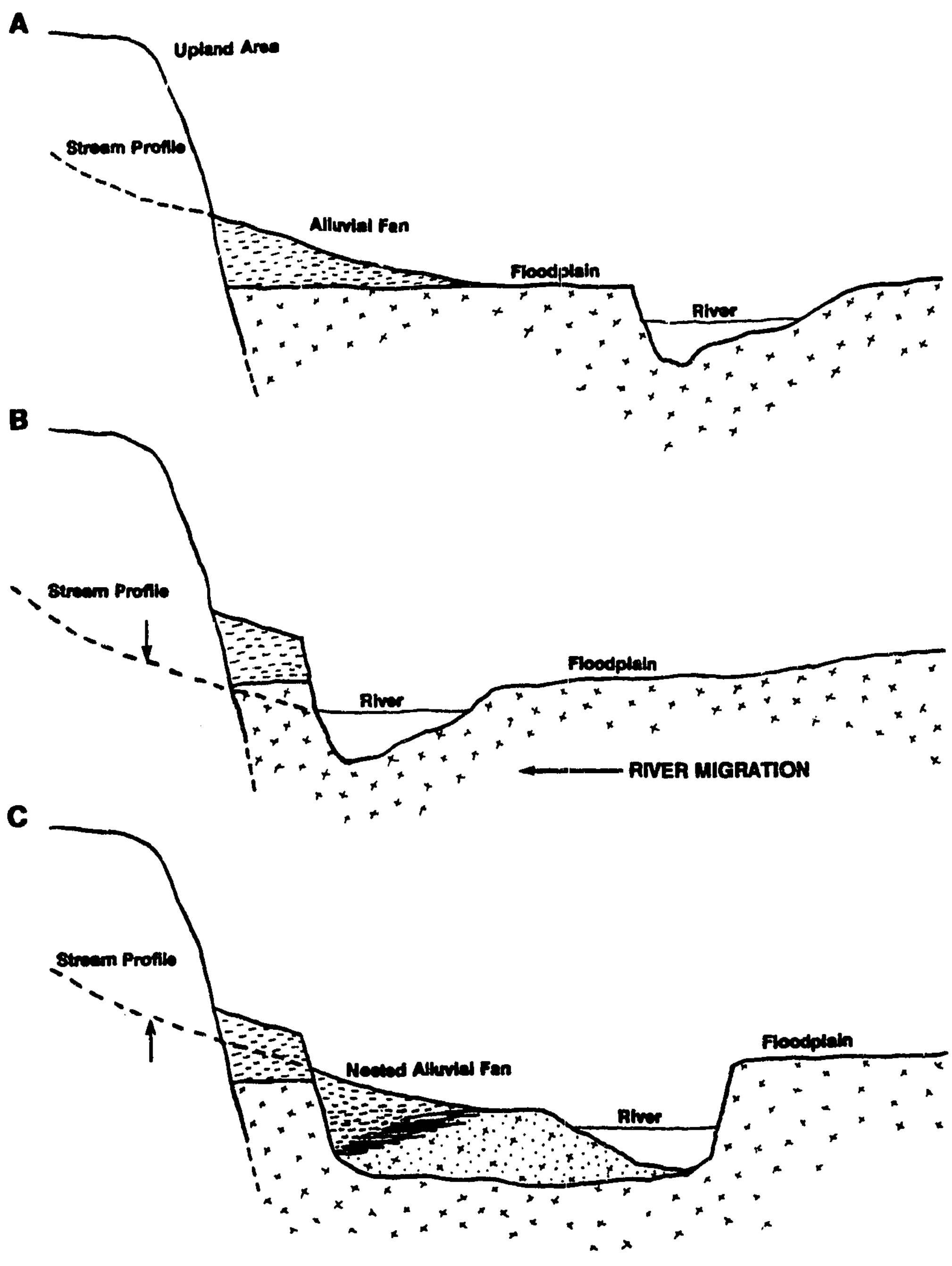


Figure 1.3 Schematic long profile illustrating the effect base level changes have on fan development. (A) shows stream and fan profile during a phase of active fan growth. (B) illustrates the dissection and truncation of the fan as the lateral migration of the river shortens and steepens the fan stream gradient. (C) shows secondary 'nested' or 'inset' fan growth as the river shifts back to the opposite side of the valley.

surfaces and subsequent fan toe entrenchment can be induced by either lowering the local base level or laterally shifting the base level towards the fan apex and thus shortening the stream length. Conversely, increasing the stream length by either raising the local base level or shifting it away from the fan apex leads to deposition along the fan toe.

While base level controls vary over both the short and long-term, recent research downplays the role of tectonism in short-term fan development. Harvey (1989, 1990) suggests that, while long-term tectonism provides the gross framework for fan location and sedimentary style, other factors such as climate and lithology dominate shorter-term fan evolution.

1.3.2 Climate

Because climate directly and indirectly affects both the short and long-term processes of fan development the response of fans to climatic change is complex. Climate effects fan development over the short-term by influencing the magnitude and frequency of storm events. These, in turn, affect slope wash, sediment yield, sediment calibre, and stream discharge, as well as type and amount of vegetative cover (Schumm 1977).

Generally, with an increase in mean annual precipitation a corresponding increase in discharge and vegetative cover occurs. Yet discharge is tempered by varying temperatures and rates of evapotranspiration. Therefore, the relationship between precipitation and sediment yield is multi-faceted and complex. Knox (1972) graphically represented this interaction by illustrating the effect of precipitation and vegetation on geomorphic work (Figure 1.4). Short-term climatic change also indirectly influences fan development by controlling vegetative cover. Vegetation limits the amount of water available for runoff, erosion and sediment transport, and enhances deposition of sediments by impeding flow on the fan surface.

The effect of stream discharge on alluvial fans has been interpreted through studies centred on fan-basin relationships. Bull (1964) found an empirical relationship between fan size and the size of its source area:

$$A_f = cA_d^n$$

where, A_f = fan area
c = a coefficient varying with local lithology (Hooke 1968), tectonics (Denny 1965), and antecedent basin conditions (Ryder 1971a)
A_d = catchment planimetric area
n = a coefficient (c. 0.9)

However, while this allometric relationship (Bull 1975) is widely accepted and may be applicable to some fan-basin conditions, Church and Mark (1980) suggest it oversimplifies the dynamic fan-basin relationship. They empirically demonstrate that the coefficient 'n' is rarely significantly less than one, and that "the best results fall impressively close to isometry (n=1.0)" regardless of scale.

The effect of discharge on fan slope has also been analyzed within the fan-basin approach (Melton 1965; Hooke 1968; Ryder 1971b). Because fan slope tends to decrease with increasing size of the fan, Hooke (1968) attributed low gradients to higher storm discharges from larger source areas; large discharges have higher flow velocities and should be able to transport at a lower angle what smaller discharges can transport at a higher angle. Similarly, larger discharges should be able to transport sediment farther

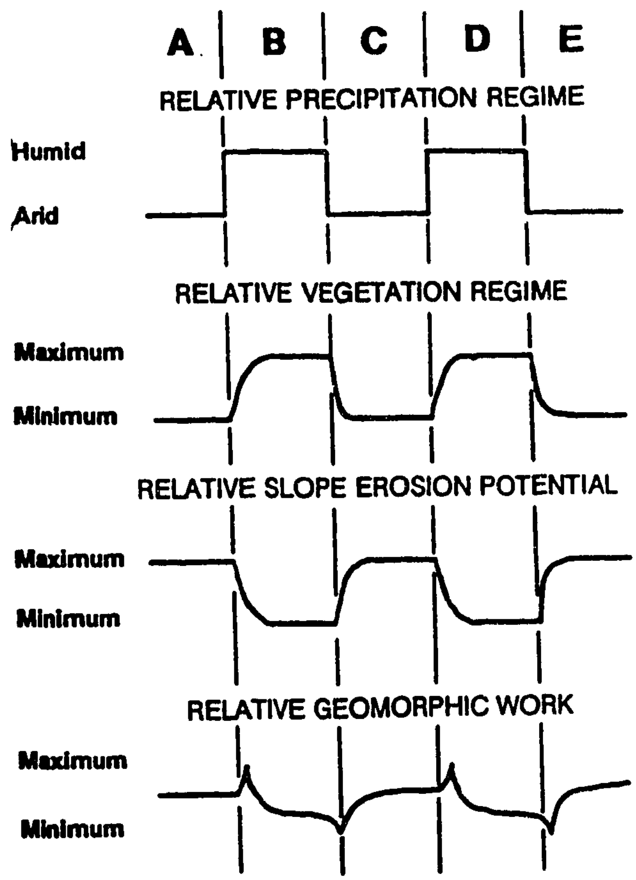


Figure 1.4 Relative geomorphic response to abrupt changes in climatic regime (from Knox 1972). Relative geomorphic work is most efficient where the precipitation regime is relatively high in comparison to the amount of vegetative cover.

down-fan than smaller discharges and should produce lower fan gradients. While laboratory and field studies have generally borne this out (Hooke 1968), Harvey (1984, 1989) noted that the sediment load concentration and mode of deposition significantly temper the relationship between basin size and fan gradient.

The effect of climate on fan development is not limited to short-term transportational and depositional processes. Long-term evolutionary cycles of fan progradation and dissection have been attributed to climatic factors (Lustig 1965; Harvey 1989), but the evidence for the effects of climatic change in long-term fan development is inconclusive. Research in Europe and north Africa indicates that cold, dry glacial periods throughout the Quaternary were associated with enhanced fan aggradation (Harvey 1984, 1989), while research in the Canadian Cordillera indicates that cool, moist periglacial conditions were associated with fan growth (Ryder 1971a, 1971b). Similarly, Australian research (Williams 1973; Wasson 1979) suggests that fan aggradation is associated with moister climatic periods and fan dissection with dryer periods.

1.3.3 Lithology

Fan source area lithology influences fan slope in at least one of three ways: 1) by partially controlling clast size; 2) by affecting the depositional process (ranging from mass flow to fluvial deposits); and 3) by limiting the concentration of stream sediment load (Hooke 1968). The effects of each of these factors have been quantitatively identified in both laboratory (Hooke 1968) and field conditions (Bull 1962; Denny 1965; Lustig 1965; Ryder 1971a; Hooke and Rohrer 1977; Kostaschuk *et al.* 1986).

Hooke (1968) demonstrated that a decrease in fan slope angle occurs with a corresponding decrease in sediment size. Morphometric studies of several fans in California have supported this finding regardless of drainage basin size (Bull 1962, 1964).

The effect of depositional form (Table 1.1) illustrates the correlation between slope angle and dominant modes of deposition (Bull 1977; Kostaschuk *et al.* 1986). Hooke's (1968) laboratory experiments found sieve and debris flow deposits to increase slope angle by up to five degrees more than fluvial deposits.

Increased sediment load within stream channels was initially identified by Bull (1964) as influencing fan gradient. Comparing fans with source areas of similar size, Bull (1964) noted that steeper fans were formed from the source areas with more easily erodible materials. Presumably, source areas with comparatively indurated materials produced lower sediment concentrations which, in turn, influenced the mode of deposition (Bull 1964; Hooke 1968; Hooke and Rohrer 1979).

Source area lithology is also linked to fan size. Lecce (1991) demonstrated that the relatively erodible catchments produce larger drainage basins with small fans as a result of increased within-basin storage. Conversely, catchments underlain by resistant rock produced smaller, steeper basins and large fans as sediment is easily transported from the catchment.

Table 1.1 The effect of depositional form on fan slope (after Bull 1977)

	Steep Slopes	⟶			Shallow Slopes
Dominant mode of deposition	Sieve	Sieve	Debris flow	Waterlaid	Waterlaid fines
Other modes of deposition	None	Debris flow	Waterlaid	Debris flow	None

1.4 Alluvial Fan Facies

Fan deposition is a function of the change in channel hydraulic geometry as the stream emerges from the confines of an upland region (Bull 1964, 1979; Denny 1965). Whether the feeder stream emerges onto the fan surface at the apex, upslope of the apex or at the intersection point, the increase in channel width causes a decrease in flow depth and velocity, culminating in sediment deposition. Similarly, deposition may occur if stream competence or capacity is reduced by flowing over permeable material (Hooke 1967; Bull 1977).

Little empirical work has been done on the relationship between water and sediment discharge on alluvial fans (Bull 1977). However, Harvey (1989) notes that the primary controls over depositional mechanisms are the water-to-sediment ratio and the availability of fine-grained sediments. While high water-to-sediment ratios tend to generate fluvially dominated deposits, low water-to-sediment ratios tend to produce mass flow facies. Variations in sediment grain-size also have an effect. As the proportion of fines increases, viscosity increases and the internal strength of the matrix may support coarse clasts, creating matrix-supported mass flows.

Fans comprised solely of fluvial deposits have been termed 'wet' fans (Schumm 1977), yet most fans are a composite of depositional processes. The proportion of mass flow deposits to fluvial deposits varies through time, both between fans and within fans.

Mass Flow Facies - Due to the high internal strength and density of mass flows, these deposits are heterogeneous, poorly sorted sediments with well-defined lobate margins that often form levees on the upper fan surface (Blackwelder 1928; Hooke 1967;

Beaty 1974). Some mass flows may demonstrate slight vertical alignment of clasts (Wells and Harvey 1987) and may show weak clast sorting within the deposit (Harvey 1989).

Three types of mass flow facies have been identified in the alluvial fan environment based on matrix characteristics. 'Cohesive sediment-gravity flow' (debris or mud flows) deposits typically demonstrate debris and clast-rich sediments supported by a fine grained matrix (Blackwelder 1928; Hooke 1967). These deposits are similar to 'non-cohesive sediment-gravity flows' (NCSGF) but can be differentiated from them by the relative lack of silts and clays in the NCSGF matrix (Blair 1987). A third type of mass flow deposit has recently been identified by Wells and Harvey (1987) as a flushed hyperconcentrated flow. While this deposit is entirely clast supported, its 'collapse structure' fabric indicates a flushing of the matrix upon deposition.

Fluvial Facies - The fluvial deposits commonly found on alluvial fans include both sheetflow and channel deposits as well as sieve deposits in gravel-dominated environments. Sheetflow deposits may consist of beds of sorted gravels, sands, silts or clays (Harvey 1989) and their deposition immediately below the fan intersection point may be crossbedded, laminated or massive (Bull 1977). Channel deposits backfill the stream-entrenched channels and typically consist of more poorly sorted and coarser sediments. They are relatively easily identified in section as lenticular 'scour and fill' features and often exhibit within-channel fining-up sequences.

Sieve deposits are coarse-grained lobate features found on fans whose source-areas provide few fine-grained sediments. Usually consisting of large, well-sorted subangular blocks, these deposits allow channel flow and the associated suspended load to percolate through while trapping coarse material (Hooke 1967).

1.5 Alluvial Fan Facies Associations

Of the myriad of facies combinations possible, both vertically and horizontally within an alluvial fan, two predominant facies associations (Figure 1.5) have been identified (Miall 1978). The 'Trollheim' type exhibits alternating debris flow, sheet flow and channel gravel facies while the 'Scott' type of facies association consists of sheet flow and channel gravel facies interspersed with various sand facies. The Trollheim facies association is typical of dynamic upper or proximal fan environments, while the Scott facies association is typical of fluvially dominated fans or more distal fan environments (Figure 1.5).

Spatial and temporal factors often produce variations in the observed facies associations (Wasson 1979; Harvey 1984). Short-term channel avulsions and entrenchment may vary facies associations considerably, both laterally and vertically throughout the fan. Similarly, long-term evolution and enlargement of fan source area may induce a progressive vertical change from Trollheim to Scott facies associations (Kostaschuk *et al.* 1986; Harvey 1989, 1990).

1.6 Nature of the Study

Recognizing the existing spatial bias within fan literature and the need for further studies in a variety of topographic and climatic environments, the semi-arid Dinosaur

Provincial Park badlands of southern Alberta provide an excellent opportunity to diversify and expand existing fan research. Geomorphological studies within these badlands have been largely process oriented (Campbell 1970, 1974, 1982, 1987; Bryan and Campbell 1980, 1986) and the existing research has made only cursory reference to the region's numerous alluvial fans (O'Hara 1986; Bryan *et al.* 1987). The study of alluvial fans within Deadlodge Canyon is a contribution to understanding the recent geomorphic history of the badlands and provides further information towards a comprehensive theory of fan development.

The present study has two objectives: first, to describe and interpret a chronology for the post-glacial development of alluvial fans in Deadlodge Canyon; and, second, to quantify and describe the variations in floristic composition existing on badland fan surfaces.

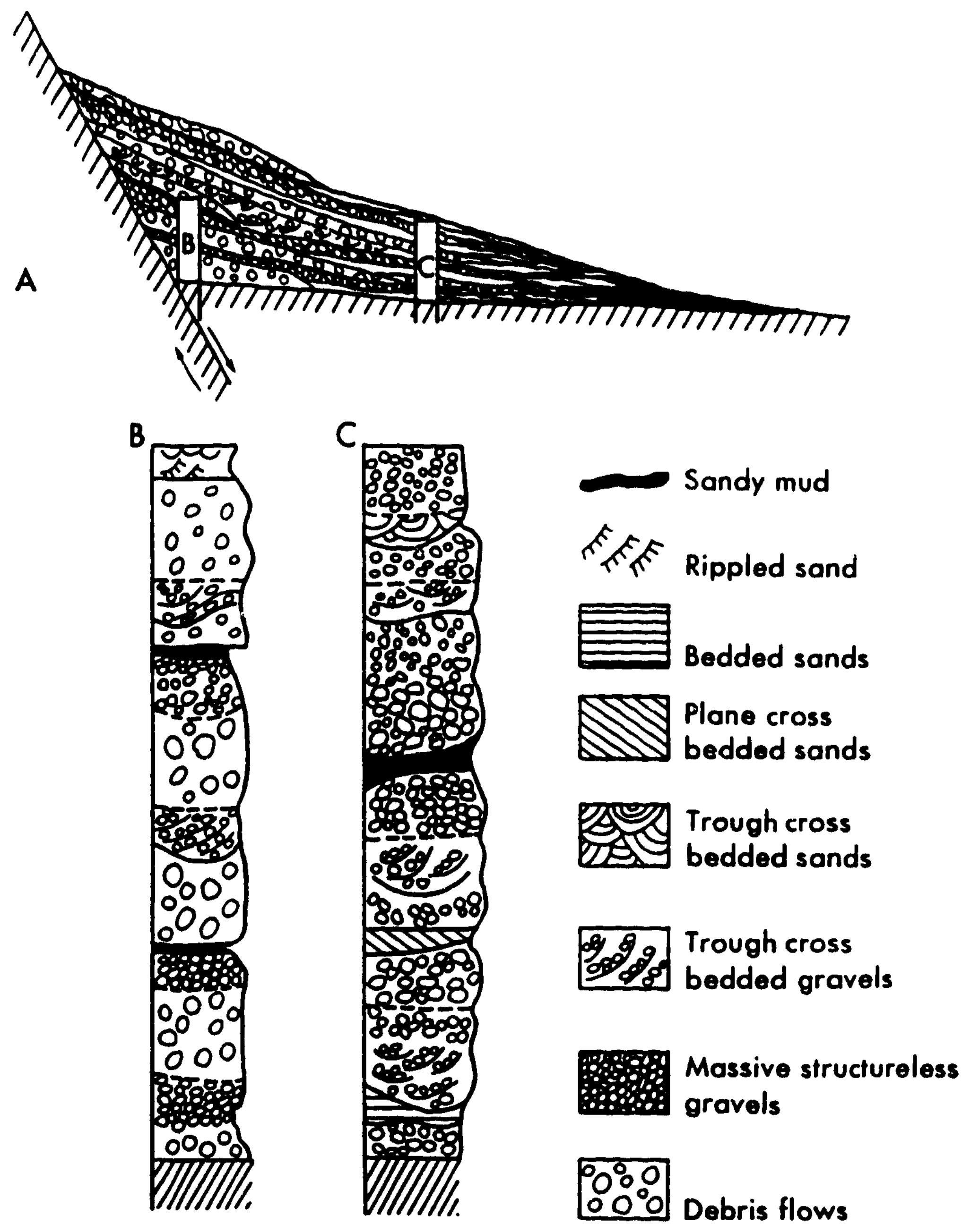


Figure 1.5 Schematic of Trollheim (B) and Scott (C) vertical facies associations and their typical down-fan spatial association (A) (from Miall 1978)

1.7 References

BEATY, C.B. 1970. Age and estimated rate of accumulation of an alluvial fan, White Mountains, California, U.S.A.. American Journal of Science, **268**: 50-70.

BEATY, C.B. 1974. Debris flows, alluvial fans and a revitalized catastrophism. Zeitschrift für Geomorphologie Supplementband, **21**: 39-51.

BLACKWELDER, E. 1928. Mudflow as a geologic agent in semi-arid mountains. Geological Society of America Bulletin, **39**: 465-484.

BLAIR, T.C. 1987. Sedimentary processes, vertical stratification sequences and geomorphology of the Roaring River alluvial fan, Rocky Mountain National Park. Journal of Sedimentary Petrology, **57**: 1-18.

BLISSENBACH, E. 1954. Geology of alluvial fans in semi-arid regions. Geological Society of America Bulletin, **65**: 179-195.

BRYAN, R.B. and I.A. CAMPBELL. 1980. Sediment entrainment and transport during local rainstorms in the Steveville Badlands, Alberta, Canada. Catena, **7**: 51-65.

BRYAN, R.B. and I.A. CAMPBELL. 1986. Runoff and sediment discharge in a semi-arid ephemeral drainage basin. Zeitschrift für Geomorphologie Supplementband, **58**: 121-143.

BRYAN, R.B., I.A. CAMPBELL and A. YAIR. 1987. Postglacial geomorphic development of the Dinosaur Provincial Park Badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

BULL, W.B. 1962. Relations of alluvial fan size and slope to drainage basin size and lithology in western Fresno County, California. U.S. Geological Survey Professional Paper, **430-B**: 51-53.

BULL, W.B. 1963. Alluvial fan deposits in western Fresno County, California. Journal of Geology, **71**: 243-251.

BULL, W.B. 1964. Geomorphology of segmented alluvial fans in western Fresno County, California. U.S. Geological Survey Professional Paper, **352-E**: 89-128.

BULL, W.B. 1975. Allometric change of landforms. Geological Society of America Bulletin, **86**: 1489-1498.

BULL, W.B. 1977. The alluvial fan environment. Progress in Physical Geography, **1**: 222-270.

BULL, W.B. 1979. Threshold of critical stream power. Geological Society of America Bulletin, **90**: 453-464.

CAMPBELL, I.A. 1970. Erosion rates in the Steveville Badlands, Alberta. Canadian Geographer, **14**: 202-214.

CAMPBELL, I.A. 1974. Measurement of erosion on badlands surfaces. Zeitschrift für Geomorphologie Supplementband, **21**: 122-137.

CAMPBELL, I.A. 1982. Surface morphology and rates of change during a ten year period in the Alberta Badlands. *In* Badland Geomorphology and Piping. *Edited by* R.B. Bryan and A. Yair. Geobooks, Norwich, England, 221-237.

CAMPBELL, I.A. 1987. Infiltration characteristics of badlands surfaces and storm runoff. *In* Proceedings, International Conference on Infiltration Development and Application, University of Hawaii, Honolulu, 251-260.

CHURCH, M. and D. MARK. 1980. On size and scale in geomorphology. Progress in Physical Geography, **4**: 342-390.

DENNY, C.S. 1965. Alluvial fans in the Death Valley region, California and Nevada. U.S. Geological Survey Professional Paper, **466**: 1-62.

DENNY, C.S. 1967. Fans and pediments. American Journal of Science, **265**: 81-105.

DERBYSHIRE, E. and L.A. OWEN. 1990. Quaternary alluvial fans in the Karakoram Mountains. *In* Alluvial Fans: a Field Approach. *Edited by* A.H. Rachocki and M. Church, John Wiley and Sons, 27-54.

DREW, F. 1873. Alluvial and lacustrine deposits and glacial records of the Upper Indus Basin. Geological Society of London Quarterly Journal, **29**: 441-471.

ECKIS, R. 1928. Alluvial fans in the Cucamonga District, southern California. Journal of Geology, **36**: 111-141.

FRASER, G.S. and L. SUTTNER. 1986. Alluvial fans and fan deltas. International Human Resources Development Corporation, Houston, Texas.

HARVEY, A.M. 1984. Aggradation and dissection sequences in Spanish alluvial fans: influence on morphologic development. Catena, **11**: 289-304.

HARVEY, A.M. 1989. The occurrence and role of arid zone alluvial fans. *In* Arid Zone Geomorphology, *Edited by* D.S.G. Thomas, Halsted Press, New York, 136-158.

HARVEY, A.M. 1990. Factors influencing Quaternary alluvial fan development in southeast Spain. *In* Alluvial Fans: A Field Approach. *Edited by* A.H. Rachocki and M. Church, John Wiley and Sons, Toronto, 247-270.

HARVEY, A.M. and W. H. RENWICK. 1987. Holocene alluvial fan and terrace formation in the Bowland Fells, northwest England. Earth Surface Processes and Landforms, **12**: 249-257.

HOOKE, R. LeB. 1965. Alluvial fans. Unpublished Ph.D. thesis, California Institute of Technology, Pasadena.

HOOKE, R. LeB. 1967. Processes on arid-region alluvial fans. Journal of Geology, **75**: 438-460.

HOOKE, R. LeB. 1968. Steady-state relationships on arid-region alluvial fans in closed basins. American Journal of Science, **266**: 609-629.

HOOKE, R. LeB. and W.L. ROHRER. 1979. Geometry of alluvial fans: effect of discharge and sediment size. Earth Surface Processes, **4**: 147-166.

KESEL, R.H. 1985. Alluvial fan systems in a wet-tropical environment, Costa Rica. National Geographic Research, **1**: 450-469.

KUHN, T.S. 1970. The structure of scientific revolutions. University of Chicago Press, Chicago.

KNOX, J.C. 1972. Valley alluviation in southwestern Wisconsin. Annals, Association of American Geography, **62**: 401-410.

KOSTASCHUK, R.A., G.M. MacDONALD and P.E. PUTNAM. 1986. Depositional processes and alluvial fan drainage basin morphometric relationships near Banff, Alberta, Canada. Earth Surface Processes and Landforms, **11**: 471-484.

LECCE, S.A. 1988. Influence of lithology on alluvial fan morphometry, White and Inyo Mountains, California and Nevada. Unpublished M.Sc. Thesis, Department of Geography, Arizona State University.

LECCE, S.A. 1990. The alluvial fan problem. *In* Alluvial Fans: a Field Approach, *Edited by* A.H. Rachocki and M. Church, John Wiley and Sons, 3-26.

LEGGETT, R.F., R.J.E. BROWN and G.H. JOHNSTON. 1966. Alluvial fan formation near Aklavik, NWT, Canada. Geological Society of America Bulletin, **77**: 15-30.

LUSTIG, L.K. 1965. Clastic sedimentation in Deep Springs Valley, California. U.S. Geological Survey Professional Paper, **352-F**: 131-192.

MAIZELS, J. 1990. Long-term palaeochannel evolution during episodic growth of an exhumed Plio-Pleistocene alluvial fan, Oman. *In* Alluvial Fans: a Field Approach. *Edited by* Rachocki, A.H. and Church, M., John Wiley and Sons, Toronto, 271-304.

McARTHUR, J.L. 1987. The characteristics, classification and origin of the Late Pleistocene fan deposits in the Cass Basin, Canterbury, New Zealand. Sedimentology, **34**: 459-471.

MELTON, M.A. 1965. The geographic and paleoclimatic significance of alluvial deposits in southern Arizona. Journal of Geology, **73**: 1-38.

MIALL, A.D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. Canadian Society of Petroleum Geologists, Memoir **5**: 597-604.

NILSEN, T.H. and T.E. MOORE. 1984. Bibliography of alluvial fan deposits. Geobooks, Norwich, England.

O'HARA, S.L. 1986. Postglacial geomorphic evolution and alluvial chronology of a valley in the Dinosaur Badlands, Alberta. Unpublished M.Sc. Thesis, University of Alberta, Edmonton, Alberta.

PACKARD, F.A. 1974. The hydraulic geometry of a discontinuous ephemeral stream on a bajada near Tucson, Arizona. Unpublished Ph.D. thesis, University of Arizona, Tucson, Arizona.

RACHOCKI, A. 1981. Alluvial fans: an attempt at an empirical approach. John Wiley and Sons, Toronto, Canada.

RANNIE, W.F., L.H. THORLEIFSON and J.T. TELLER. 1989. Holocene evolution of the Assiniboine River paleochannels and Portage La Prairie alluvial fan. Canadian Journal of Earth Sciences, **26**: 1834-1841.

RYDER, J.N. 1971a. The stratigraphy and morphology of periglacial alluvial fans in south central British Columbia. Canadian Journal of Earth Sciences, **8**: 279-298.

RYDER, J.N. 1971b. Some aspects of the morphometry of periglacial alluvial fans in south central British Columbia. Canadian Journal of Earth Sciences, **8**: 1252-1264.

SCHUMM, S.A. 1977. The fluvial system. John Wiley and Sons, Toronto.

SCHUMM, S.A. and R.W. LICHTY. 1965. Time, space and causality in geomorphology. American Journal of Science, **263**: 110-119.

SURELL, A. 1841. Etude Sur Les Torrents Des Hautes Alpes, First Edition, Paris.

SUWA, H. and S. OKUDA. 1983. Deposition of debris flows on a fan surface, Mount Yakedale, Japan. Zeitschrift für Geomorphologie Supplementband, **46**: 79-101.

SYMINGTON, F. 1969. The Canadian Indian. McClelland and Stewart Publishing Company, Toronto, Canada.

WASSON, R.J. 1974. Intersection point deposition on alluvial fans: an Australian example. Geografiska Annaler, **56**: 83-92.

WASSON, R.J. 1977. Catchment processes and the evolution of alluvial fans in the Lower Derwent Valley, Tasmania. Zeitschrift für Geomorphologie Supplementband, **21**: 147-168.

WASSON, R.J. 1979. Sedimentation history of the Mundi Mundi alluvial fans, western New South Wales. Sedimentary Geology, **22**: 21-51.

WELLS, S.G. and A.M. HARVEY. 1987. Sedimentologic and geomorphic variations in storm generated alluvial fans, Howgill Fells, northwest England. Geological Society of America Bulletin, **98**: 182-198.

WILLIAMS, G.E. 1973. Late Quaternary piedmont sedimentation, soil formation, and paleoclimates in arid south Australia. Zeitschrift für Geomorphologie Supplementband, **17**: 102-125.

2.0 CHRONOLOGY AND DEVELOPMENT OF FINE-GRAINED ALLUVIAL FANS, DEADLODGE CANYON, DINOSAUR PROVINCIAL PARK, ALBERTA, CANADA*

* A version of this chapter has been submitted for publication. Seemann and Campbell. Canadian Journal of Earth Sciences.

2.1 Introduction

A series of fine-grained alluvial fans line the lower Red Deer River's Deadlodge Canyon in Dinosaur Provincial Park, Alberta (Plate 2.1 and Figure 2.1). Within this badland environment, fan deposits constitute approximately 25% of the area covered by surficial materials and play an important role in long-term sediment storage. These fans develop where ephemeral tributary channels emerge from valley-side catchments and flow onto the pointbars forming the Red Deer River floodplain. As the streams flow from the confines of their rugged badland catchments, changes in channel hydraulic geometry lead to a decrease in stream power, reduced stream competence, and sediment deposition.

Most geomorphic research in the badlands of Dinosaur Provincial Park has been process-oriented (Campbell 1970, 1974, 1982, 1987; Bryan and Campbell 1980, 1986) with little attention given to the region's numerous fans (O'Hara 1986; Bryan *et al.* 1987). O'Hara (1986), studying valley development in a tributary of the Red Deer River, estimated the age of arroyo-truncated fans to be greater than 5400 years old by correlating a superpositioned aeolian deposit on the fans to a similar deposit elsewhere in the park, dated at 5400 ±800 BP (Bryan *et al.* 1987). Widespread fan development was interpreted by O'Hara (1986) to have commenced in association with early-Holocene climatic warming (roughly 8000-9000 BP) and to have ceased during a period of maximum aridity (from about 5000-6000 BP) marked by the deposition of aeolian sediments. However, the absence of Mazama Ash, a regional chronostratigraphic marker (6845 ±50 BP, Bacon 1983), in any of the exposed fan deposits suggests a younger, more dynamic environment than originally proposed. Major questions, therefore, remain

Plate 2.1 1983 airphoto mosaic of a south-facing pointbar in Deadlodge Canyon, Dinosaur Provincial Park, Alberta. Note the pronounced scroll bar development and superpositioned fans prograding across the pointbar from adjacent badland catchments. Labelled fans F1 - F3 were surveyed in the present study and correspond to fans F1 - F3 in Figures 2.1 and 3.1.

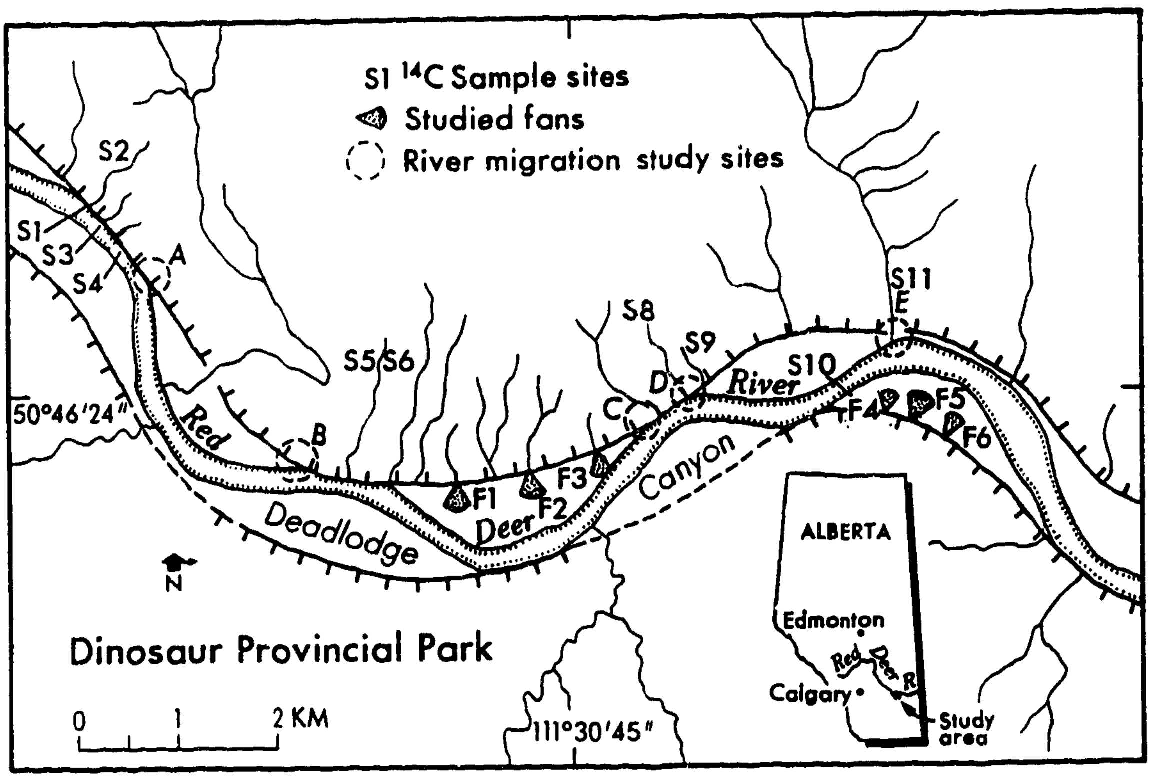


Figure 2.1 Location of study area and sampled sites within Deadlodge Canyon, Dinosaur Provincial Park, Alberta

concerning the age, rate of development and evolution of these fine-grained alluvial fans. This study interprets the chronology and development of fans within Deadlodge Canyon and proposes a model of fan evolution hinging on the rate of pointbar migration along the Red Deer River.

2.2 Regional Geology and Physiography

Fan source-area lithology is dominated by fine-grained clayey sandstones and mudrocks of the deltaic Upper Cretaceous Judith River -formerly Oldman- Formation (Koster 1984). This highly erodible bedrock is overlain by Quaternary fluvial, glacial and glaciolacustrine deposits (Koster and Currie 1987; Shetsen 1987)(Figure 2.2). Although the timing of regional Pleistocene glacial events remains uncertain, the history and sequence of Late Wisconsinan events have recently been proposed (Christiansen 1979; Dyke and Prest 1987; Bryan *et al.* 1987; Campbell and Evans 1990; Evans 1991; Evans and Campbell 1992; Rains *et al.* in press).

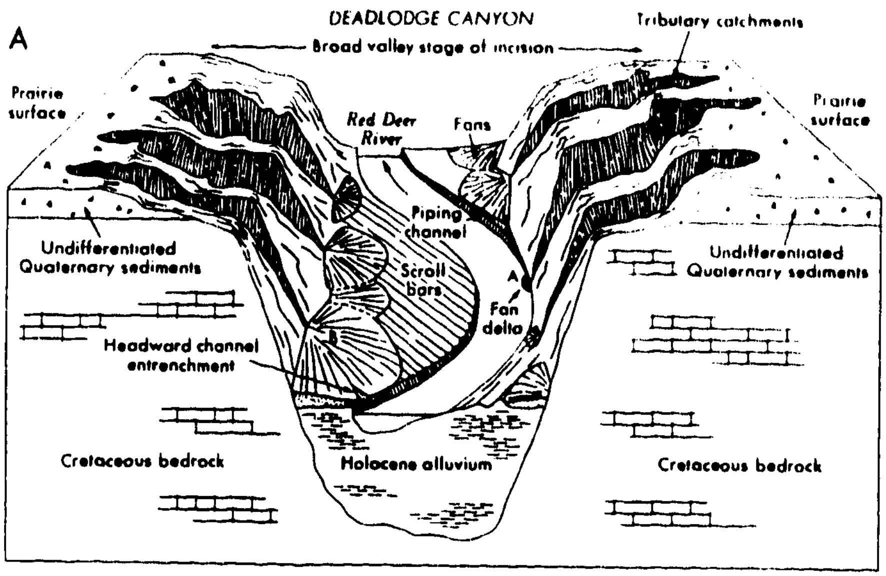
Following the retreat of the Laurentide Ice Sheet from the region, a series of large proglacial lakes developed (about 15,000 BP) along the ice margin (Teller 1987; Evans and Campbell 1992). Continued wasting of the ice front, augmented by increasing meltwater, culminated in the catastrophic drainage of the lakes to the southeast through a series of spillways (Kehew and Lord 1986, 1987). The largest of these spillway channels, in what is now the Red Deer River valley, developed rapidly through a two-stage degradational process (Bryan *et al.* 1987). Initial incision scoured a broad valley through surficial glacial and glaciolacustrine deposits, exposing the poorly consolidated

Judith River Formation. The second phase of erosion incised rapidly and cut deeply into the weak bedrock to form a valley floor as much as c. 100 - 120 m below the present prairie surface (McPherson 1968; Bryan *et al.* 1987). With such a low regional base-level, tributary channels actively enlarged their own catchments and contributed enormous sediment loads to the waning meltwater discharge of the Red Deer River. This progressive increase in the river's sediment load led to 30 - 50 m of valley in-filling and to the present valley-in-valley form (Figure 2.2). There are no radiometric dates available for the timing of this major incision of the Red Deer River. However, ^{14}C dates from Little Sandhill Creek, a tributary of the Red Deer River, indicate that deep valley incision had begun by at least 10,000 BP (Campbell and Evans 1990; Evans and Campbell 1992).

2.3 Study Area

Deadlodge Canyon, a 15 km reach of the Red Deer River, is located approximately 40 km northeast of Brooks, Alberta, in Dinosaur Provincial Park. The 'canyon', a valley up to 70 m deep and 1 km wide with a broad alluvial floodplain, dramatically dissects the southern Albertan prairie. Constrained predominantly by bedrock valley walls, the shallow and relatively "straight" Red Deer River maintains an average meander wavelength of approximately 3.1 km and a sinuosity (calculated as a ratio between the length of channel and the axial length of the valley) of 1.1 through Deadlodge Canyon (Neill 1965; Hydrocon Engineering 1986). Distinct scroll bar development on the river's pointbars are accentuated by preferential Cottonwood

A



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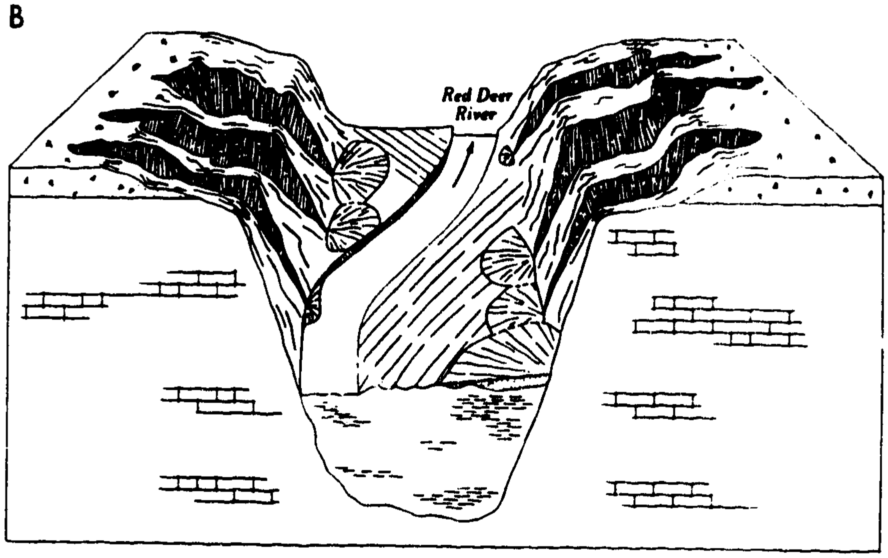

Figure 2.2 Schematic diagram illustrating the geomorphic features within Deadlodge Canyon and their evolutionary change with the down-valley migration of the Red Deer River. The fan at (A) in the upper diagram illustrates early fan development as a fan-delta progrades along the river's cutbank. The fan at (B) in the upper diagram shows fan truncation by basal sapping and stream headward entrenchment. The lower diagram illustrates relative fan development with the migration of the river to the left bank.

(*Populus deltoides*) and Buffalo Berry (*Sheppardia argentea*) growth and record the river's down-valley migration (Plate 2.1).

Several alluvial fans prograde across the floodplain and are actively engulfing the underlying scroll bars. These fans are silt dominated (Figure 2.3) and their gross surface morphology reflects the longitudinal concavity and transverse convexity characteristic of most fans. Fan axial length averages approximately 150 m yet may extend up to 250 m. Detailed surface morphology surveys on 6 fans (Figure 2.1) indicate that average surface gradient varies from 1.7° near the apex to 0.6° at the toe, while the mean fan relief is approximately 3.2 m (Table 2.1).

Fan vegetative cover is dominated by grass communities (*Stipa comata*, *Koeleria cristata*) near the apex and grades through a sagebrush-dominated community (*Artemisia cana*) to a shrub community (*Symphoricarpos occidentalis*) at the toe (Seemann and Chesterman in prep.). Valley-side slopes within the contributing basins are steep and largely devoid of vegetation, while the valley floors are grass covered.

2.4 Rate of Fan Development

The age and rate of fan development in Deadlodge Canyon may be inferred from three independent lines of evidence: 1) minimum estimates of fan age can be established by comparing mean annual catchment erosion rates and sediment supply to fan volumes; 2) maximum or limiting estimates of alluvial fan age can be approximated by determining the Red Deer River's mean rate of lateral migration (down-valley pointbar shift) within Deadlodge Canyon; and, 3) radiocarbon dates obtained from basal

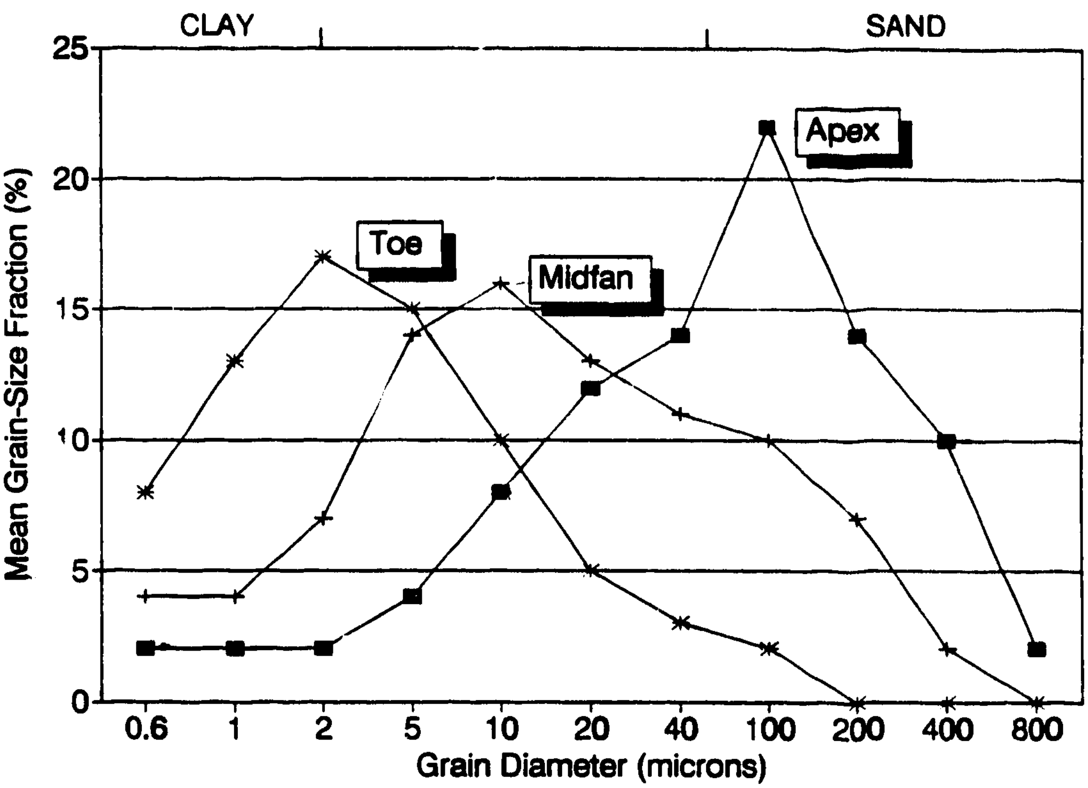

Figure 2.3 Mean grain size distributions of fan surface samples (0 - 30 cm) at apex, mid-point and toe of fans F2 and F5 (see Figures 2.1 and 3.1). Down-fan fining varies from very fine sands at the apex to clays at the toe.

Table 2.1 Fan morphometric characteristics

Fan No.	Fan length (m)	Fan longitudinal gradient: Upper third (°)	Middle third (°)	Lower third (°)	Relief (m)
1	130.1	2.3	1.5	0.5	3.36
2	236.0	1.1	1.7	0.7	4.93
3	152.6	1.2	1.6	1.0	3.41
4	104.0	2.6	1.7	0.3	2.36
5	220.0	1.0	0.9	0.3	2.93
6	114.1	2.2	1.6	0.9	2.30
Means	159.4	1.7	1.5	0.6	3.22

and within-fan deposits can be used to corroborate the minimum and maximum estimates of fan development obtained by the first two techniques.

2.4.1 Catchment Erosion and the Rate of Fan Development

Three north-facing and three south-facing fans (Figure 2.1) were used to estimate fan age by comparing their catchment sediment-supply rates to their respective fan volumes (Table 2.2).

Sediment supply rates to fans were calculated using measurements of basin surface area and mean annual erosion rates. The contributing basin surface area was delimited on 1:10,000 scale panchromatic air photographs (AS 2682, 77-113) and measured with a Ushikata 360d computing planimeter. The areas of the contributing basins were defined by the peripheries of the badland catchments as both surface sediment supply and runoff from the prairies were found to be negligible (Underhill 1962; Campbell 1974; Prairie Farm Rehabilitation Administration 1983). Areas of the contributing basins were adjusted to account for the steep badland catchment slopes by using Lustig's (1965) formula:

[1] $$S_b = P_b / \cos \theta$$

where, S_b is the surface area of the basin; P_b is the planimetric area of the basin; and, θ is the mean basin slope of 28° (Campbell 1970)(Table 2.2). Mean annual surface erosion rates in the Dinosaur Provincial Park badlands have been measured in both a ten-year study of badland erosion (Campbell 1982) and calculated on the basis of a variety of sediment load studies of ephemeral streams (Bryan and Campbell 1980, 1986). Both

Table 2.2 Fan ages based on fan size and erosion rates in contributing basins

	South facing fans			North facing fans			
Fan Number	F 1	F 2	F 3	F 4	F 5	F 6	Mean
Fan Relief (m)	3.36	4.93	3.41	2.36	2.93	2.30	3.21
Fan Radius (m)	130	236	152	104	220	114	159
Fan Area (x 10^3 m^2)	13.7	41.6	11.8	21.5	81.2	19.0	31.5
Basin Area (x 10^3 m^2)	157.9	215.6	203.0	86.5	619.4	169.5	242.1
Fan Volume (x 10^3 m^3)	65.3	329.8	90.5	40.1	254.1	43.1	136.9
Basin Sediment Yield (m^3/yr)	631.4	862.3	812.2	346.1	2477	677.9	967.8
Estimated Fan Age (yr)	104	382	111	116	103	64	146.6

types of study indicate average badland erosion rates of approximately 4.00 mm/year. Combining this erosion rate with the basin surface area calculations allows an estimate of the potential mean annual sediment supply to fans.

Estimates of the supply and volume of material in the alluvial fans requires three assumptions. First, the sediment delivery ratio from the basins to the fans is assumed to be 100 %. Second, the relatively small size of the fans (mean fan length = 159 m; mean relief = 3.2 m) means minor irregularities in fan geometry, due to longitudinal surface concavity and transverse surface convexity, are negligible in the calculation of fan volume. Third, as fans approximate a segment of a cone, the mean fan radius can be used to estimate fan volume. Thus:

[2] $$F_v = P\,[O.5(h \times r)]$$

where, F_v is fan volume, P is the fan toe perimeter length, h is the height of the fan apex above the lowest point at the fan toe, and r is the mean fan radius. Values for P, h, and r were obtained through a detailed survey of six fan surfaces (Figure 2.1).

Palynological and sedimentological examination of lacustrine deposits on the southern Alberta high plains shows that the present climate has more or less prevailed over the past three millennia and lacustrine depositional rates have generally remained uniform (Sauchyn 1990; Vance 1991). Assuming that catchment erosion conditions mirror the behaviour of these lacustrine depositional basins, it appears that the Deadlodge Canyon fans have developed fairly rapidly (mean fan age = 147 years). This, however, also assumes that all sediment eroded from the basin is deposited on the fan and is stored as defined in equation 2. In fact, erosion and sediment transport are not uniformly constant processes in the badlands (Campbell 1989) and some in-basin storage or fan backfilling (Harvey 1989) occurs. In addition to variations in sediment delivery ratios, the fan volume, as defined in equation 2, does not account for the volume of subsurface fan sediments which may have interdigited with pointbar sediments during the early stages of development. Therefore, these calculations likely provide only a minimum estimate of fan age.

2.4.2 River Migration and the Rate of Fan Development

Two sets of panchromatic air photographs (1950: 1:40,000 and 1988: 1:30,000) record a 38 year period of pointbar migration along part of the Red Deer River. Comparing five sites within Deadlodge Canyon (Figure 2.1) a mean migration rate of 2.8 m/year (range: 4.2 to 0.8 m/year) over nearly 40 years was calculated (Table 2.3). This 38 year record confirms earlier estimates of down-valley pointbar migration. Neill (1965) and Kondla and Crawford (1971) estimated lateral migration rates on the lower Red Deer River to approximate 3.0 m/year and 3.3 m/year, respectively, though their measurements were based on 11 and 19 year periods. Similarly, Hickin and Nanson (1984), studying the influence of grain size on river migration, found down-valley pointbar migration rates on the comparable Milk River to be 3.00 m/year.

Given the Red Deer River's meander wavelength of approximately 3.1 km and a relatively rapid down-valley migration rate of 2.8 m/year, complete pointbar replacement within Deadlodge Canyon occurs on an approximately 1100 year cycle. Within this replacement cycle, however, the 2.5 km long pointbars migrate past any

Table 2.3 Estimated rates of pointbar migration at five sites (see Figure 2.1) along Deadlodge Canyon

Site	Site environment	Migration distance in 38 years (m)*	Migration rate (m/year)
A - Jackknife Cr Flats	Erosional	152	4.0
B - Jackknife Cr Flats	Depositional	30	0.8
C - Cottonwood Flats	Depositional	91	2.4
D - Dunbar Flats	Erosional	160	4.2
E - Dunbar Flats	Depositional	99	2.6
Mean:	---	106.4	2.8

* Measurement error is estimated to be accurate within ±15m

given point within Deadlodge Canyon in about 900 years. Therefore, the maximum age of Deadlodge Canyon fans, which are limited by the presence of a migrating pointbar at the tributary mouth, appears to be in the order of 900 years.

2.4.3 Radiocarbon Dates and the Rate of Fan Development

Radiocarbon dates from ten bone and one wood sample in truncated fan exposures in Deadlodge Canyon (Table 2.4; Figure 2.4) all fall within the minimum and maximum fan age approximations determined by the rates of sedimentation and pointbar migration.

Samples 2, 3, 4, 7, 9 and 10 were obtained from remnant fan deposits exposed in the cutbank of the Red Deer River and suggest that fan accretion of up to some 1.5 m has occurred over the last 600 years. Similarly, samples 1, 5, 6, 8 and 11 indicate that active tributary valley-side fan development has occurred over roughly the last 450 years with the deposition of up to 2 m of alluvium.

Sample 10, obtained from the base of a fan deposit exposed in the cutbank of the Red Deer River, dated at 210± 90 BP which is beyond the reliable testing limits of conventional radiocarbon dating. Despite the ambiguous ^{14}C activities of such young samples, however, an age of less than 300 BP can be confidently assigned (Taylor 1987). Thus, this sample suggests active fan aggradation had continued into the last few hundred years before the onset of fan truncation by the Red Deer River.

The eleven radiocarbon dates, combined, indicate a mean vertical accretion rate on the upper fan of 3.8 mm/year (Table 2.4) for the uppermost fan deposits. Assuming relatively uniform late Holocene depositional rates (Sauchyn 1990; Vance 1991), linear

Table 2.4 Basal and within-fan radiocarbon dates from Deadlodge Canyon

Sample No.	Location down-fan	Burial depth (cm)	Material	Stratigraphic position	Date	AECV Number	Deposition rate (mm/year)
S1	mid-fan	109	bone	in-fan	350± 90	1282C	3.1
S2	apex	47	bone	in-fan	190± 90	1281C	2.4
S3	apex	138	bone	in-fan	440± 90	1280C	3.1
S4	apex	102	bone	in-fan	670± 90	1271C	1.5
S5	mid-fan	194	bone	in-fan	190± 90	1279C	10.2
S6	mid-fan	45	bone	in-fan	180± 90	1270C	2.5
S7	apex	20	bone	in-fan	250± 90	1277C	0.8
S8	mid-fan	40	bone	in-fan	260± 90	1278C	1.5
S9	apex	143	bone	in-fan	530± 90	1274C	2.7
S10	mid-fan	184	wood	fan-base	210± 90	1275C	8.8
S11	mid-fan	210	bone	in-fan	450± 90	1272C	4.7

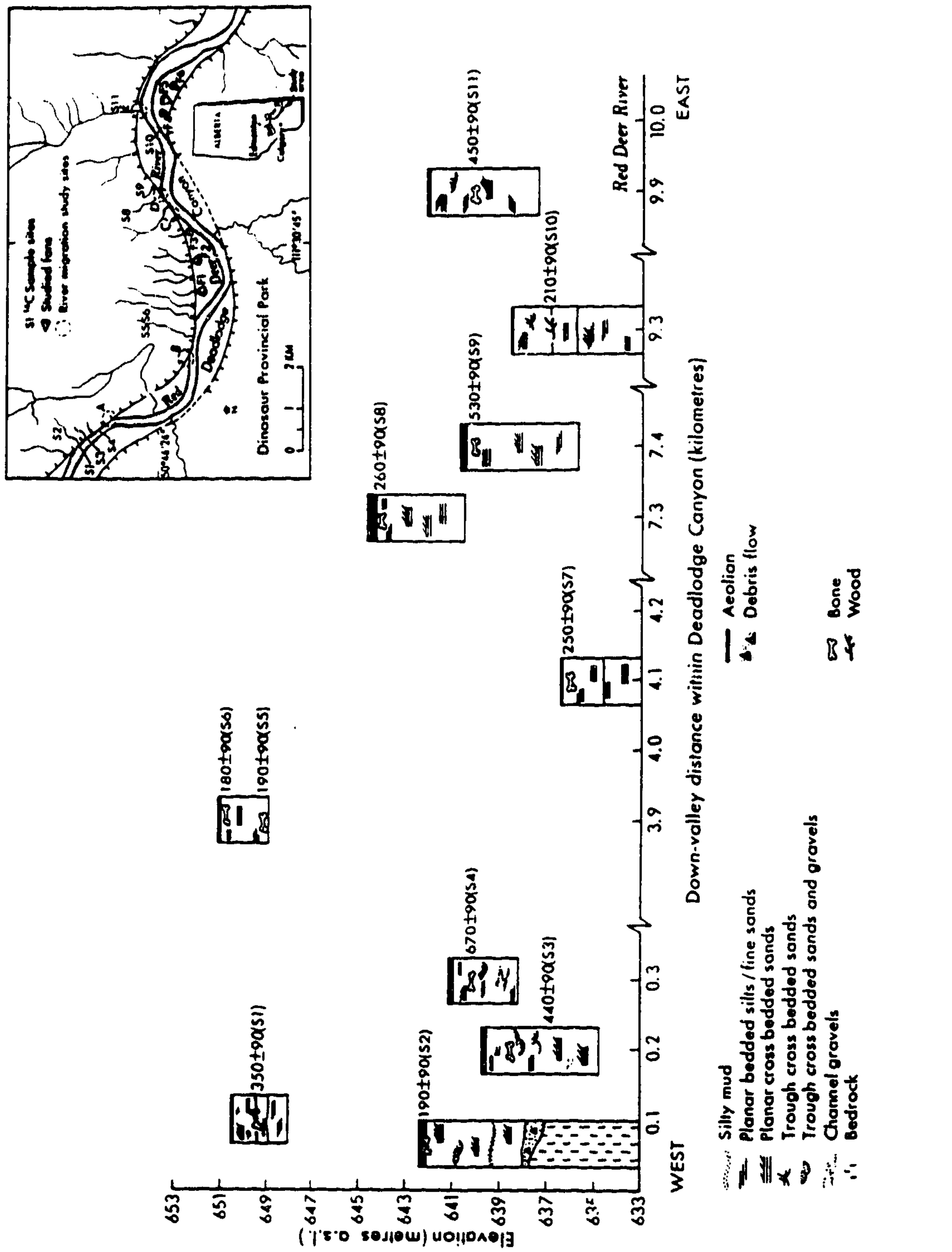

Figure 2.4 Logged sections along the Red Deer River valley axis illustrating stratigraphic context at the sites from which radiocarbon samples were obtained

extrapolation of this accretion rate over a mean fan thickness of 3.22 m (Table 2.1) suggests an average fan age of approximately 850 years and confirms the maximum age estimate based on the down-valley river migration rate of the pointbars on which the fans have accumulated.

In summary, the outlined approximations of fan ages within Deadlodge Canyon collectively suggest substantial fan development has occurred within the last millennium and attest to the dynamic geomorphic environment of the region. An empirical estimate of fan age, based on assumed maximum basin sediment delivery rates and fan volume, suggests a mean minimum fan age of about 150 years, while down-valley river migration rates suggest a maximum fan age of approximately 900 years. Within-fan radiocarbon samples obtained in Deadlodge Canyon both confirm and support these minimum and maximum estimates by consistently producing ages which fall within this range.

2.5 Geomorphic Evolution of Deadlodge Canyon Fans

The geomorphic evolution of the fans in Deadlodge Canyon is inextricably linked to the down-valley migration of the Red Deer River's pointbars. The cyclical development and destruction of the fans occurs in response to stream gradient changes on the fan surface that occur with the passing of the pointbar (Figure 2.2). At the mouths of tributaries in which the tributary sediment supply rate exceeds that of river erosion, fan growth begins as small fan-deltas at the base of the river's cutbank. With the approach of the pointbar, on-lapping of river alluvium commences and a progressive interdigitation of fan and floodplain deposits ensues. Valley in-filling or fan backfilling accompanies the gradual vertical accretion of sediment as the tributary stream grades to its new base level. The accretion of sediment is characterised by the fluvial deposition of low angle, planar laminations of fine sand and silt at the apex, grading to micro-laminations of silt and clay at the toe. While an overall down-fan fining of sediment is clearly evident (Figure 2.3), particle size sorting on these fan surfaces does not appear to improve distally. This effect is a function of the prevalent high magnitude, low frequency runoff events which transport sediment to the fans and the presence of bedrock-derived swelling bentonitic clays (Campbell 1987) which impede infiltration. Episodic, large runoff events and relatively impermeable fan surfaces allow transportation of coarser material further down-fan while the size of sediment introduced to the fan remains more or less constant.

The eventual destruction of the fans occurs primarily by basal sapping of the pointbar cutbanks by the Red Deer River. However, there is also secondary erosion by piping and headward entrenchment. Undercutting of the cutbank and the progressive migration of the pointbar eventually leads to the truncation of superpositioned fans. This truncation results in a corresponding shortening of the stream length and a steepening of the local hydraulic gradient. The change in hydraulic gradient combined with such conducive site characteristics as high alkalinity (Bryan *et al.* 1988), high bentonite content (Bryan *et al.* 1984; Campbell 1987), and the presence of a number of low-permeability subsurface layers, provides an ideal environment for the development of piping channels (Jones 1981). Although small pipe conduits can be seen throughout the fan cutbank sections, dominant piping development occurs at the fan/floodplain contact

(Plate 2.2). Continued enlargement of these dominant piping channels frequently leads to roof collapse and further headward erosion (Plate 2.3).

The cyclical development of fans within Deadlodge Canyon occurs on approximately an 1100 year cycle; and, both palynological and sedimentologic records indicate climatic conditions similar to those at present have prevailed over the last 3000 years (Sauchyn 1990; Vance 1991). Therefore, it is probable that several fan-building cycles have occurred during the late Holocene as regular replacement of the Red Deer River's pointbars occurs. Evidence for at least one such previous cycle is visible throughout Deadlodge Canyon. Isolated remnant fan surfaces, approximately 1-1.5 m higher than existing fans, are preserved within most tributary valleys where they are protected from erosion in the main Red Deer River valley. These older fan deposits are not dated. While they could represent the immediately preceding fan-building cycle, they may also reflect either a much older, more extensive episode of fan-building, or an older episode of fan-building which graded to a previous, higher baselevel in the Red Deer valley.

This model of rapid fan growth and erosion leads to two important points about the Deadlodge Canyon fans. First, with complete fan regeneration occurring approximately every 1100 years, the fans are not as old as their contributing basins. Thus, the functional fan-basin relationship outlined by Bull (1964), and widely published in the literature, can not be applied to these dynamic fan systems. Second, the rapid recycling of the fan materials is controlled by the rate of migration of the pointbars and is not directly a function of climatic controls except where climatic changes may

Plate 2.2 Piping channel mouth exposed along the cutbank of the Red Deer River. The mouth is approximately 1.8 m wide and 0.55 m high.

Plate 2.3 Stream headward entrenchment, looking up-fan toward the apex; near S3 (Figure 2.1). Field assistant for scale.

influence rates of sediment supply in the contributing basins or pointbar migration in the main Red Deer River valley. Without further dating control on older remnant fan surfaces, any effect mid-Holocene climatic changes may have had on fan development is indeterminate.

2.6 Conclusions

Silt-dominated alluvial fans have received little attention in Canada (Leggett *et al.* 1966; Keeble 1971) and have not been previously studied in detail in the badlands of southern Alberta. Alluvial fans in the Red Deer River's Deadlodge Canyon demonstrate that these small (< 300 m in length), low relief (< 5 m) features are linked to channel gradient changes on the fan surfaces resulting from pointbar migration down-valley. Cyclical fan development begins with the development of a fan-delta at the base of the Red Deer River's cutbank. Subsequent fan growth occurs with the approach of the migrating pointbar. Interdigitation of fan and floodplain sediments gradually results in lengthening of the tributary channel, and a corresponding fan backfilling as the channel grades to its new local base-level. Continued fan progradation is dominated by episodic fluvial deposition of very fine sands, silts and clays in response to sporadic, often high intensity convective storms. Eventual destruction of the fans occurs primarily by distal truncation due to basal sapping induced by the downstream-migrating channel. Secondary erosion by channel piping and headward entrenchment also contributes to the erosion of the fans.

Three independent estimates of fan age indicate that fan development occurs rapidly and that the Deadlodge Canyon fans are no more than 900 years old. Comparison of mean catchment erosion rates to fan volumes suggests minimum fan ages of 150 years., while estimates of mean down-valley river migration suggest a maximum fan age of 900 years. Eleven conventional radiocarbon dates obtained from remnant fan deposits in the cutbank of the Red Deer River confirm these minimum and maximum age estimates and suggest a mean vertical accretion rate of 3.8 mm/year. This model of fan development suggests that fine-grained fan growth in the Dinosaur Provincial Park badlands occurs cyclically, rapidly and independently of climatic changes.

2.7 References

BACON, C.R. 1983. Eruptive history of Mount Mazama and Crater Lake Caldera, Cascade Range, U.S.A.. Journal of Volcanology and Geothermal Research, **18**: 57-115.

BRYAN, R.B. and CAMPBELL, I.A. 1980. Sediment entrainment and transport during local rainstorms in the Steveville Badlands, Alberta, Canada. Catena, 7: 51-65.

BRYAN, R.B. and CAMPBELL, I.A. 1986. Runoff and sediment discharge in a semiarid ephemeral drainage basin. Zeitschrift für Geomorphologie Supplementband, **58**: 121-143.

BRYAN, R.B., CAMPBELL, I.A. and SUTHERLAND, R.A. 1988. Fluvial geomorphic processes in semiarid ephemeral catchments in Kenya and Canada. Catena Supplement, **13**: 13-35.

BRYAN, R.B., CAMPBELL, I.A. and YAIR, A. 1987. Postglacial geomorphic development of the Dinosaur Provincial Park Badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

BRYAN, R.B., IMESON, A.C. and CAMPBELL, I.A. 1984. Solute release and sediment entrainment on microcatchments in the Dinosaur Provincial Park badlands, Alberta. Canadian Journal of Hydrology, **7**: 79-106.

BULL, W.B. 1977. The alluvial fan environment. Progress in Physical Geography, **1**: 222-270.

CAMPBELL, I.A. 1970. Erosion rates in the Steveville Badlands, Alberta. Canadian Geographer, **14**: 202-214.

CAMPBELL, I.A. 1974. Measurement of erosion on badlands surfaces. Zeitschrift für Geomorphologie Supplementband, **21**: 122-137.

CAMPBELL, I.A. 1982. Surface morphology and rates of change during a ten year period in the Alberta Badlands. *In* Badland Geomorphology and Piping. *Edited by* R.B. Bryan and A. Yair. Geobooks, Norwich, England, 221-237.

CAMPBELL, I.A. 1987. Infiltration characteristics of badlands surfaces and storm runoff. *In* Proceedings, International Conference on Infiltration Development and Application, University of Hawaii, Honolulu, 251-260.

CAMPBELL, I.A. 1989. Badlands and badland gullies. *In* Arid Zone Geomorphology. *Edited by* D.S.G. Thomas, Halsted Press, New York, 159-183.

CAMPBELL, I.A. and EVANS, D.J.A. 1990. Glaciotectonism and landsliding in Little Sandhill Creek, Alberta. Geomorphology, **4**: 19-36.

CHRISTIANSEN, E.A. 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Sciences, **16**: 913-938.

DYKE, A.S. and PREST, V.K. 1987. Late Wisconsinan and Holocene history of the Laurentide Ice Sheet. Geographie physique et Quaternaire, **41**: 237-264.

EVANS, D.J.A. 1991. A gravel/diamicton lag on the south Albertan Prairies, Canada: Evidence of bed armouring in early deglacial sheet-flood/spillway courses. Geological Society of America Bulletin, **103**: 975-982.

EVANS, D.J.A. and CAMPBELL, I.A. 1992. Glacial and postglacial stratigraphy of Dinosaur Provincial Park and surrounding plains, southern Alberta, Canada. Quaternary Science Reviews, **11**: 535-555.

HARVEY, A.M. 1989. The occurrence and role of arid zone alluvial fans. *In* Arid Zone Geomorphology. *Edited by* D.S.G. Thomas, Halsted Press, New York, 136-158.

HYDROCON ENGINEERING LTD. 1986. Guidelines for flooding and bank stabilization - Dinosaur Provincial Park. Report to Alberta Parks and Recreation, Calgary, Alberta.

JONES, J.A. 1981. The nature of soil piping: a review of research. British Geomorphological Research Group, Research Monograph **3**: 1-301.

KEEBLE, A.B. 1971. The geomorphology of alluvial fans near Aklavik, NWT. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, Edmonton.

KEHEW A.K. and LORD, M.L. 1986. Origin and large-scale erosional features of glacial lake spillways in the northern Great Plains. Geological Society of America Bulletin, **97**: 162-177.

KEHEW A.K. and LORD, M.L. 1987. Glacial lake outbursts along the mid-continent margins of the Laurentide Ice Sheet. *In* Catastrophic Flooding: Binghampton Symposia in Geomorphology (International Series, Number 18). *Edited by* L. Mayer and D. Nash, Allen and Unwin Publishing, Boston, Massachusetts, 95-120.

KONDLA, N.G. and CRAWFORD, H.R. 1971. An ecological survey of Dinosaur Provincial Park. Report for Provincial Parks Planning, Recreation and Parks, Government of Alberta.

KOSTER, E.H. and CURRIE, P.J. 1987. Upper Cretaceous coastal plain sediments at Dinosaur Provincial Park, southeast Alberta. Geological Society of America Centennial Field Guide - Rocky Mountain Section, 9-14.

LEGGETT, R.F., BROWN, R.J.E. and JOHNSTON, G.H. 1966. Alluvial fan formation near Aklavik, NWT, Canada. Geological Society of America Bulletin, **77**: 15-30.

LUSTIG, L.K. 1965. Sediment yield of the Castaic Watershed, western Los Angeles County, California - A quantitative approach. U.S. Geological Survey Professional Paper, **422-F**.

McPHERSON, H.J. 1968. Historical development of the Lower Red Deer River Valley, Alberta. The Canadian Geographer, **12**: 227-240.

NEILL, C.R. 1965. Channel regime of the Lower Red Deer River. Alberta Research Council, Open file report 1965-b, Edmonton, Alberta.

O'HARA, S.L. 1986. Postglacial geomorphic evolution and alluvial chronology of a valley in the Dinosaur Badlands, Alberta. Unpublished M.Sc. Thesis, University of Alberta, Edmonton, Alberta.

PRAIRIE FARM REHABILITATION ADMINISTRATION. 1983. The determination of gross and effective drainage areas in the prairie provinces. Hydrology Report 104, PFRA, Hydrology Division, Regina, Saskatchewan, Canada.

RACHOCKI, A. 1981. Alluvial fans: an attempt at an empirical approach. John Wiley and Sons, Toronto, Canada.

RAINS, R.B., SHAW, J., SKOYE, R., SJOGREN, D. and KVILL, D. in press. Late Wisconsinan subglacial mega-flood paths in Alberta.

SAUCHYN, D.J. 1990. A reconstruction of Holocene geomorphology and climate, western Cypress Hills, Alberta and Saskatchewan. Canadian Journal of Earth Sciences 27: 1504-1510.

SHETSEN, I. 1987. Quaternary geology, southern Alberta. Alberta Research Council Map, Natural Resources Division, Terrain Sciences Department, 1:500,000.

TAYLOR, R.E. 1987. Radiocarbon dating: an archaeological perspective. Academic Press, Orlando, Florida, United States.

TELLER, J.T. 1987. Proglacial lakes and the southern margin of the Laurentide Ice Sheet. *In* North America and adjacent oceans during the last deglaciation. *Edited by* W.F. Ruddiman and H.E. Wright, Jr., Geological Society of America, Boulder, Colorado, 39-70.

UNDERHILL, A.G. 1962. Report on the effect of a change in vegetation on runoff and erosion characteristics of Alberta streams. Water Resources Division, Alberta Department of Agriculture, Edmonton, Alberta, Canada.

VANCE, R.E. 1991. A palaeobotanical study of Holocene drought frequency in southern Alberta. Unpublished Ph.D. Thesis, Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia.

3.0 VEGETATIVE PATTERN ON FINE-GRAINED ALLUVIAL FANS, DINOSAUR PROVINCIAL PARK, SOUTHERN ALBERTA

3.1 Introduction

The badlands of Dinosaur Provincial Park, Alberta form some of the most spectacular and dynamic erosional environments on the Canadian prairies. The high erosion rates (*ca.* 4 mm/year) typical of these environments produce fine-grained sediment loads in excess of *ca.* 1000 tonnes/km^2/yr (Campbell 1974, 1981, 1982; Bryan and Campbell 1980, 1986). Much of this sediment is transported via ephemeral streams to temporary storage in the alluvial fan systems which line many of the badland valleys. The largest of these fan systems prograde across the broad floodplain of the Red Deer River (Plate 2.1) and occasionally coalesce to form low-relief bajadas. In addition to their important geomorphic role in sediment storage (Harvey 1989) and their rapid development and progradation (Seemann and Campbell submitted), the fans also appear to have a significant biogeographic influence on floristic composition (Plate 3.1).

Although vegetational zonation of floodplain communities within the Dinosaur badlands of southern Alberta has been identified (Kondla and Crawford 1971), the marked gradational changes in floristic composition on alluvial fans have not been previously examined. The objectives of this study are to: 1) quantitatively identify the vegetative patterns present on the fan surfaces, and 2) relate those patterns to selected environmental factors.

3.2 Study Area

The alluvial fans along the lower Red Deer River within Dinosaur Provincial

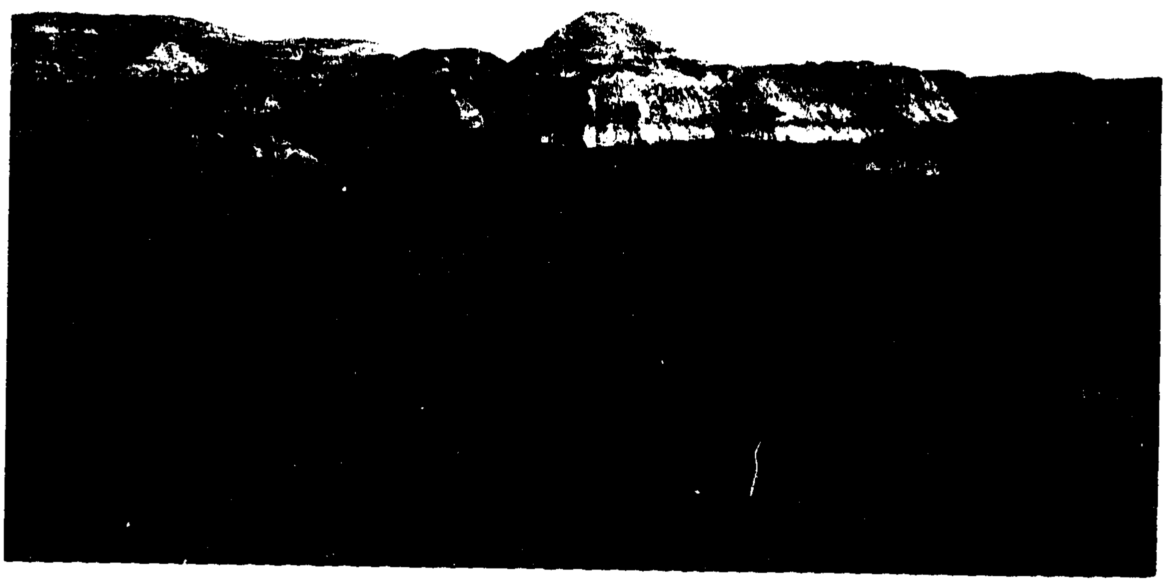

Plate 3.1 Marked vegetation change between the alluvial fan and floodplain communities. View up-fan (F2 in Figure 3.1) with floodplain community in foreground and alluvial fan community beginning immediately behind field assistant.

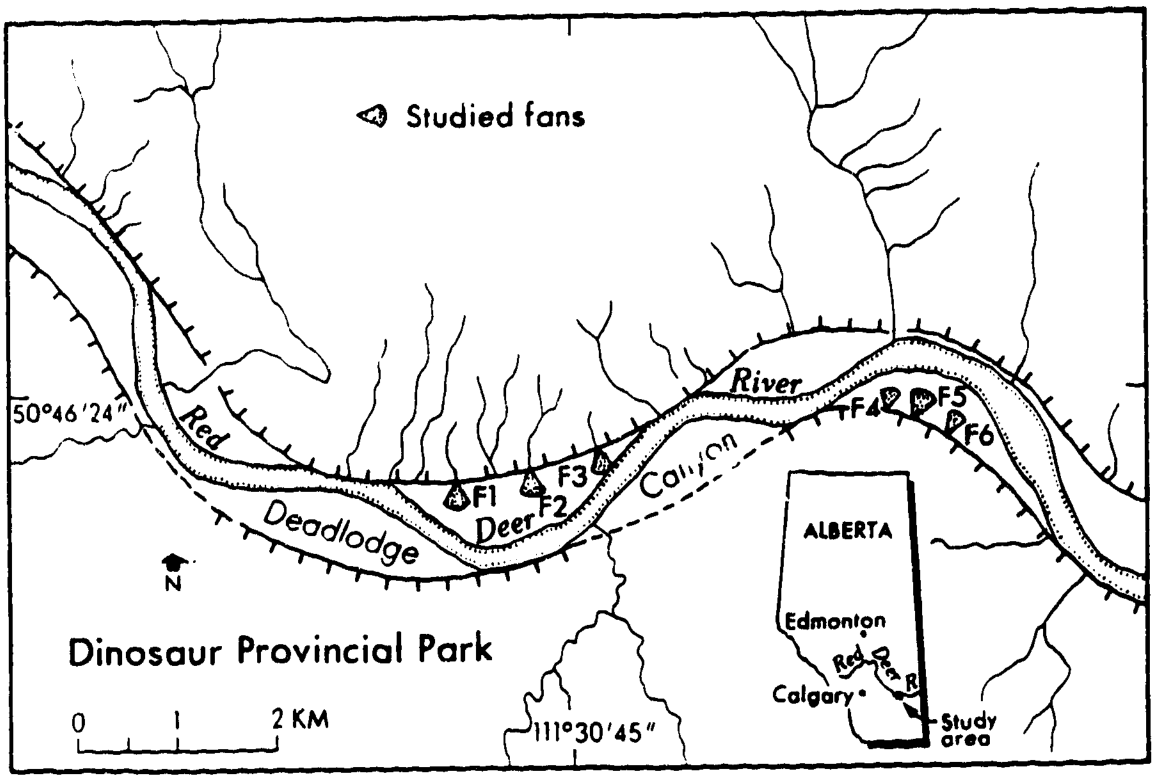

Figure 3.1 Location of Deadlodge Canyon and the surveyed alluvial fans (F1 - F6). Fans F2 and F5 were cored at apex, mid-fan and toe for soil samples.

Park, Alberta (Figure 3.1) form at the base of Deadlodge Canyon's valley walls, some 70 m below the adjacent prairie surface. These fine-grained fans (Figure 2.3) extend as much as 300 m across the 500 m wide pointbars of the Red Deer River and develop where ephemeral tributary streams deposit sediments as they exit adjacent badland catchments. The fans typically exhibit a longitudinal surface concavity and a distinct down-fan fining of sediments (Figure 2.3), which reflect the increasingly diffuse nature of fan surface runoff from apex to toe.

Two sets of fans were studied, with three fans in each set: the first, on the north side of the river and the second, four kilometres downstream, on the south side of the river (Figure 3.1). Of the six fans examined, the average fan length was 154 m and the mean fan gradient varied from 1.7 ° near the apex to 0.6 ° at the toe. The vertical relief of the fans ranged from 2.3 to 4.9 m while the average feature relief was 3.2 m (Table 2.1). There were no significant signs of anthropogenic disturbance, although some light grazing by cattle may have occurred within the last 150 years (Todd Irwin, pers. comm., 1990).

3.2.1 Local Geology and Physiography

Fan source area geology consists predominantly of deltaic, Upper Cretaceous, Judith River (formerly Oldman) sediments (Dodson 1971; McLean 1971; Koster 1984). These weakly indurated sandstones and sandy mudrocks are overlain by poorly consolidated, Late Pleistocene glacial and glaciolacustrine deposits of varying thicknesses (Koster 1984; Shetsen 1987; Campbell and Evans 1990). Post-glacial incision through these deposits was initiated by catastrophic drainage of Late Wisconsinan ice marginal lakes (Teller 1987; Kehew and Lord 1987). Subsequent rapid fluvial downcutting through these weak sediments, combined with later subaerial erosion, has created an extensive area of badlands (Bryan *et al.* 1987; Evans and Campbell 1992). Regional prairie soils are generally classified as Brown Solodized Solonetz (Clayton and Marshall 1972; Kjearsgaard *et al.* 1983); yet poorly developed Orthic Regosols predominate on the fan surfaces.

3.2.2 Regional Climate and Vegetation

The study area lies in the semiarid Short Grass ecoregion (Köppen: Bsk) of southern Alberta. Mean annual precipitation, averaging *ca.* 350 mm, falls primarily during short, moderate-intensity summer rainstorms (Bryan and Campbell 1980; Strong and Leggat 1981). Data from the Brooks One Tree meteorological station, 20 km southwest of the study area, indicates 89% of rainfall and 65% of total precipitation falls within the period May to September (Environment Canada 1982). Snowfall contributes approximately one third of the total mean annual precipitation, but high winds rapidly remove any snow accumulating on exposed, open and relatively flat-lying areas (Harty 1984). Mean monthly temperatures range from 18°C in July to -14°C in January. Alternating warm maritime and cold continental air masses produce dramatic temperature variations year around, especially during the winter months (July: 4°C - 36°C ; January: 8°C - -38°C). Westerly chinook (föhn) winds during the winter and early spring also contribute to the dramatic range of temperatures, promoting early snow melt episodes

(Harty 1984) and soil dessication (Moss 1944).

The regional vegetation is broadly classed as a grassland community and has been variously defined as a "mixed-grass" prairie association (Coupland 1950; Sims and Coupland 1979) and as a "short-grass" prairie association (Sims *et al.* 1978; Strong and Leggat 1981). Regardless of the classification, the region is characterized by the presence of six key graminoids (Coupland 1950; 1952). Considered to be the principle grassland climax community species, *Stipa comata*, *S. spartea*, *Koeleria cristata*, *Agropyron smithii*, *A. dasystachum* and *Bouteloua gracilis* predominate as the natural upland vegetation (Coupland 1952). Much of the upland areas surrounding Dinosaur Provincial Park have been either cultivated for cereal crop production or heavily grazed as pasture land; therefore, do not reflect the natural grassland climax community.

3.3 Methodology

In order to minimize the effects of anthropogenic disturbance, three north-facing and three south-facing alluvial fans were selected from within the natural preserve, a restricted-access area, of Dinosaur Provincial Park (Figure 3.1). A single axial transect was surveyed down the length of each fan from apex to toe and the floristic composition was sampled at 10 m intervals along the transect. At each sample site, percent vegetative cover was recorded in 10 - 0.5 m x 0.5 m quadrats placed systematically about the site (Figure 3.2) and then averaged for the site. Cover data were estimated visually and the half-meter quadrats were used to enhance the precision of visual estimation. A total of 1070 quadrats were surveyed, 590 on south-facing fans and 480 on north-facing fans.

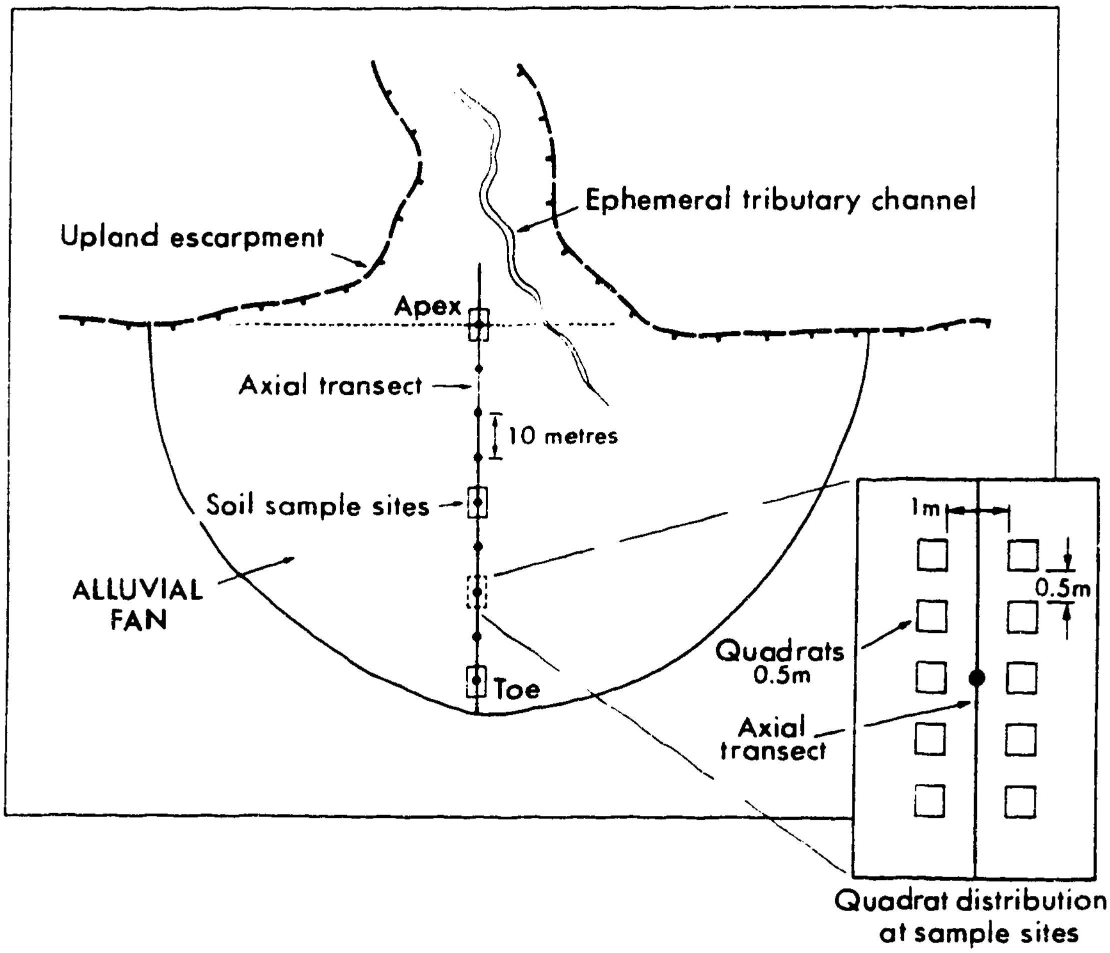

Figure 3.2 Schematic of fan vegetative cover sampling pattern along a single axial transect longitudinally bisecting the fan. Inset shows detailed quadrat survey pattern at each site.

The nomenclature adopted follows Moss (1983) and measurements were conducted during fair weather to minimize the effects of wind on the estimations. Vascular plants, lichens, mosses, litter, bare ground and standing dead plants were estimated in the field plots between July 11 to August 7, 1990; cover estimates may, therefore, under-represent some spring ephemerals.

3.3.1 Environmental Parameters

The influence of sample site aspect (north/south), slope angle, position (percent distance down-fan), litter and bare ground were considered as environmental variables possibly influencing vegetative pattern on all six fans. In addition to these variables, analysis of grain-size, nutrient levels, pH, salinity and moisture on one north-facing and one south-facing fan was undertaken to assess their influence on the species data.

Soil samples were taken at apex, mid-fan and toe positions along two of the fans, one north-facing (F2 in Figure 3.1) and one south-facing (F5 in Figure 3.1). Cores (∅ = 2.5 cm) were taken from the rooting zone, defined as 0 - 30 cm by Sims and Singh (1971), at each of the three positions. Samples were weighed, frozen within 8 hours and transported to the laboratory for analysis. Upon thawing, soil subsamples were oven-dried over 24 hours to determine gravimetric moisture content and air-dried for textural analysis (Klute 1986) using both hydrometers and a Micromeritics 5100 sedigraph. Samples were dispersed in a sodium hexa-metaphosphate (5%) solution for 24 hours to ensure complete disaggregation of fine silts and clays. Soil organic content, NH_4-N, PO_4-P, K, Na, SO_4-S, pH, and electrical conductivity were analyzed by Alberta

Agriculture's Soil and Animal Nutrition Laboratory following standardized techniques outlined in Klute (1986) and Page (1982).

3.3.2 Data Analysis

To enable direct examination of the cover data and confirm the observed floristic pattern, the abundance scores from the sample sites on each fan were arithmetically standardized over 12 fan slope units (FSU). For illustrative purposes, FSU 1-12 represent mean cover values from apex to toe on south-facing fans, while FSU 13-24 represent mean cover values from toe to apex on north-facing fans. The total of 24 fan slope units, so defined, therefore descriptively represent the north-south trends in vegetative cover exhibited on the alluvial fans within Deadlodge Canyon.

Empirical analysis of vegetative pattern and its relationship with the specified environmental variables was carried out using CANOCO, a FORTRAN program specifically designed to discern such ecological relationships (ter Braak 1987a,b; 1990). An extension of DECORANA (Hill 1979), this program provides six types of multivariate gradient analysis for direct (constrained) and indirect (unconstrained) ordination of the data.

Mean site abundance values for each vascular species, lichen and moss were used in analyzing the species-environment relationships. Preliminary analysis of the vegetation data using detrended correspondence analysis (DCA) demonstrated a linear ordination technique was most appropriate for the data as the length of the first ordination axis was only 2.34 standard deviation units (ter Braak 1987a). Ordination axes greater than 4.00

standard deviation units indicate a strong non-linear relationship between the data and the measured environmental variables (ter Braak 1987a). Principle component analysis (PCA), an unconstrained form of linear ordination, was therefore used to analyze the raw data. Strong multicollinearity was found among several of the environmental variables tested. Forward selection of these variables, a feature of CANOCO (ter Braak 1990), was used to minimize the number of variables analyzed without losing their explanatory power over the species data set. A Monte Carlo permutation test (ter Braak 1987a; 1990) verified and was used to ensure the statistical significance of the environmental variables chosen ($P = 0.05$).

3.4 Results

3.4.1 Direct Examination of the Vegetation Data

Averaging the percent cover of individual species across each of 24 fan slope units (Table 3.1) demonstrates that several species are preferentially distributed down the length of the fans. Figure 3.3 indicates some of the dominant species on the fans and illustrates their relative positions on the fan surfaces. *Calamovilfa longifolia*, *Sphaeralcea coccinea*, *Bouteloua gracilis* and *Stipa comata* are largely restricted to the upper fan and are more abundant on south-facing slopes. Similarly, lichen, while most abundant on upper fan surfaces, diminishes down-fan regardless of aspect. *Agropyron smithii* and *Artemisia cana* are present across all fan slope units yet peak within mid-fan slopes of both north- and south-facing fans. In contrast, *Agrostis scabra*, which is also ubiquitous across all fan slope units, decreases slightly on mid-fan slopes. *Solidago*

TABLE 3.1 Mean percent cover of surveyed plant species across both south-facing fan slope units (FSU 1 - 12) and north-facing fan slope units (FSU 13 - 24). Abundance values are arithmetic means with values less than 0.01 identified as trace values (T). Species order connotes diminishing relative abundance over all six fans

Species	Fan slope units 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Artemisia cana	2.25	3.51	3.50	4.01	12.20	11.55	9.90	7.26	10.17	6.12	3.90	9.61	4.13	2.22	11.54	16.26	8.35	9.69	18.64	19.03	10.15	11.07	3.06	2.30
Symphoricarpos occidentalis					0.77	1.70	4.49	9.15	10.09	17.00	17.07	12.76	25.14	15.16	9.38	3.09	4.96	1.62	8.84					
Agropyron smithii	0.13	0.20	0.52	1.03	1.15	[illegible]	9.95	1.06	1.03	0.47	0.31	0.48	0.10	0.13	0.21	0.90	0.81	1.23	0.74	0.77	0.96	0.60	0.50	0.11
Artemisia frigida	0.01	0.22	0.51	0.01	0.11	0.35	0.30	2.47	0.09							0.03			0.03	3.43	0.35	3.05	0.42	0.32
Stipa comata	0.56	1.79	0.52	0.77	0.46	0.17	0.99	0.10	0.01			0.03							0.01	0.02	2.45	0.64	1.10	0.70
Rosa woodsii								0.11	1.39	0.07	1.90	0.21	0.70	2.02	0.03	0.02								
Agrostis scabra	0.26	0.14	0.13	0.07	0.04	0.04	0.04	0.03	0.09	0.09	0.05	0.30	0.14	0.25	0.19	0.13	0.09	0.20	0.04	0.05	0.02	0.03	0.06	0.31
Opuntia ...acantha		0.10	0.51	0.07		0.03		0.17									0.14			0.02	0.67	0.19	0.10	0.10
Stipa viridula	0.01	0.01	0.02	0.05	0.16	0.33	0.19	0.31	0.37	0.10	0.60	0.01	0.01			0.02	0.02	0.03	0.10	0.02			0.05	T
Koeleria cristata	0.05	0.11	0.05	0.02	0.07	0.24	0.04	0.11	0.27	0.04		0.02	0.01	T	0.01	0.03	0.03	0.06	0.03	0.07	0.08	0.06	0.03	0.06
Plantago patagonica	0.25	0.22	0.11	0.03	0.02		0.01	0.01	T			0.01		0.03	0.02		0.01					0.01	0.05	0.23
Solidago missouriensis						0.02	0.07	0.07	0.04	0.24	0.11	0.37	0.09	0.05	0.16	0.01	0.03	0.07						
Erigeron caespitosus	0.02	0.01	0.08	0.01																			0.03	0.01
Bouteloua gracilis	1.07	0.96	0.72	0.67	0.26	0.11	0.06	1.77	0.01											T	0.03	0.06	0.09	0.40
Eurotia lanata	0.60	0.02	0.13		0.27	0.31	0.01	0.01	0.01	0.19	0.02									0.01	0.36	0.42	1.96	0.05
Calamovilfa longifolia	1.23	0.49	0.11	0.08	0.19	0.04	0.06	0.01												T				T
Sphaeralcea coccinea	0.08	0.51	0.13	0.09	0.11			0.04				0.01										0.09		0.13
C... umbellata	0.12	0.06	0.16	0.07	0.03	0.07		0.02	T		0.01							0.03	0.01	0.01	0.06	0.10	0.08	0.04
Aster laevis									0.05	0.02	0.95		0.20	0.32	0.06	0.01	0.02							
Aster ericoides												0.02	0.39	1.31	0.05	0.34	0.13		T					
Allium textile	0.02	T	0.01	0.02	0.04	T	0.01	0.02	0.01		T												T	0.01
Lepidium densiflorum			0.01	0.02	0.01	0.01	0.06	0.04	0.01			0.05				T								
Lomatium foeniculaceum	0.04	0.04	0.02	0.04	0.02	0.01	T		0.01											T				
Chenopodium album				0.01	0.02	0.01		T	0.06	T	0.02	.2	T	0.02	0.01	T	0.02		0.01					
Grindelia squarosa											02	1.06	0.16	0.09	0.11	0.09								
Achillea millefolium										0.13	0.01	0.07	0.14				0.02	0.02	0.04					
...menoxis richardsonii	0.01	0.04				T		T																T
Gutierrezia sarothrae	0.02	0.01								0.02	0.05								T					
Oryzopsis hymenoides	0.01	0.02	1.16	0.01			T											T	0.01	0.02				
Descurainia pinnata						T	0.01	0.01	0.12			0.04	0.01											
Fritillaria pudica	0.01	0.02		0.02	0.01			0.01																
Agropyron spicatum				0.02									0.03		T	T							T	0.02
Linum lewisii	0.04															0.01	T		0.01	0.01				
Vicia americana				T					0.05	0.01	0.03	T							T	T				
Taraxacum officinale											0.19	0.02		0.01										
Phlox hoodii						0.04							0.01										T	0.02

Species	Fan slope units 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Smilacina stellata							0.06	0.09	0.01	0.13	0.04	0.06		0.01										
Carex brevior	0.01	0.01	0.16	T	T		T	0.02	0.02	T	0.03													
Populus deltoides								0.17	0.67		0.10	11.80	7.1											
Thermopsis rhombifolia	0.13					0.49	0.15	1.19				0.63												
Lappula squarosa	0.02	0.01		T	T			T				0.01									0.02			
Viola adunca										0.01	0.03	0.07												
Astragalus sp.				T											0.01	T								
Heterotheca villosa				0.05	T											0.01								
Carex stenophylla												0.23	0.03											
Fragaria virginiana											0.09			0.02										
Astragalus striatus					0.01															0.01				
Polygonum arenastrum												0.01	0.01											
Castilleja sp.												0.06												
[illegible] *ensis*	0.02																							
[illegible] *sericea*	0.02																							
[illegible] *occidentalis*							0.01																	
[illegible] *vivipara*	0.07		0.01	0.02							T												0.01	0.07
[illegible] *holboellii*			T	0.01	0.01	T		0.01	T															
Sa[illegible]								1.90		2.90	0.09													
Tragopogon dubius		0.04									0.03	0.05												
Agropyron dasystachyum		0.02		0.04	0.02																			
Clematis ligusticifolia											0.01	0.95												
Campanula rotundifolia										0.06	0.01													
Betula occidentalis												2.54												
Helianthus annuus												0.16												
Shepherdia argentea											0.13													
Epilobium sp.											0.07													
Koeleria macrantha	0.07																							
Amaranthus retroflexus												0.03												
Agrostis stolonifera													0.02											
Gaillardia aristata												0.02												
Penstemon nitidus																								T
Astragalus drummondii											T													
Setaria viridis															T									
Number of Species	29	26	23	29	23	23	22	30	25	19	30	33	29	15	15	18	14	18	18	17	11	13	16	22
Lichen	0.58	0.32	0.1[illegible]	0.30	0.1[illegible]	0.1[illegible]	0.16	0.03	0.01	0.08	0.04		T	0.01		0.02	0.08	0.03		0.02	0.05	0.06	0.11	0.56
Moss	0.17	0.32	0.34	0.35	0.21	0.25	0.08	0.03	0.04	0.03	0.37		3.17	0.01				0.01	T	T			0.14	0.01
Litter	12.67	24.69	22.00	20.66	38.07	26.60	32.84	38.18	46.70	54.20	53.17	46.83	40.00	23.75	10.2[illegible]	38.18	44.28	50.01	50.01	60.85	58.5[illegible]	36.00	51.00	21.31
Bare Ground	80.24	72.70	71.80	73.30	62.52	60.80	60.60	60.50	47.03	25.77	20.63	52.80	20.77	61.47	63.09	51.70	51.62	44.22	38.05	38.52	37.00	42.62	47.72	77.17

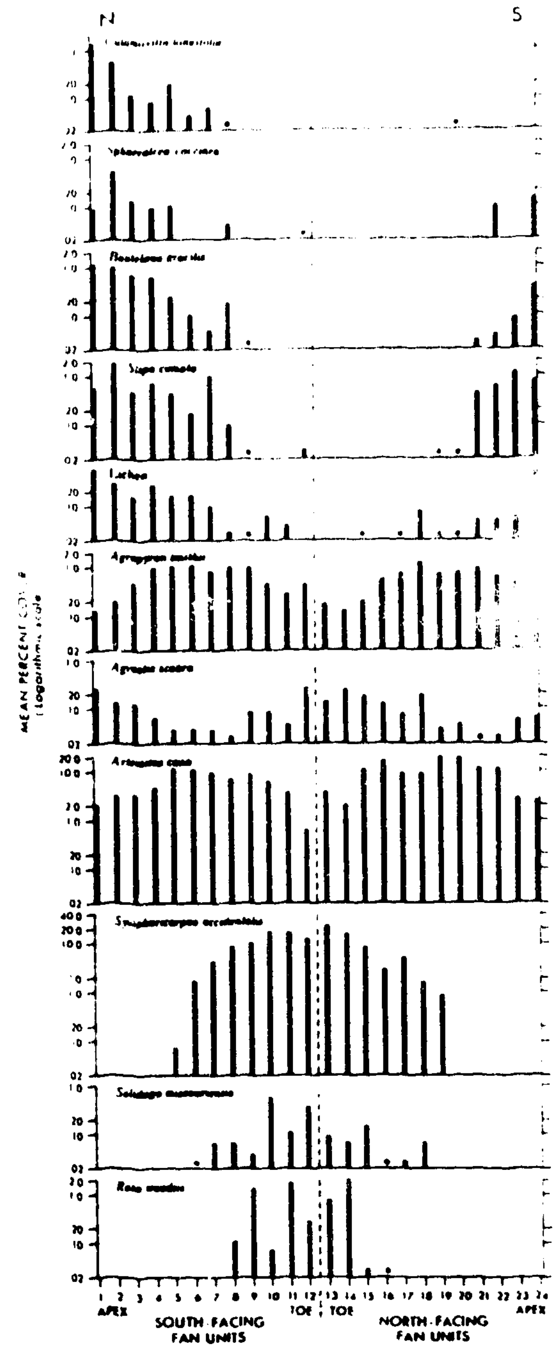

Figure 3.3 Mean percent cover values for dominant species over each of 24 fan slope units. Units 1-12 represent the mean percent cover values of three south-facing fans (F1 - F3, Figure 3.1) and units 13-24 represent the mean percent cover values of three north-facing fans (F4 - F6, Figure 3.1). Asterisks denote mean percent cover values of 0.02 or less.

missouriensis and the shrubs *Symphoricarpos occidentalis* and *Rosa woodsii* are confined mainly to lower fan slopes. Additional species showing peak abundance on the upper fan slopes include *Artemisia frigida*, as well as the cacti *Opuntia polyacantha* and *Corypantha vivipara* and the forbs *Erigeron caespitosus*, *Commandra umbellata*, *Eurotia lanata*, and *Lomatium foeniculaceum*. Species largely found only on the lower fan slope units include *Aster ericoides*, *A. laevis*, *Chenopodium album*, *Grindelia squarrosa*, *Smilicina stellata* and *Populus deltoides*. As with *Calamovilfa longifolia*, a number of species were noticeably more abundant on south-facing slopes, including *Allium textile*, *Arabis holboellii*, *Carex brevior*, *Fritillaria pudica*, *Lepidium densiflorum*, and *Lomatium foeniculaceum*.

Mean species richness (Table 3.1) varies from a low of 10 at a mid-fan position to a high of 33 at the fan toe and, despite considerable variation, shows greatest species diversity on the upper and lower fan slopes. Lichen, moss and the first 13 species listed in Table 3.1 were found on all six fans, while *Bouteloua gracilis*, *Calamovilfa longifolia*, *Eurotia lanata*, *Sphaeralcea coccinea* and *Commandra umbellata* were found on five of the six fans.

3.4.2 Multivariate Analysis of the Vegetation Data

Empirical examination of the vegetation data necessitated a two-part PCA ordination to account for the two distinct sets of environmental variables. The first PCA ordination analyzed only the environmental variables measured on all six fans as they related to the species data from all six fans. The second PCA ordination analyzed the

19 environmental variables measured on fans F2 and F5 (Figure 3.1) and related those variables to the species data from the two fans.

The first PCA ordination (on the data for all six fans) showed the first four axes accounted for 97.1 % of the variation in the species data (Table 3.2a), with 83.9 % explained by the first axis and 92.1 % explained by the first two axes.

Forward selection of all 19 environmental variables prior to the second PCA ordination, indicated litter, bare ground, salinity, aspect and site position "best" explained the variation in the species data at the conventional 5 % significance level. The principle component analysis of these five variables on the fan F2 and fan F5 species data demonstrated that 99.2 % of the species data was accounted for by the first four axes, and that 94.4 % of the variation was explained by the first axis (Table 3.2b).

Both PCA runs clearly delineated axis 1 as predominantly a litter/bare ground axis (Table 3.3). Axis 2 is primarily delimited by salinity and more weakly by stand position on the fan (Table 3.3). Both the overall ordination of the species data and the variation explained by axis 1 were found to be statistically significant ($P \leq 0.01$).

Figure 3.4 is a biplot derived from the first PCA ordination and illustrates the relative positions of the sample sites and the environmental variables on all six fans. The environmental variables shown with longer arrows are more strongly correlated with the ordination axes, and indicate a closer explanatory relationship to the observed site pattern. Species and site scores plotted close to the origin of the diagram are weakly correlated with measured environmental variables. Sites scores plotted in the same general direction as a given environmental variable are positively correlated with that

Table 3.2 Summary of principle component analysis on (A) Fans F1 - F6 with seven environmental variables; and (B) Fans F2 and F5 with nineteen measured environmental variables

A.

PCA Axes	1	2	3	4
Eigenvalues	.839	.073	.038	.022
Species-environment correlations	1.00	.924	.615	.322
Cumulative percentage variance				
of species data	83.9	91.2	95.0	97.1
of species-environment relations	91.0	97.7	99.2	99.5

B.

PCA Axes	1	2	3	4
Eigenvalues	.944	.027	.011	.009
Species-environment correlations	.997	.927	.618	.245
Cumulative percentage variance				
of species data	94.4	97.2	98.3	99.2
of species-environment relations	97.0	99.4	99.8	99.9

Table 3.3 Matrix correlations of principle environmental variables with the first three PCA axes of fine-grained alluvial fans

Environmental Variable	Correlations based on fans F1 - F6			Correlations based on fans F2 and F5		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Slope	.090	-.302	.442			
Site position	-.126	.460	.456	-.181	-.342	-.517
Aspect	.178	.004	.525	-.399	-.300	-.850
Litter	.983	-.185	-.074	-.999	-.037	.006
Bare ground	-.975	-.210	-.119	.996	-.020	.014
Species richness	.167	-.360	-.719			
Salinity				.001	.863	.080

variable, and the greater the plotted distance from the origin the stronger the correlation (ter Braak 1987b). Hence, as would be expected, the dominant variables, bare ground and litter, display a strong inverse relationship to one another (r = -.92) and show a distinct association with site pattern (Figure 3.4). Despite considerable overlap, upper fan site scores are generally positively correlated with bare ground, while lower fan site scores are positively correlated with litter. Clearer, but weaker, relationships are seen between the site scores and position, slope angle and species richness. Lower fan site scores appear positively correlated to position and negatively correlated to both slope angle and species richness.

A triplot diagram (ter Braak 1987b)(Figure 3.5), generated from the second PCA ordination (all 19 variables measured on fans F2 and F5), shows the relative positions of 1) predominant species, 2) sites, and 3) environmental variables. As with the site scores of the biplot (Figure 3.4), species scores are positively correlated with environmental variables if their positions lie in the same general direction as that variable, and stronger correlations are indicated by species scores plotted further from the origin. Site scores in Figure 3.5 reflect the same general environmental associations as Figure 3.4, although, with the introduction of soil samples into the analysis, axis 2 now shows a strong correlation with salinity (r = .86). Moisture and clay content, both closely correlated with salinity (r = .83 and r = .69, respectively), show strong positive correlations with lower fan site scores while sand content displays a positive correlation with upper fan site scores (Figure 3.5).

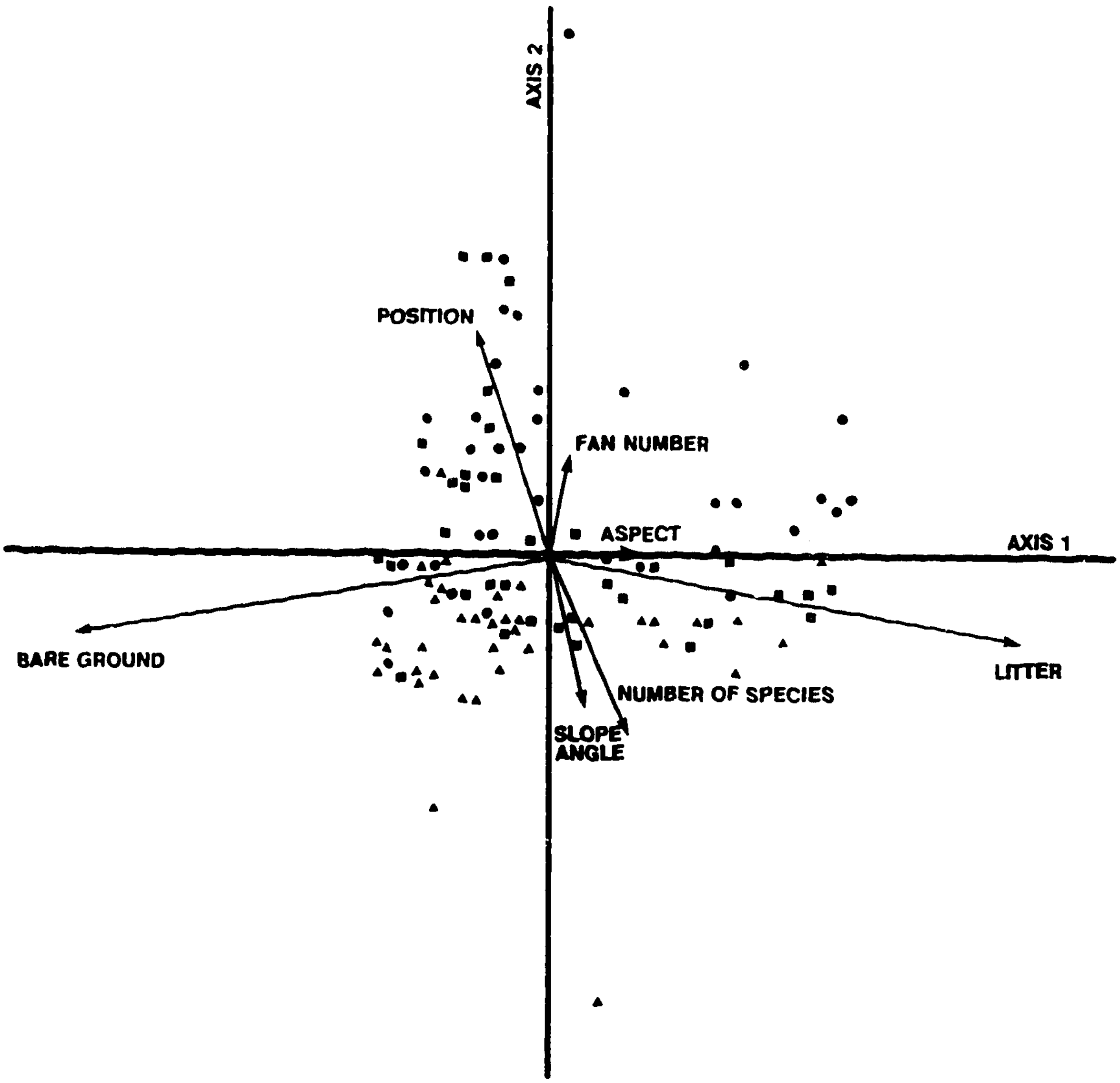

Figure 3.4 Biplot ordination diagram based on PCA of alluvial fan vegetation data. Ordination incorporates species variation on all six fans studied and shows both site scores and environmental variables. Site scores are subdivided into 3 groups and are plotted as: upper third (▲), middle third (■), and lower third (●) of the fan surface. See Tables 3.2 and 3.3 for ordination statistics.

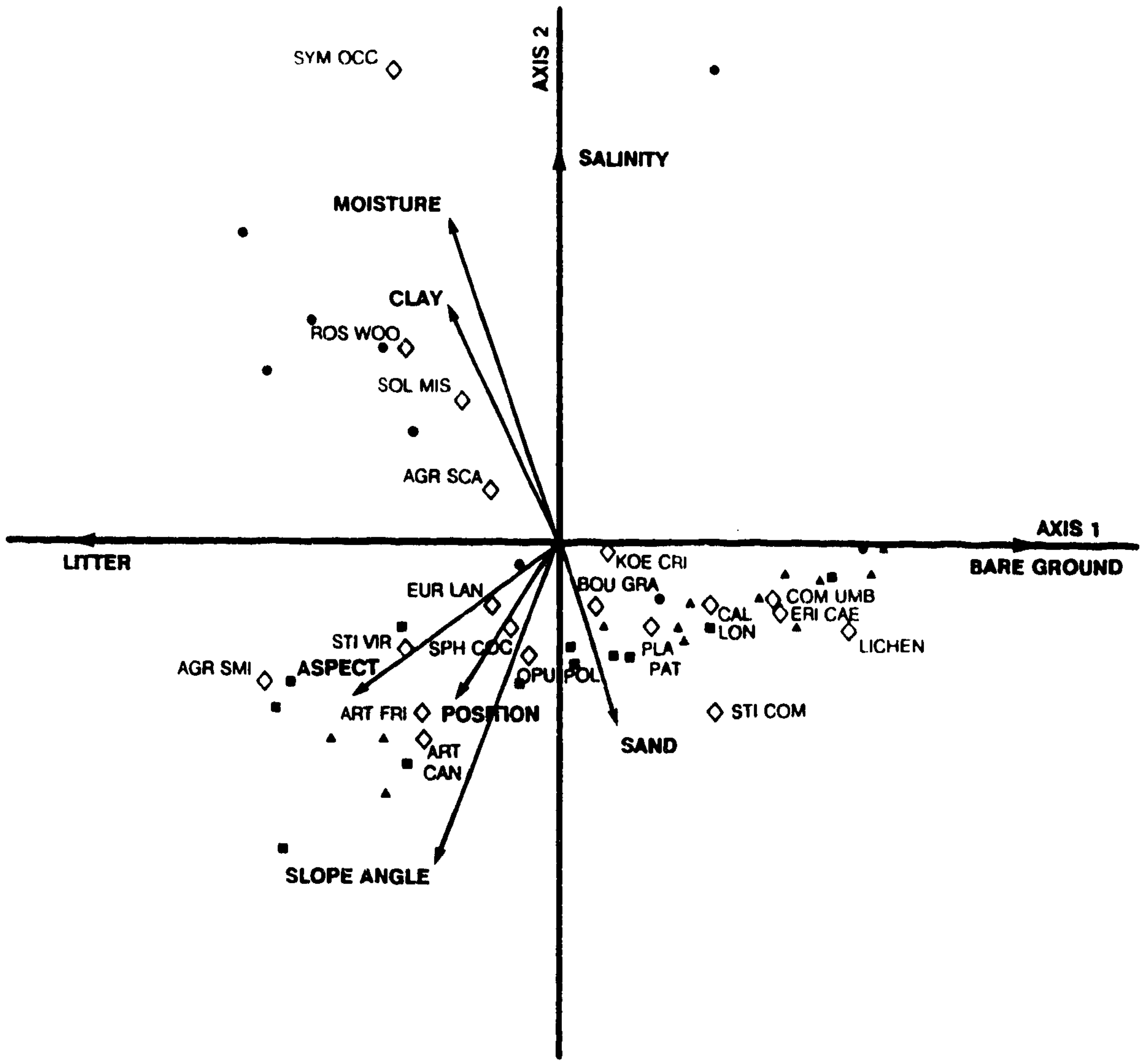

Figure 3.5 Triplot ordination diagram (ter Braak 1987b) based on PCA of alluvial fan vegetation data. Ordination incorporates species variation on one north-facing and one south-facing (fans F2 and F5, Figure 3.1) and shows 1) predominant species scores, 2) site scores, and 3) predominant environmental variables. Species abbreviations are derived from the first three letters of both the plant genus and species names (see Table 3.1). Site scores are subdivided into 3 groups and are plotted as: upper third (▲), middle third (■), and lower third (●) of the fan surface. Species scores are plotted as (◇) . See Tables 3.2 and 3.3 for ordination statistics.

The species scores in Figure 3.5 show lichen is most strongly correlated with the first PCA axis (r = .62). However, the forbs *Commandra umbellata* (r = .41), *Erigeron caespitosus* (r = .40) and grasses *Stipa comata* (r = .35) and *Calamovilfa longifolia* (r = .32), are also positively correlated with the first axis and demonstrate a close association with most of the upper fan site scores (Figure 3.5). Similarly, *Symphoricarpos occidentalis* (r = .93), *Rosa woodsii* (r = .42), and to a lesser extent *Solidago missouriensis* (r = .25) have positive correlations with the second PCA axis and are strongly associated with lower fan site scores. *Agropyron smithii*, *Stipa viridula*, *Artemisia cana* and *A. frigida*, however, are negatively correlated with both PCA axes and are most closely associated with mid-fan site scores (Figure 3.5).

3.5 Discussion

Several researchers have examined the vegetation/micro-environmental relationships of grassland communities on the Canadian prairies (Moss 1944; Coupland 1950; Ayyad and Dix 1964; Coxson and Looney 1986; Lieffers and Larkin-Lieffers 1987) and have identified distinct community associations defined primarily along a moisture gradient. Ayyad and Dix (1964) found *Festuca scabrella*, *Carex obtusata*, and *Galium boreale* preferred moister, cooler lower slopes, while *Phlox hoodii*, *Stipa comata* and *Artemisia frigida* preferred dryer, warmer upper slopes. *Koeleria cristata* and *Agropyron dasystachyum* were found to have optimal densities in more intermediate positions (Ayyad and Dix 1964). Similarly, Coupland (1950) identified a gradient between a *Stipa-Bouteloua* community commonly found in drier, coarser textured soils and a *Bouteloua-Agropyron* community found in more clay-rich, saline soils. A *Symphoricarpos* dominated shrub community was also identified as prevailing at the mesic margins of the moisture gradient (Coupland 1950). More recently, Coxson and Looney (1986) identified distinct community associations along a moisture gradient in southern Albertan coulees. *Symphoricarpos occidentalis* and *Rosa woodsii* were identified as indicator species with mesic affinities, while *Bouteloua gracilis*, *Artemisia frigida*, *Stipa comata*, and *Plantago patagonica* were found to be associated with more xeric conditions.

Analogous trends in vegetative pattern occur on the alluvial fan surfaces studied here. *Stipa comata*, *Calamovilfa longifolia*, *Commandra umbellata*, *Erigeron caespitosus*, *Plantago patagonica* are dominant on the upper fan surfaces where sandier, drier and less saline conditions prevail (Figures 2.3, 3.3 and 3.5). Conversely, *Symphoricarpos occidentalis*, *Rosa woodsii*, and *Solidago missouriensis* are most abundant on the clayey, moister, and more saline lower fan surfaces (Figures 2.3, 3.3 and 3.5). The vegetational gradient between these two communities is seen in the gradual disappearance of dominant species with distance from their respective niches and the predominance of such species as *Agropyron smithii*, *Artemisia cana*, *A. frigida* and *Stipa viridula* on the mid-fan surfaces (Table 3.1; Figures 3.3 and 3.5). These distinct plant community associations on the alluvial fan surfaces are comparable to those found elsewhere on the prairies (Ayyad and Dix 1964; Coxson and Looney 1986) and indicate the role soil moisture gradients may have on fan vegetative pattern (Coupland 1950).

Soil moisture is considered the dominant factor governing productivity (Redmann

1975) and composition (Coupland 1961) within grassland communities, and it establishes a gradient along which these communities vary (Coupland 1950). This xeric-mesic gradient is primarily controlled by slope runoff characteristics and is largely a function of slope shape, angle and aspect (Ayyad and Dix 1964; Lieffers and Larkin-Lieffers 1987). Although the influence of soil moisture in the present study was not clearly identified as a principal environmental variable (Table 3.3), the two strongest environmental factors identified (bare ground-litter and salinity), are directly influenced by the runoff characteristics on the alluvial fan surfaces.

The observed bare ground-litter gradient (PCA axis 1), extending from fan apex to toe, appears to be largely a function of the periodic, high intensity runoff events in this dynamic, badland environment. Discharge on alluvial fan surfaces, typically, is greatest at the apex and decreases exponentially down-fan as bifurcation into smaller distributary channels occurs. Litter is therefore periodically and differentially 'flushed' down-fan by the infrequent, high magnitude flood events common to the area and/or is buried by the rapid vertical accretion (*ca.* 3.8 mm/yr, Seemann and Campbell submitted) of fluvial sediments on the proximal or upper fan surface.

The strong positive correlation of salinity (PCA axis 2) with moisture, clay and lower fan sites suggests salinity, too, is a function of fan runoff characteristics. Bryan *et al.* (1984) noted relatively high concentrations of sodium (>79%) and sulphate, as well as lesser amounts of potassium, calcium, magnesium and chlorine, in soil (regolith) solutions during runoff experiments in the badlands. These solutes, introduced to the fan system at the apex, have the greatest propensity to be transported to the distal fan surfaces, hence explain the concentration of salts in this region. The predominance of clays, and more specifically swelling bentonitic clays (Campbell 1987), on the lower fan surface compounds the concentration of salts as infiltration is reduced and high evaporation rates enhance the precipitation of solutes at or near the surface (Bryan *et al.* 1984; Campbell 1987).

Interestingly, and in direct contrast to the findings of other researchers (Lieffers and Larkin-Lieffers 1987), species abundance and diversity were highest on the south-facing fans (Tables 3.1 and 3.3; Figure 3.3). This is probably attributable to the slope and vegetative differences within the respective fan drainage basins. Mature badland catchments on the south side of the Red Deer River have well vegetated, gentle sloping valley walls and broad valley floors which impede and limit both the runoff and the sediment delivered to the fans. In contrast, catchments on the north side of the Red Deer River are typically steep sided with narrow valley floors and are largely devoid of vegetation, thereby enhancing the discharge delivered to the fans. The more efficient drainage characteristics of the catchments on the north side of the river, therefore, likely provide more moisture to their respective fans than those catchments on the south side of the river, especially during rainfalls of low intensity.

3.6 Conclusions

The Deadlodge Canyon alluvial fans are representative of the numerous fans found throughout the Dinosaur Provincial Park badlands and reflect the typical species associations found on the fan surfaces. Direct examination of the species cover data as well as multivariate analysis of the data, both indicate that clear vegetation patterns exist on the alluvial fan surfaces. Three communities can be clearly identified on the fans and appear to be correlated with a xeric-mesic gradient established by the runoff and sediment patterns characteristic of these alluvial fans. The dominant floristic elements characterizing the xeric, upper fan community are the grasses *Stipa comata* and *Calamovilfa longifolia*, although *Bouteloua gracilis*, *Koeleria cristata*, *Commandra umbellata* and *Erigeron caespitosus* were also associated with the upper fan community. At the other extreme, *Symphoricarpos occidentalis* and *Rosa woodsii* characterise the mesic, lower fan community. The dominance of *Artemisia cana* and *Agropyron smithii* on mid-fan slopes represent the third easily identified vegetative community. These observed plant community associations are remarkably similar to other grassland associations recognized on prairie hill slopes (Ayyad and Dix 1964) and in southern Albertan coulees (Coxson and Looney 1986).

The floristic preference in composition and abundance for south-facing aspects on the fan surfaces studied, particularly at or near the fan apex, may be attributable to the relatively efficient discharge characteristics of barren, steep-sided south-facing catchments.

3.7 References

AYYAD, M.A.G. and DIX, R.L. 1964. An analysis of a vegetation - microenvironmental complex on prairie slopes in Saskatchewan. Ecological Monographs, **34**: 421-442.

BRYAN, R.B. and CAMPBELL, I.A. 1980. Sediment entrainment and transport during local rainstorms in the Steve... Badlands, Alberta, Canada. Catena, **7**: 51-65.

BRYAN, R.B. and CAMPBELL, I.A. 1986. Runoff and sediment discharge in a semiarid ephemeral drainage basin. Zeitschrift für Geomorphologie Supplementband, **58**: 121-143.

BRYAN, R.B., CAMPBELL, I.A. and YAIR A. 1987. Postglacial Geomorphic Development of the Dinosaur Provincial Park Badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

BRYAN, R.B., IMESON, A.C. and CAMPBELL, I.A. 1984. Solute release and sediment entrainment on microcatchments in the Dinosaur Park badlands, Alberta, Canada. Journal of Hydrology, **7**: 79-106.

CAMPBELL, I.A. 1974. Measurement of erosion on badlands surfaces. Zeitschrift für Geomorphologie Supplementband, **21**: 122-137.

CAMPBELL, I.A. 1981. Spatial and temporal variations in erosion measurements. *In* Erosion and sediment transport measurements (Proceedings of the Florence Symposium, June 1981), IAHS Publication, **133**: 447-156.

CAMPBELL, I.A. 1982. Surface morphology and rates of change during a ten year period in the Alberta Badlands. *In* Badland geomorphology and piping. *Edited by* R.B. Bryan and A. Yair. Geobooks, Norwich, England, 221-237.

CAMPBELL, I.A. 1987. Infiltration characteristics of badlands surfaces and storm runoff. Proceedings, International Conference on Infiltration Development and Application, University of Hawaii, Honolulu, 251-260.

CAMPBELL, I.A. and EVANS, D.J.A. 1990. Glaciotectonism and landsliding in Little Sandhill Creek, Alberta. Geomorphology, **4**: 19-36.

CLAYTON, J.S. and MARSHALL, I.B. 1972. Soil Map of Canada. Soil Research Institute, Department of Agriculture, Ottawa, Canada.

COUPLAND, R.T. 1950. Ecology of mixed prairie in Canada. Ecological Monographs, **20**(4): 272-315.

COUPLAND, R.T. 1952. Grassland communities of the western Canadian prairies - climax and subclimax. Proceedings of the 6^{the} International Grassland Congress, **1**: 625-631.

COUPLAND, R.T. 1961. A reconsideration of grassland classification in the northern great plains of North America. Journal of Ecology, **49**: 135-167.

COXSON, D.S. and LOONEY, J.H. 1986. Vegetation patterns within southern Alberta coulees. Canadian Journal of Botany, **64**: 2464-2475.

DODSON, P. 1971. Sedimentology and taphonomy of the Oldman Formation (Campanian), Dinosaur Provincial Park, Alberta (Canada). Palaeogeography, Palaeoclimatology, and Palaeoecology, **10**: 21-74.

ENVIRONMENT CANADA 1982. Canadian Climate Normals 1951 - 1980: Temperature and Precipitation on the Prairie Provinces. Canadian Climate Program, Atmospheric Environment Services, Ottawa.

EVANS, D.J.A. and CAMPBELL, I.A. 1992. Glacial and postglacial stratigraphy of Dinosaur Provincial Park and surrounding plains, southern Alberta, Canada. Quaternary Science Reviews, **11**: 535-555.

HARTY, K.M. 1984. The geomorphic role of snow in a badland watershed. Unpublished M.Sc. Thesis, Department of Geography, University of Alberta, Edmonton, Alberta.

HARVEY, A.M. 1989. The occurrence and role of arid zone alluvial fans. *In* Arid Zone Geomorphology. *Edited by* D.S.G. Thomas, Halsted Press, New York, 136-158.

HILL, M.O. 1979. Decorana: a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Section of Ecology and Systematics, Cornell University, Ithaca, New York.

KEHEW, A.K. and LORD, M.L. 1987. Glacial lake outbursts along the mid-continent margins of the Laurentide Ice Sheet. *In* Catastrophic Flooding: Binghampton Symposia in Geomorphology (International Series, No. 18). *Edited by* L. Mayer and D. Nash, Allen and Unwin Publishing, Boston, Massachusetts, 95-120.

KJEARSGAARD, A.A., PETERS, T.W. and PETTAPIECE, W.W. 1983. Soil survey of the County of Newell, Alberta. Alberta Soil Survey Report No. 41, Research Branch, Agriculture Canada.

KLUTE, A. 1986. Methods of soil analysis: physical and mineralogical methods. 2nd edition, No. 9, Part I in the series Agronomy, American Society of Agronomy, Inc., Madison, Wisconsin, USA.

KONDLA, N.G. and CRAWFORD, H.R. 1971. An ecological survey of Dinosaur Provincial Park. Report for Provincial Parks Planning, Department of Recreation and Parks, Government of Alberta.

KOSTER, E.H. 1984. Sedimentology of a foreland coastal plain: Upper Cretaceous Judith River Formation at Dinosaur Provincial Park. Canadian Society of Petroleum Geologists, Alberta Research Council, Edmonton.

LIEFFERS, V.J. and LARKIN-LIEFFERS, P.A. 1987. Slope, aspect, and slope position as factors controlling grassland communities in the coulees of the Oldman River, Alberta. Canadian Journal of Botany, **65**: 1371-1378.

McLEAN, J.R. 1971. Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains. Saskatchewan Research Council, Geology Division. Report No. **11**.

MOSS, E.H. 1944. The prairie and associated vegetation of south-western Alberta. Canadian Journal of Research Section C, **22**: 11-31.

MOSS, E.H. 1983. Flora of Alberta. 2nd ed. *Revised by* J.G. Packer. University of Toronto Press, Toronto.

PAGE, A.L. 1982. Methods of soil analysis: chemical and microbiological properties. 2nd edition, No. 9, Part II in the series Agronomy, American Society of Agronomy, Inc., Madison, Wisconsin, USA.

REDMANN, R.E. 1975. Production ecology of grassland plant communities in western North Dakota. Ecological Monographs, **45**: 83-106.

SEEMANN, M.R. and CAMPBELL, I.A. (submitted). Chronology and development of fine-grained alluvial fans, Deadlodge Canyon, Dinosaur Provincial Park, Alberta. Canadian Journal of Earth Sciences.

SHETSEN, I. 1987. Quaternary geology, southern Alberta. Alberta Research Council, Map, Natural Resources Division, Terrain Sciences Department, Edmonton, Alberta, 1:500,000.

SIMS, P.L. and COUPLAND, R.T. 1979. Producers. *In* Grassland ecosystems of the world: analysis of grasslands and their uses. *Edited by* R.T. Coupland. Cambridge University Press, London 49-72.

SIMS, P.L. and SINGH, J.S. 1971. Herbage dynamics and net primary production in certain grazed and ungrazed grasslands in North America. *In* Preliminary analysis of structure and function in grasslands. *Edited by* N.R. French, Colorado State University, Fort Collins, 59-124.

SIMS, P.L., SINGH, J.S. and LAUENROTH, W.K. 1978. The structure and function of ten western North American grasslands. Journal of Ecology, **66**: 251-285.

STRONG, W.L. and LEGGAT, K.R. 1981. Ecoregions of Alberta. ENR Technical Report Number: T/4, Alberta Energy and Natural Resources, Edmonton, Alberta.

TELLER, J.T. 1987. Proglacial lakes and the southern margin of the Laurentide Ice Sheet. *In* North America and the adjacent oceans during the last deglaciation. *Edited by* W.F. Ruddiman and H.E. Wright, Jr., Geological Society of America, Boulder, Colorado, 39-70.

TER BRAAK, C.J.F. 1987a. CANOCO - a FORTRAN program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis, principle components analysis and redundancy analysis (Version 2.1). TNO Institute of Applied Computer Science, Statistics Department, Wageningen, The Netherlands.

TER BRAAK, C.J.F. 1987b. Ordination. *In* Data analysis in community and landscape ecology. *Edited by* R.G.H. Jongman, C.J.H. ter Braak and O.F.R. van Tongeren, Pudoc, Wageningen, The Netherlands.

TER BRAAK, C.J.F. 1990. Update notes: CANOCO (Version 3.10). Agricultural Mathematics Group, Wageningen, The Netherlands.

4.0 CONCLUSIONS

Recognizing the existing spatial bias toward alluvial fan research in the American southwest (Lecce 1990), the relative paucity of Canadian fan studies, and the need for further fan research in a variety of topographic and climatic environments (Wasson 1977), the study of alluvial fans in the semi-arid badlands of southern Alberta provides a unique opportunity for continued fan research. The present study focuses on both a geomorphic and a biogeographic approach to understanding the alluvial fan systems developing in Deadlodge Canyon, Dinosaur Provincial Park, Alberta. The geomorphic component of the study outlines a chronology for the post-glacial development of the Deadlodge Canyon fans, while the biogeographic component quantifies and describes the vegetative pattern existing on the alluvial fan surfaces.

4.1 Deadlodge Canyon Fans

Several small, fine-grained alluvial fans line the Red Deer River in Deadlodge Canyon and prograde across the River's broad floodplain from adjacent badland catchments. These silt-dominated fans extend up to approximately 250 m and average about 150 m in length. Their gross surface morphology reflects the longitudinal concavity and transverse convexity typical of most arid-region fans and the average slope angle on the fan surfaces varies from approximately 1.7° near the apex to 0.6° near the toe. Local fan relief seldom exceeds about 5 m as periodic fan destruction occurs as a result of down-valley pointbar migration within the Red Deer River valley.

Cyclical fan development originates along the cutbanks of the Red Deer River where the sediment supply rate of tributary streams exceeds that of river erosion. The resultant fan-deltas gradually enlarge as continued sediment input is augmented by on-lapping and interdigitation of riverine sediments with the approach of the migrating pointbar. This gradual progradation of the juvenile fan and growth of the pointbar lengthens the fan tributary channel and leads to fan backfilling as the stream grades to its new local base-level.

The accretion of fan sediments is characterized by the fluvial deposition of low-angle planar laminations of fine sand and silt on the upper fan, and grades to micro-laminations of silt and clay on the lower fan. While this overall down-fan textural fining is clearly evident, sorting does not appear to improve distally on the fan surfaces. This apparently anomalous trend is attributed to the periodic, high magnitude runoff events common to the area which are predisposed to transport coarser sediments further down-fan while the size of sediment introduced at the fan apex remains more or less constant.

The eventual passing of the migrating pointbar precipitates the truncation and destruction of the fans. Primary erosion is a result of basal sapping by the Red Deer River, and the consequent foreshortening of the tributary stream leads to secondary erosion by headward entrenchment and channel piping.

4.1.1 Fan Chronology and Rate of Development

Three independent lines of evidence indicate fan development along the Red Deer River occurs rapidly and that the Deadlodge Canyon fans are no more than about 900 years old. An empirical estimate of fan age based on maximum basin sediment delivery rates and fan volumes indicates a mean minimum fan age of about 150 years. Similarly, calculation of the mean rate of down-valley pointbar migration within Deadlodge Canyon over a 38 year period suggests a maximum fan age of approximately 900 years. Eleven conventional radiocarbon dates confirm these calculated minimum and maximum age estimates and delimit a mean vertical accretion rate of 3.8 mm/yr.

The cyclical development and destruction of fans appears to occur on approximately an 1100 year cycle and, given that the present climatic conditions prevailed over the last 3000 years (Sauchyn 1990; Vance 1991), several fan-building cycles may thus have occurred during the late Holocene. Isolated fan remnant surfaces, approximately 1 - 1.5 m higher than present fan surfaces, exist throughout Deadlodge Canyon and provide evidence for at least one such earlier cycle.

4.1.2 Fan Vegetative Pattern

Three discernable vegetative communities exist along a moisture gradient that extends down the length of the Deadlodge Canyon fans. The dominant floristic elements characterising the xeric, coarser-grained upper fan community are the grasses *Stipa comata* and *Calamovilfa longifolia*. At the other extreme, *Symphoricarpos occidentalis* and *Rosa woodsii* characterise the clayey, mesic and more saline lower fan community. In between these two communities, the predominance of *Artemisia cana* and *Agropyron smithii* represent a third less clearly identified community. Discharge characteristics on the alluvial fan surfaces appear to establish the primary environmental gradients found to be associated with the change in down-fan floristic composition. In contrast to the findings of other researchers (Ayyad and Dix 1964; Coxson and Looney 1986) a number of species demonstrated a preference for south-facing aspects. This anomaly is attributed to the comparatively high discharge efficiencies of the south-facing drainage basins.

4.2 Implications

The geomorphic and biogeographic studies presented here have several important implications and considerations worth highlighting. (1) Fan development is usually assumed to occur penecontemporaneously with the formation of its related drainage basin. Therefore, fan volume and area are expected to bear a functional relationship to the size of its respective drainage basin (Bull 1964; 1975; 1977). However, with complete fan regeneration occurring approximately every 1100 years, the Deadlodge Canyon fans are not as old as their contributing basins and the functional fan-basin relationships outlined by Bull (1964), and widely published in the literature, can not be applied to these dynamic fan systems. (2) The development of the Deadlodge Canyon fans is partly controlled by base-level changes influencing fan tributary streams and varies in response to pointbar migration in the Red Deer River valley. Therefore, fan development is not a function of Holocene climatic change except where such change influenced the rate of sediment supply to the fans or the down-valley migration of the pointbars. (3) The relatively rapid down-valley migration of the Red Deer River through Deadlodge Canyon (*ca.* 2.8 m/yr) attests to the dynamic nature of badland erosional processes as well as the magnitude of geomorphic work within the Dinosaur badlands. (4) The rapid vertical accretion rate of 3.8 mm/year on upper fan surfaces suggests an extremely dynamic depositional environment in which overburden of up to

5 m may reflect a period of less than 1000 years. (5) The tripartite floristic zonation observed on the fan surfaces appears consistent across all fans, regardless of size. Therefore, as a fan progrades across the floodplain, fan vegetative communities apparently replace those on the floodplain and alter the existing floristic architecture.

4.3 Future Research

As the present research provides only an initial study of the fine-grained alluvial fans in Deadlodge Canyon, the results and conclusions raise several questions which merit further investigation. Three broad areas of inquiry remain unanswered.

The first concerns the post-glacial history of fan development within Deadlodge Canyon. As fan regeneration appears to occur relatively quickly (*ca.* 1100 yrs), investigation of earlier post-glacial fan building episodes is warranted. Direct investigation of the isolated fan remnants, still evident within fan drainage basins, would aid in the reconstruction of a post-glacial chronology of Canyon development, as well as contribute proxy evidence to post-glacial paleoclimatic research.

The second broad area of inquiry centers around the internal structure of these semi-arid, fine-grained alluvial fans. Sedimentologic research focussed on facies associations and correlations, as well as differential sedimentation rates, may provide recognition criteria for ancient facies equivalents and may offer some insight into Holocene climatic regimes.

The final broad area of inquiry focuses on the impact rapid fan progradation has on the Deadlodge Canyon floral and faunal floodplain communities. Kondla and

Crawford (1971) and Savoy (1990) emphasize the role riparian habitats have on both resident and transitory faunal populations in Dinosaur Provincial Park. Focused studies on 1) the rate of lateral fan progradation, 2) the change in floristic composition between the fan toe and floodplain, and 3) the influence vegetational change has on select faunal communities, would all assist in continuing to assess the biogeographic impact of badland fans on riparian habitats.

Continued fan research along both of these broad avenues of inquiry would provide a significant and meaningful contribution to our understanding of the ecological, paleoecological and geomorphic role of fine-grained alluvial fans within Deadlodge Canyon, Dinosaur Provincial Park.

4.4 References

BULL, W.B. 1964. Geomorphology of segmented alluvial fans in western Fresno County, California. U.S. Geological Survey Professional Paper, **352-E**: 89-128.

BULL, W.B. 1975. Allometric change of landforms. Geological Society of America Bulletin, **86**: 1489-1498.

BULL, W.B. 1977. The alluvial fan environment. Progress in Physical Geography, **1**: 222-270.

KONDLA, N.G. and CRAWFORD, H.R. 1971. *An Ecological Survey of Dinosaur Provincial Park*. Report for Provincial Parks Planning, Government of Alberta.

LECCE, S.A. 1990. The Alluvial Fan Problem. *In* Alluvial Fans: a Field Approach, *Edited by* A.H. Rachocki and M. Church, John Wiley and Sons, 3-26.

SAUCHYN, D.J. 1990. A Reconstruction of Holocene Geomorphology and Climate, Western Cypress Hills, Alberta and Saskatchewan. Canadian Journal of Earth Sciences, **27**: 1504-1510.

SAVOY, E. 1990. The Importance of Riparian Habitats to Prairie Birds: A Case Study - Dinosaur Provincial Park, Alberta. *In* Proceedings of the Biology and Management of Southern Alberta's Cottonwoods Conference, *Edited by* S.B. Rood and J.M. Mahoney, University of Lethbridge.

VANCE, R.E. 1991. A Paleobotanical study of Holocene Drought Frequency in Southern Alberta. Unpublished Ph.D. Thesis, Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, 180.

WASSON, R.J. 1977. Catchment Processes and the Evolution of Alluvial Fans in the Lower Derwent Valley, Tasmania. Zeitschrift fur Geomorphologie Supplementband, **21**: 147-168.

5.0 APPENDIX: MEAN FAN SITE FLORA ABUNDANCE DATA

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F1.1	F1.2	F1.3	F1.4
Achillea millefolium				
Agropyron sp				
Agropyron sp2				0.01
Agropyron dasystachyum			0.05	
Agropyron smithii				
Agropyron spicatum				
Agrostis scabra	1	0.54	0.36	0.33
Agrostis stolonifera				
Allium textile	0.09	0.03		
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	0.6	0.25	2.54	0.77
Artemisia frigida			0.05	1.22
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii	2			
Betula occidentalis				
Bouteloua gracilis	2.95	3.45	2.75	2.15
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior	0.02		0.04	0.48
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara	0.12	0.23		0.03
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				0.03
Eurotia lanata	2.2	1.9	0.06	0.4
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica	0.02	0.03	0.01	
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F1.1	F1.2	F1.3	F1.4
Hymenoxis richardsonii	0.04		0.08	
Koeleria cristata				0.01
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa	0.12	0.02	0.02	
Lepidium densiflorum				
Lichen Black	0.59	1.19		0.19
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii	0.03			
Linum rigidum				
Lomatium foeniculaceum	0.06	0.15	0.12	0.07
Moss				
Opuntia polyacantha			0.1	0.04
Oryzopsis hymenoides				3.5
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	1.36	0.12	0.65	0.28
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea	0.12	0.33	1.52	0.38
Stipa comata	0.07	1.22	3.1	
Stipa viridula				
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius			0.13	
Vicia americana				
Viola adunca				
Standing Dead	0.5	0.4	0	
Litter	12.4	21.7	25.2	25.2
Bare Ground	77.5	72.5	64.4	69

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F1.5	F1.6	F1.7	F1.8
Achillea millefolium				
Agropyron sp				
Agropyron sp2			1.16	
Agropyron dasystachyum	0.13	0.07		
Agropyron smithii	1.24	2.09	1.55	2.15
Agropyron spicatum				
Agrostis scabra	0.18	0.12	0.09	0.07
Agrostis stolonifera				
Allium textile	0.06	0.02		
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	6.06	13.13	11.79	11.47
Artemisia frigida	0.03	0.33	0.04	0.9
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp	0.01			
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis	2	0.79	0.29	0.34
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior	0.01	0.01		
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata			0.21	
Corypantha vivipara	0.05			
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata		0.8	0.85	
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica	0.07	0.02		
Gaillardia aristata				
Grass #1	0.12			
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F1.5	F1.6	F1.7	F1.8
Hymenoxis richardsonii				
Koeleria cristata		0.18	0.84	0.52
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa	0.01	0.01		
Lepidium densiflorum				
Lichen Black	0.3			
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum	0.11	0.06	0.02	0.02
Moss				
Opuntia polyacantha	0.22			
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				0.12
Plantago patagonica	0.06	0.05		
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea	0.27	0.32		
Stipa comata	1.95	0.58	0.18	0.27
Stipa viridula	0.15	0.44	0.24	1.11
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.47	0	0.67	1.11
Litter	23.5	29.8	25	66.4
Bare Ground	70.5	62.5	66	69.5

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F1.9	F1.10	F1.11	F1.12
Achillea millefolium				0.26
Agropyron sp		0.2		
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	1.17	1.6	1.36	0.55
Agropyron spicatum				
Agrostis scabra	0.03	0.02	0.09	0.02
Agrostis stolonifera				
Allium textile	0.02	0.05	0.04	
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	9.18	12.45	9.65	11.35
Artemisia frigida	1.11	6.5	0.28	
Aster ericoides				
Aster laevis			0.16	0.05
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis	0.16	5.3	0.04	
Calamovilfa longifolia				
Campanula rotundifolia				0.14
Carex brevior	0.01	0.06	0.05	0.01
Carex stenophylla				
Castilleja sp				
Chenopodium album				0.01
Clematis ligusticifolia				
Comandra umbellata		0.07	0.01	
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				0.55
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica		0.02		
Gaillardia aristata				
Grass #1				1.94
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				0.07
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F1.9	F1.10	F1.11	F1.12
Hymenoxis richardsonii		0.01		
Koeleria cristata	0.1	0.09	0.61	0.07
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa		0.01		
Lepidium densiflorum	0.01			
Lichen Black		0.01		
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum	0.01		0.01	
Moss				
Opuntia polyacantha		0.5		
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	0.01	0.03	0.01	
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				0.03
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				0.64
Sphaeralcea coccinea		0.11		
Stipa comata	2.61	0.3	0.02	
Stipa viridula	0.55	0.63	0.76	0.55
Symphoracarpos occidentalis				12.4
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana			0.13	
Viola adunca				0.03
Standing Dead	1.03	0.5	0.6	0
Litter	18.4	29.6	27.4	71
Bare Ground	74	67	70	25

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F1.13	F1.14	F1.15	F2.1
Achillea millefolium	0.03	0.2		
Agropyron sp				
Agropyron sp2	0.04			
Agropyron dasystachyum				
Agropyron smithii	0.01	1.19	0.76	0.18
Agropyron spicatum				
Agrostis scabra	0.01	0.85	0.14	
Agrostis stolonifera				
Allium textile				0.01
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana		0.01	0.04	0.58
Artemisia frigida				
Aster ericoides				
Aster laevis	0.15			
Astragulus drummondii				
Astragulus missouriensis				0.05
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				0.12
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				0.33
Campanula rotundifolia	0.03			
Carex brevior				
Carex stenophylla		0.02	1.34	
Castilleja sp			0.15	
Chenopodium album	0.06			
Clematis ligusticifolia				
Comandra umbellata				0.16
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				0.05
Eurotia lanata				
Fargaria virginiana	0.26			
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large			0.02	
Forb #5 small			0.05	
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata		0.05		
Grass #1				
Grass #2				
Grindelia squarosa			5.55	
Gutierrezia sarothrae				0.01
Hedysarum boreale				
Helianthus annuus			0.49	
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F1.13	F1.14	F1.15	F2.1
Hymenoxis richardsonii				
Koeleria cristata		0.03	0.01	0.24
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa			0.03	
Lepidium densiflorum				
Lichen Black				0.9
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				0.16
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica			0.03	0.01
Polygonum arenastrum				
Populus deltoides	0.3			
Rosa acicularis	0.06	0.06		
Rosa woodsii	0.1	1.03	0.04	
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis		0.95		
Sphaeralcea coccinea				
Stipa comata				0.26
Stipa viridula	1.79			
Symphoracarpos occidentalis	34.4	9.8		
Taraxacum officinale		0.01		
Thermopsis rhombifolia				
Tragopogon dubius	0.11	0.16		
Vicia americana	0.06	0.01		
Viola adunca	0.1			
Standing Dead	0.49	0.05	0	0.57
Litter	70.5	17.3	4.28	12.45
Bare Ground	14.5	77.4	91.2	85.9

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.2	F2.3	F2.4	F2.5
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.03	0.1	0.36	0.25
Agropyron spicatum				
Agrostis scabra		0.01	0.05	0.09
Agrostis stolonifera				
Allium textile	0.02	0.01	0.01	
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	1.94	1.58	2.13	4.71
Artemisia frigida	0.04	0.02	0.2	
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				2.6
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia	0.44	0.05	0.14	0.25
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata	0.03	0.23	0.11	0.22
Corypantha vivipara	0.01	0.01		
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus			0.03	0.02
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica			0.02	0.01
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae	0.1	0.01	0.02	
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.2	F2.3	F2.4	F2.5
Hymenoxis richardsonii				
Koeleria cristata	0.1	0.08	0.24	0.28
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black	0.93	0.61	1.42	0.5
Lichen Green		0.02		
Lichen Lvs				
Lichen Orange		0.02		
Lichen White				
Linum lewisii	0.09			
Linum rigidum				
Lomatium foeniculaceum				
Moss			0.1	0.13
Opuntia polyacantha				0.2
Oryzopsis hymenoides				
Oxytropis sericea	0.09	0.05		
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	0.01	0.02	0.01	0.01
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	0.21	1.17	1.07	0.79
Stipa viridula				0.02
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.07	0.15	0.84	2.54
Litter	4.6	3.62	23.3	32.5
Bare Ground	93	94.6	90.8	64.2

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.6	F2.7	F2.8	F2.9
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.29	0.46	0.53	0.53
Agropyron spicatum				0.05
Agrostis scabra	0.05		0.04	0.02
Agrostis stolonifera				
Allium textile	0.01	0.01		
Amaranthus retroflexus				
Arabis holboellii	0.01		0.05	0.01
Artemisia cana	1.76	2.91	2.34	3.61
Artemisia frigida	0.01	0.21		
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii		0.01		
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia	0.14	0.26	0.46	0.01
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				0.02
Clematis ligusticifolia				
Comandra umbellata	0.14			0.21
Corypantha vivipara		0.01		0.01
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus	0.01	0.01	0.02	
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				0.01
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa			0.06	0.26

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.6	F2.7	F2.8	F2.9
Hymenoxis richardsonii				
Koeleria cristata	0.11	0.01		0.03
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum	0.01		0.06	
Lichen Black	0.42	0.19	0.75	0.43
Lichen Green				
Lichen Lvs				
Lichen Orange	0.01	0.01		
Lichen White		0.01		
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	0.25	0.94	0.68	0.79
Opuntia polyacantha	1.4			
Oryzopsis hymenoides				0.04
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica		0.02	0.02	
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	1.52	0.37	0.12	0.59
Stipa viridula				
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				0.01
Viola adunca				
Standing Dead	3.86	0.67	3.2	4.18
Litter	45.5	15.5	32	32.6
Bare Ground	53.8	78.5	67.2	65.9

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.10	F2.11	F2.12	F2.13
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.41	0.39	1.09	0.68
Agropyron spicatum				
Agrostis scabra	0.01	0.01	0.07	0.03
Agrostis stolonifera				
Allium textile		0.1	0.01	
Amaranthus retroflexus				
Arabis holboellii	0.02	0.03	0.01	0.01
Artemisia cana	7.63	5.98	8.05	8.63
Artemisia frigida			0.4	0.8
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus		0.02		
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia	0.95	0.17		0.02
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album	0.06		0.02	
Clematis ligusticifolia				
Comandra umbellata	0.1			
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				0.01
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica	0.02			
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa		0.01		

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.10	F2.11	F2.12	F2.13
Hymenoxis richardsonii				
Koeleria cristata			0.03	0.04
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum	0.02	0.01	0.05	0.02
Lichen Black		1.02	0.16	0.69
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	0.43	1.16	0.26	0.93
Opuntia polyacantha			0.1	
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica		0.02		
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	0.79	0.81	0.35	0.04
Stipa viridula				
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	19.6	3.11	8.63	5.94
Litter	49	42.1	55.8	27.2
Bare Ground	48.6	54.8	40.5	68.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.14	F2.15	F2.16	F2.17
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.77	0.62	0.92	1.33
Agropyron spicatum				
Agrostis scabra	0.02	0.13	0.07	0.07
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	1.35	6.8	3.58	2.75
Artemisia frigida	0.4		0.04	1.81
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia		0.07	0.02	0.02
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album	0.01			0.01
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata		0.02		0.01
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata	0.09	0.04	0.01	
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2		0.01		
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.14	F2.15	F2.16	F2.17
Hymenoxis richardsonii	0.01			
Koeleria cristata			0.03	0.03
Koeleria macrantha				
Lappula occidentalis		0.03	0.01	
Lappula squarrosa				
Lepidium densiflorum	0.02	0.16		
Lichen Black	0.67	0.3	0.3	0.06
Lichen Green				
Lichen Lvs				
Lichen Orange	0.02	0.01		
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	1.04	0.22	0.27	0.12
Opuntia polyacantha				
Oryzopsis hymenoides			0.01	
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica		0.02		0.01
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis			0.01	0.05
Sphaeralcea coccinea				
Stipa comata	0.46	0.61	0.12	
Stipa viridula	0.01	0.01		
Symphoracarpos occidentalis				1.86
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.58	2.92	5.76	20.05
Litter	11	41.95	49.9	74.2
Bare Ground	87	56.9	46.7	24.4

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.18	F2.19	F2.20	F2.21
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	1.12	0.77	1.19	0.85
Agropyron spicatum				
Agrostis scabra	0.06		0.15	0.39
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii	0.02	0.01		
Artemisia cana	0.37	8.76	0.12	4.14
Artemisia frigida	0.01			
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album	0.01	0.01	0.32	
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata	0.07	0.26	0.44	
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata	0.02	0.03	0.02	0.02
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.18	F2.19	F2.20	F2.21
Hymenoxis richardsonii				
Koeleria cristata	0.45	0.2		0.02
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum	0.13	0.02	0.04	
Lichen Black	0.09	0.04		
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum		0.02		
Moss	0.08	0.13		0.01
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis			0.12	0.02
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula				
Symphoracarpos occidentalis	8.21	13.95	14.5	13
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana			0.02	0.05
Viola adunca				
Standing Dead	8.86	10	3.29	7.7
Litter	72.9	74.3	88.6	94.2
Bare Ground	26.6	20.5	11.1	5

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.22	F2.23	F2.24	F2.25
Achillea millefolium	0.12			
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.54	0.37	0.31	0.13
Agropyron spicatum				
Agrostis scabra	0.08	0.2	0.02	0.32
Agrostis stolonifera				
Allium textile		0.01		
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	9.87	14.6	2.13	0.47
Artemisia frigida				
Aster ericoides				
Aster laevis				
Astragulus drummondii		0.01		
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata		0.03		
Corypantha vivipara		0.01		
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata		0.03	0.09	
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa		0.05		
Gutierrezia sarothrae		0.15		
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.F., 1990

Fan No.Site No:	F2.22	F2.23	F2.24	F2.25
Hymenoxis richardsonii				
Koeleria cristata	0.06			
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				0.03
Lichen Black	0.37	0.22		
Lichen Green				
Lichen Lvs				
Lichen Orange	0.01			
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	0.17		1.12	
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				0.01
Populus deltoides				
Rosa acicularis				
Rosa woodsii	0.1	0.39	6.84	0.04
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea			0.4	
Smilicina stellata				
Solidago missouriensis	0.11	0.11	0.02	
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula				
Symphoracarpos occidentalis	9.81	6.9	17.6	17.9
Taraxacum officinale			0.03	
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana	0.02	0.04		
Viola adunca				
Standing Dead	5.3	2.1	16.07	3.39
Litter	51.8	57.5	97.3	24.1
Bare Ground	45.6	41.6	2.3	67.8

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F2.26	F3.1	F3.2	F3.3
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.11	0.28	0.29	0.28
Agropyron spicatum				
Agrostis scabra	0.14			
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	3.12	6.77	3.14	4.56
Artemisia frigida				0.4
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis			0.02	0.12
Calamovilfa longifolia		4.65	2.19	1.27
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata		0.23		
Corypantha vivipara			0.02	
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus		0.01		
Eurotia lanata				
Fargaria virginiana				
Forb #1		0.01		
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				0.02
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa	0.04			
Gutierrezia sarothrae		0.01		
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F2.26	F3.1	F3.2	F3.3
Hymenoxis richardsonii				0.03
Koeleria cristata				0.07
Koeleria macrantha		0.22		
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black			0.03	
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum			0.02	
Moss			0.36	0.83
Opuntia polyacantha				
Oryzopsis hymenoides			0.03	0.06
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica		0.01		
Polygonum arenastrum	0.03			
Populus deltoides				
Rosa acicularis				
Rosa woodsii	0.04			
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis	0.04			
Sphaeralcea coccinea	0.02			
Stipa comata		0.19	0.93	1.34
Stipa viridula		0.02		
Symphoracarpos occidentalis	19.8			
Taraxacum officinale				
Thermopsis rhombifolia		0.4		
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.7	0	0.1	0.16
Litter	5.9	15.4	11.53	20.38
Bare Ground	74.7	78.5	82.6	76.2

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F3.4	F3.5	F3.6	F3.7
Achillea millefolium				
Agropyron sp				
Agropyron sp2	0.01	0.04		
Agropyron dasystachyum				
Agropyron smithii	0.81	1.56	1.33	1.17
Agropyron spicatum				
Agrostis scabra				
Agrostis stolonifera				
Allium textile	0.03			
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	3.99	11.25	5.38	25.93
Artemisia frigida	0.12	0.28		
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii		0.05		
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia	0.23	0.01		
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata		0.34		
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus	0.12			
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F3.4	F3.5	F3.6	F3.7
Hymenoxis richardsonii				
Koeleria cristata		0.08	0.02	0.03
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum	0.01			
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White	0.01			
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	0.28	0.55		
Opuntia polyacantha	0.08			
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	0.03			
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	0.99	0.22		
Stipa viridula	0.05			
Symphoracarpos occidentalis				2.3
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	1.07	3.4	1.83	2.69
Litter	12	13.4	6.28	16.6
Bare Ground	86	75	89.6	61.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F3.8	F3.9	F3.10	F3.11
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.77	0.84	1.4	0.41
Agropyron spicatum				
Agrostis scabra				
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	7.9	17	9.45	21.7
Artemisia frigida				
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia		0.09	0.12	
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F3.8	F3.9	F3.10	F3.11
Hymenoxis richardsonii				
Koeleria cristata	0.04			
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				0.19
Solidago missouriensis		0.06	0.06	0.34
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula	0.03	0.01		
Symphoracarpos occidentalis		5.1	3.55	23.4
Taraxacum officinale				
Thermopsis rhombifolia		1.48	0.09	0.81
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.29	1.45	3.7	2.1
Litter	1.1	3.04	4.71	3.7
Bare Ground	91	76.8	85	58.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F3.12	F3.13	F3.14	F3.15
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.35	1.24	0.25	0.15
Agropyron spicatum				
Agrostis scabra			0.04	
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	7.77	29.5	3.32	0.01
Artemisia frigida				
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia	0.02			
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower	0.02			
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F3.12	F3.13	F3.14	F3.15
Hymenoxis richardsonii				
Koeleria cristata				
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides	0.5	2		
Rosa acicularis				
Rosa woodsii	0.33	0.71	7.6	0.14
Salix sp.				7.5
Salix interior				
Salix sp.2	5.7			
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata	0.28		0.04	0.4
Solidago missouriensis	0.16			
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula		0.05		
Symphoracarpos occidentalis	23.3	15	21.9	27.2
Taraxacum officinale				
Thermopsis rhombifolia	3.57			
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	10.08	4.1	11.45	55.41
Litter	11.4	10.2	16.3	18.6
Bare Ground	53	52	58.6	30

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F3.16	F3.17	F3.18	F4.1
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.62	0.52	0.35	0.1
Agropyron spicatum				
Agrostis scabra		0.02	0.16	0.15
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus			0.08	
Arabis holboellii				
Artemisia cana	0.76	6.38		3.49
Artemisia frigida				0.2
Aster ericoides			0.07	
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis			7.75	
Bouteloua gracilis				1
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior		0.1		
Carex stenophylla				
Castilleja sp			0.02	
Chenopodium album			16.25	
Clematis ligusticifolia		0.1	0.85	
Comandra umbellata				
Corypantha vivipara				0.07
Crataegus rotundifolia				
Descuraina pinnata			0.12	
Epilobium sp	0.2			
Erigeron caespitosus				0.02
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower	0.03			
Forb #3 the weed		0.4		
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F3.16	F3.17	F3.18	F4.1
Hymenoxis richardsonii				
Koeleria cristata			0.04	
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum			0.12	
Lichen Black				0.2
Lichen Green				
Lichen Lvs				0.11
Lichen Orange				0.05
Lichen White				0.08
Linum lewisii				
Linum rigidum				0.02
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				0.28
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				0.11
Polygonum arenastrum				
Populus deltoides			35.4	
Rosa acicularis				
Rosa woodsii	3.53	0.39	0.02	
Salix sp.	4.8			
Salix interior	5.9			
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata	0.11		0.18	
Solidago missouriensis	0.15	0.38	0.11	
Sphaeralcea coccinea				
Stipa comata			0.1	0.31
Stipa viridula			0.02	
Symphoracarpos occidentalis	7.3	1.83	9.63	
Taraxacum officinale	0.86	0.21	0.06	
Thermopsis rhombifolia			1.9	
Tragopogon dubius				
Vicia americana				
Viola adunca			0.2	
Standing Dead	17.6	0.4	7.64	0.11
Litter	18.2	5.04	97	21.31
Bare Ground	53	87.9	2.9	75.9

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F4.2	F4.3	F4.4	F4.5
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.19	0.64	1.3	0.95
Agropyron spicatum				
Agrostis scabra	0.11	0.06	0.06	0.15
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	5.4	10.8	2.35	16.95
Artemisia frigida	1.2	11.5	0.99	10.3
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				0.02
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis	0.23	0.14	0.08	0.02
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara	0.03			
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata	2.8			
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8			0.07	0.02
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F4.2	F4.3	F4.4	F4.5
Hymenoxis richardsonii				
Koeleria cristata		0.02	0.07	0.04
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa			0.06	
Lepidium densiflorum				
Lichen Black				
Lichen Green	0.12	0.07	0.02	
Lichen Lvs	0.02		0.12	
Lichen Orange	0.02			
Lichen White				
Linum lewisii				0.03
Linum rigidum	0.05			
Lomatium foeniculaceum				
Moss	0.41			
Opuntia polyacantha	0.23	0.58		0.02
Oryzopsis hymenoides				
Oxytropis sericea				0.06
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	0.12			
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea		0.24		
Stipa comata	0.08	0.88	0.65	0.03
Stipa viridula				0.03
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.21	1.41	0.3	2.97
Litter	77	78.2	86.7	92.4
Bare Ground	22.3	23.3	13.3	6.1

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F4.6	F4.7	F4.8	F4.9
Achillea millefolium	0.12	0.06		
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.97	2.31	1.23	0.82
Agropyron spicatum				
Agrostis scabra	0.12	0.59	0.13	0.12
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	8.48	0.11	2.48	14.3
Artemisia frigida	0.08			
Aster ericoides	0.01		0.32	0.94
Aster laevis				0.02
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album	0.03		0.05	0.01
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				0.03
Gutierrezia sarothrae	0.01			
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				0.02

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F4.6	F4.7	F4.8	F4.9
Hymenoxis richardsonii				
Koeleria cristata		0.02		
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				0.01
Lichen Black				
Lichen Green				
Lichen Lvs		0.01	0.05	0.04
Lichen Orange		0.01		
Lichen White				
Linum lewisii	0.02		0.01	0.03
Linum rigidum				
Lomatium foeniculaceum				
Moss		0.02		
Opuntia polyacantha			0.42	
Oryzopsis hymenoides				
Oxytropis sericea	0.02	0.01		
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica			0.03	
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				0.02
Sphaeralcea coccinea				
Stipa comata	0.02			
Stipa viridula	0.21	0.05	0.03	
Symphoracarpos occidentalis	2.32	0.77		
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	3.07	2.28	3.91	2.77
Litter	94.5	92.3	84.7	75
Bare Ground	3.9	7.7	15.3	24.2

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F4.10	F4.11	F4.12	F5.1
Achillea millefolium			0.4	
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.15	0.02	0.26	
Agropyron spicatum				
Agrostis scabra	0.26	0.62	0.15	0.02
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	7.1			0.53
Artemisia frigida				0.03
Aster ericoides	2.43	3.55	0.87	
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				0.1
Calamovilfa longifolia				0.01
Campanula rotundifolia				
Carex brevior				
Carex stenophylla			0.1	
Castilleja sp				
Chenopodium album	0.03	0.05	0.01	
Clematis ligusticifolia				
Comandra umbellata				0.12
Corypantha vivipara				0.13
Crataegus rotundifolia				
Descuraina pinnata			0.04	
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				1.4
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				0.01
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa			0.13	
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F4.10	F4.11	F4.12	F5.1
Hymenoxis richardsonii				
Koeleria cristata				0.01
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				0.24
Lichen Green				0.21
Lichen Lvs				1.48
Lichen Orange				0.08
Lichen White				0.08
Linum lewisii				
Linum rigidum				0.01
Lomatium foeniculaceum				
Moss				0.02
Opuntia polyacantha				0.01
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii			0.03	
Plantago patagonica	0.07	0.06		0.11
Polygonum arenastrum			0.03	
Populus deltoides				
Rosa acicularis				
Rosa woodsii			2.32	
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis	0.01			
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata				1.25
Stipa viridula				
Symphoracarpos occidentalis			30.9	
Taraxacum officinale			0.05	
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.12	0	1.73	0.14
Litter	26.25	4.85	98.8	29.8
Bare Ground	52.15	92.4	1.4	70.2

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F5.2	F5.3	F5.4	F5.5
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.02	1.04	0.71	0.97
Agropyron spicatum			0.03	0.01
Agrostis scabra	0.09	0.07	0.06	
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	2	1.51	4.26	1.58
Artemisia frigida	0.11	0.04		
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis	0.29	0.03	0.03	
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				0.1
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus		0.07		
Eurotia lanata	3.18	1.85	2.46	1.12
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F5.2	F5.3	F5.4	F5.5
Hymenoxis richardsonii				
Koeleria cristata			0.05	0.15
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black	0.3	0.11	0.17	0.06
Lichen Green				
Lichen Lvs		0.01	0.01	
Lichen Orange	0.05			
Lichen White		0.01		0.01
Linum lewisii				
Linum rigidum	0.03	0.01		
Lomatium foeniculaceum				
Moss	0.01			
Opuntia polyacantha		0.06		
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica	1			
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	0.68	0.48	1.02	0.31
Stipa viridula				
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	0.4	3.64	0.66	5.43
Litter	24.4	68.9	59.8	62.9
Bare Ground	75.6	31.1	39.2	39.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F5.6	F5.7	F5.8	F5.9
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.9	1.33	0.78	0.68
Agropyron spicatum				
Agrostis scabra	0.01			
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	10.06	12.75	12.2	18.8
Artemisia frigida	0.07	0.07	0.05	0.01
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata		1.68		
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F5.6	F5.7	F5.8	F5.9
Hymenoxis richardsonii				
Koeleria cristata	0.1	0.04	0.09	0.12
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black	0.11	0.01		
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White	0.02			
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha		2		
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea	0.03			
Stipa comata	0.12	0.41		0.01
Stipa viridula				
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	2.86	3.91	2.46	1.62
Litter	58.8	94.3	11.95	29.7
Bare Ground	40.4	5.5	78.2	58.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F5.10	F5.11	F5.12	F5.13
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.54	0.61	0.55	0.69
Agropyron spicatum				
Agrostis scabra				
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	26.2	19.22	22.17	11.75
Artemisia frigida				
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F5.10	F5.11	F5.12	F5.13
Hymenoxis richardsonii				
Koeleria cristata	0.18	0.04	0.08	0.13
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				0.2
Sphaeralcea coccinea				
Stipa comata			0.01	
Stipa viridula		0.01		0.05
Symphoracarpos occidentalis			0.2	4.42
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	3.26	7.37	3.04	5.07
Litter	14	17.46	11	12.38
Bare Ground	61.5	65	68.7	73.2

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F5.14	F5.15	F5.16	F5.17
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.71	0.99	0.35	0.66
Agropyron spicatum				
Agrostis scabra	0.01	0.01	0.04	0.06
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	18.56	12.11	17.1	15.65
Artemisia frigida				
Aster ericoides		0.1	0.04	0.03
Aster laevis			0.06	
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				0.01
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like			0.04	
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				0.1
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F5.14	F5.15	F5.16	F5.17
Hymenoxis richardsonii				
Koeleria cristata	0.06	0.05	0.02	0.02
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis			0.08	
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula	0.03	0.02		0.04
Symphoracarpos occidentalis	3.78	1.79	24.8	8.2
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	2.84	2.31	2.36	3.29
Litter	14.5	13.45	14.8	20.9
Bare Ground	67.7	67.7	50.5	59.9

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F5.18	F5.19	F5.20	F5.21
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.56	0.45	0.26	0.31
Agropyron spicatum	0.01		0.01	
Agrostis scabra	0.07	0.06	0.16	0.12
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	24.22	21.32	4.31	6.5
Artemisia frigida	0.09			
Aster ericoides	0.03	0.07	0.18	0.38
Aster laevis		0.08	0.27	0.85
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp		0.02		
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				0.08
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa		0.02	0.36	0.26
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F5.18	F5.19	F5.20	F5.21
Hymenoxis richardsonii				
Koeleria cristata	0.06	0.02		0.01
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii			0.15	0.63
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis		0.8	0.11	
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula				
Symphoracarpos occidentalis		3.6	9.25	23.5
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	2.18	7.01	1.24	2.46
Litter	16.5	15.75	12	25.6
Bare Ground	65.3	62	77.6	56

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F522	F5.23	F5.24	F6.1
Achillea millefolium		0.03		
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.13	0.09	0.28	0.2
Agropyron spicatum			0.09	
Agrostis scabra	0.01	0.11	0.11	
Agrostis stolonifera			0.06	
Allium textile				0.02
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana		5.74	6.71	2.32
Artemisia frigida				0.4
Aster ericoides	0.33	0.29	0.28	
Aster laevis	1.07	0.59	1	
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				0.01
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata				
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				0.25
Fargaria virginiana	0.03			
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa		0.21	0.28	
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F522	F5.23	F5.24	F6.1
Hymenoxis richardsonii				0.01
Koeleria cristata				0.18
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black				0.01
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				0.04
Lomatium foeniculaceum				
Moss				
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				0.01
Phlox hoodii				0.06
Plantago patagonica				0.02
Polygonum arenastrum				
Populus deltoides			21.3	
Rosa acicularis				
Rosa woodsii	8.61	0.03		
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata	0.03			
Solidago missouriensis	0.14	0.26	0.26	
Sphaeralcea coccinea				0.38
Stipa comata				1.05
Stipa viridula				0.01
Symphoracarpos occidentalis	20.25	12.4	16.45	
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				
Viola adunca				
Standing Dead	9.39	1.79	10.01	0.42
Litter	17.2	5.7	31.8	15.53
Bare Ground	53	77.1	56.7	82.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F6.2	F6.3	F6.4	F6.5
Achillea millefolium				
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.42	0.5	0.52	0.74
Agropyron spicatum	0.02			
Agrostis scabra	0.01	0.01		
Agrostis stolonifera				
Allium textile	0.01			
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	0.91	19	17.43	17.65
Artemisia frigida	0.02			
Aster ericoides				
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				0.02
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata	0.25	0.2	0.19	0.02
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus	0.02			
Eurotia lanata	0.92	0.15		0.03
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F6.2	F6.3	F6.4	F6.5
Hymenoxis richardsonii				
Koeleria cristata	0.04	0.04	0.09	0.03
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black			0.01	0.06
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				0.01
Moss				0.1
Opuntia polyacantha				0.05
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii	0.01			
Plantago patagonica	0.03	0.02		
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata	2.47	0.83	0.3	0.03
Stipa viridula	0.15			0.03
Symphoracarpos occidentalis				
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana				0.01
Viola adunca				
Standing Dead	0.94	0.19	1.02	1.32
Litter	11.9	29.2	35.7	68.3
Bare Ground	85.7	64.5	58.5	31.7

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F6.6	F6.7	F6.8	F6.9
Achillea millefolium			0.06	
Agropyron sp				
Agropyron sp2				
Agropyron dasystachyum				
Agropyron smithii	0.66	0.67	0.54	0.34
Agropyron spicatum				
Agrostis scabra			0.11	0.19
Agrostis stolonifera				
Allium textile				
Amaranthus retroflexus				
Arabis holboellii				
Artemisia cana	26.75	13.8	7.95	14.55
Artemisia frigida				
Aster ericoides			0.01	0.06
Aster laevis				
Astragulus drummondii				
Astragulus missouriensis				
Astragulus sp				
Astragulus striatus				
Atriplex nuttallii				
Betula occidentalis				
Bouteloua gracilis				
Calamovilfa longifolia				
Campanula rotundifolia				
Carex brevior				
Carex stenophylla				
Castilleja sp				
Chenopodium album				
Clematis ligusticifolia				
Comandra umbellata	0.02	0.1		
Corypantha vivipara				
Crataegus rotundifolia				
Descuraina pinnata				
Epilobium sp				
Erigeron caespitosus				
Eurotia lanata				
Fargaria virginiana				
Forb #1				
Forb #10 CR plant				
Forb #2 wallflower				
Forb #3 the weed				
Forb #4 large				
Forb #5 small				
Forb #6 red				
Forb #7 cheno like				
Forb #8				
Fritillaria pudica				
Gaillardia aristata				
Grass #1				
Grass #2				
Grindelia squarosa				0.15
Gutierrezia sarothrae				
Hedysarum boreale				
Helianthus annuus				
Heterotheca villosa				

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F6.6	F6.7	F6.8	F6.9
Hymenoxis richardsonii				
Koeleria cristata	0.03	0.05	0.04	0.06
Koeleria macrantha				
Lappula occidentalis				
Lappula squarrosa				
Lepidium densiflorum				
Lichen Black		0.06	0.2	0.02
Lichen Green				
Lichen Lvs				
Lichen Orange				
Lichen White				
Linum lewisii				
Linum rigidum				
Lomatium foeniculaceum				
Moss	0.01	0.01		
Opuntia polyacantha				
Oryzopsis hymenoides				
Oxytropis sericea				
Penstemon nitidus				
Phlox hoodii				
Plantago patagonica				
Polygonum arenastrum				
Populus deltoides				
Rosa acicularis				
Rosa woodsii				0.05
Salix sp.				
Salix interior				
Salix sp.2				
Sarcobatus vermiculatus				
Setaria viridis				
Sheppardia argentea				
Smilicina stellata				
Solidago missouriensis				
Sphaeralcea coccinea				
Stipa comata				
Stipa viridula	0.07	0.01	0.02	0.03
Symphoracarpos occidentalis			1.59	1.03
Taraxacum officinale				
Thermopsis rhombifolia				
Tragopogon dubius				
Vicia americana	0.01			
Viola adunca				
Standing Dead	0.99	0.73	1.47	1.53
Litter	70.7	44.3	40	20.6
Bare Ground	27.2	54.5	49.9	68.3

Flora Abundance Data
Dinosaur P.P., 1990

Fan No.Site No:	F6.10	F6.11	F6.12
Achillea millefolium			
Agropyron sp			
Agropyron sp2			
Agropyron dasystachyum			
Agropyron smithii	0.12	0.15	0.09
Agropyron spicatum			
Agrostis scabra	0.2	0.07	0.15
Agrostis stolonifera			
Allium textile			
Amaranthus retroflexus			
Arabis holboellii			
Artemisia cana	14.7	0.15	6.16
Artemisia frigida			
Aster ericoides		0.01	
Aster laevis			0.05
Astragulus drummondii			
Astragulus missouriensis			
Astragulus sp			
Astragulus striatus			
Atriplex nuttallii			
Betula occidentalis			
Bouteloua gracilis			
Calamovilfa longifolia			
Campanula rotundifolia			
Carex brevior			
Carex stenophylla			
Castilleja sp			
Chenopodium album			
Clematis ligusticifolia			
Comandra umbellata			
Corypantha vivipara			
Crataegus rotundifolia			
Descuraina pinnata			
Epilobium sp			
Erigeron caespitosus			
Eurotia lanata			
Fargaria virginiana			
Forb #1			
Forb #10 CR plant			
Forb #2 wallflower			
Forb #3 the weed			
Forb #4 large			
Forb #5 small			
Forb #6 red			
Forb #7 cheno like			
Forb #8			
Fritillaria pudica			
Gaillardia aristata			
Grass #1			
Grass #2			
Grindelia squarosa	0.15	0.01	0.1
Gutierrezia sarothrae			
Hedysarum boreale			
Helianthus annuus			
Heterotheca villosa			

Flora Abundance Data (Cont.)
Dinosaur P.P., 1990

Fan No.Site No:	F6.10	F6.11	F6.12
Hymenoxis richardsonii			
Koeleria cristata			0.02
Koeleria macrantha			
Lappula occidentalis			
Lappula squarrosa			
Lepidium densiflorum			
Lichen Black		0.02	0.01
Lichen Green			
Lichen Lvs			
Lichen Orange			
Lichen White			
Linum lewisii			
Linum rigidum			
Lomatium foeniculaceum			
Moss		0.02	0.5
Opuntia polyacantha			
Oryzopsis hymenoides			
Oxytropis sericea			
Penstemon nitidus			
Phlox hoodii			
Plantago patagonica			
Polygonum arenastrum			
Populus deltoides			
Rosa acicularis			
Rosa woodsii		1.44	0.02
Salix sp.			
Salix interior			
Salix sp.2			
Sarcobatus vermiculatus			
Setaria viridis			
Sheppardia argentea			
Smilicina stellata			
Solidago missouriensis	0.02		
Sphaeralcea coccinea			
Stipa comata			
Stipa viridula			0.02
Symphoracarpos occidentalis	21.7	23.6	30.1
Taraxacum officinale			
Thermopsis rhombifolia			
Tragopogon dubius			
Vicia americana			
Viola adunca			
Standing Dead	0.11	1.35	1.41
Litter	14.5	45	26.7
Bare Ground	67.2	37.5	51