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Reactivation and stabilization phases of eolian deposits under climatic and anthropogenic influences in the Rolling Plains of Texas, U.S.A.

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Dedicated to Tom,
who was killed on June 13th 1995 in Childress, Texas
leaving an incredible pain in my heart…

The Rolling Plain-s

The land so untouched at dusk,
imagine wild bison roaming....
tall grass and wilderness
beauty at peace
Two dark haired boys with big brown eyes
playing hunting near the creek
a sudden noise
screaming and shooting
--
the Marker reads...
McKenzee
“subdued” the Indians...
the END
-meaning?-
What have we done....
ending the Plain-s
As far as you see
cows pressed in feed lots
meat packaged in stores
unwrap, without blood on your hands
-
you can eat?
somebody else’s kill
detached from the soul
how dare you

Llano Estacado
the plain stakes replaced by telephone poles
communication?
not with the land anymore
grass fires go - and trash fires come
wilderness driven away
rattlers killed and coyotes trapped
I surely hope..... we pay someday
--
Welcome to plain-view
but what’s in the way
Sam’s store
selling for less
less than it’s worth?
bye-bye mom and pop’s
can’t come anymore
-
stretches of emptiness alongside the road
storefronts and hearts
Erin’s Body Shop and Weyn’s Welding
seem the only one’s left
not for long and they will be gone
less is not more - it’s somebody’s theft
--
riding along in shiny metal boxes hunting for less
to
Matador,
what are we killing
our own little towns?
The Rolling Plains tumbling away from us
nothing is plain-(s) anymore
like waffles and donuts - sugar coated
so it’ll be -- with what we will see.
Are we suffering? No, we plain-ly look away.

By Ani Tram

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Deutsche Zusammenfassung

In den Rolling Plains von Nordtexas, U.S.A. existieren zahlreiche Dünen und Flugsandvorkommen, die aufgrund unterschiedlicher Lage und Morphologie, sowie durch zwischengeschaltete Paläoböden ihre unterschiedliche Genese erkennen lassen. Anthropogene und klimatisch ausgelöste Desertifikation spielten dabei eine wichtige Rolle. Die für das nordtexanische Klima typischen trockenen Winter und hohen Windgeschwindigkeiten im Frühjahr waren und sind dafür ideale Vorraussetzungen. C^{14}-Datierungen der Paläoböden erlauben die Rekonstruktion einer zeitliche Abfolge der Sandtransportphasen bei diesem Geschehen.

Die jüngsten eolischen Reaktivierungen wurde durch die kulturlandschaftliche Entwicklung des Gebietes zum Beginn dieses Jahrhunderts verstärkt. Zeugen dieser Reakivierungen sind sogennante Zaun- und Pseudodünen in der Nähe der Stadt Post. Sie sind Zeugen einer verstärkten anthropogenen Desertifikation.

Die einzigartige historische Entwicklung der Stadt Post führte zu einer größeren Anzahl von Sand-Reaktivierungen auf den Feldern in der Nähe der Stadt. C.W. Post, der Gründer der Stadt, führte den Trockenlandanbau ein um die Bodenproduktivität erheblich zu erhöhen. Nach der Beschreibung von EAVES (1943) ließ er mehrere experimentelle Farmen in der Nähe von Post City anlegen und erforschte verschiedene Anbaumethoden und leicht zu produzierende Getreide-, Frucht- und Gemüsearten auf mehreren Farmen. C.W. Post rechnete wahrscheinlich nicht mit den für die Bodenqualität und -quantität zerstörenden Konsequenzen, die eine neue Anbautechnik mit sich brachte. In der Gegend von Post, die eine beträchtliche Anzahl von Zaun - Dünen aufweist, sind die umliegenden Felder zum Teil bis auf das Grundgestein - ein Sandstein der triassischen Dockum Gruppe - ausgeblasen.

Der von der “Soil Conservation Agency” maximale akzeptierte Bodenerosionsbetrag wurde auf 11.2 Tonnen pro Hektar und Jahr festgelegt. Er entspricht bei einer gemessenen Bodendichte von 1.3 gr/cm^3 einem Bodenverlust von 0.86 mm pro Jahr. Schon die Sandmenge nur eines Quadratkilometers ergibt dabei, wenn sie sich 100 Jahre lang zu 90% entlang einer Seite eines Zaunes anlagert, eine Zaun-Düne von 1000 Metern Länge, 22.3 Metern Breite, und 6.9 Metern Höhe. Die Dimensionen einer Reihe von Zaundünen in diesem sind aber wesentlich geringer. Auf einigen der Felder, entlang deren Rändern solche Zaundünen entwickelt sind, ist der Boden dabei bis auf das Grundgestein, einen Sandstein, ausgeblasen worden. Die heutige Landoberfläche liegt dort ca. 1 Meter unter der ehemaligen Bodenoberfläche.

Es gibt aber auch noch andere anthropogen beeinflußte eolische Ablagerungen, die im regionalen Sprachgebrauch der Rolling Plains “shinnery motts” genannt werden. Diese Ablagerungen entstehen, wenn ein höhergelegener, unebener Bereich des Feldes eine dichte Vegetation besitzt und deshalb mit einem

Traktor umrundet wird. Diese Pseudo-Dünen werden so Jahr für Jahr stärker ausgeprägt. Dies ist aus Luftbildern, die in der Nähe der Stadt Post in den Jahren 1970, 1980 und 1991 aufgenommen wurden, ersichtlich.

Die Kulturlandschaftsentwicklung dieses Jahrhunderts trug erheblich zu den jüngsten Sandreaktivierungen bei. Durch Ergebnisse dieser Arbeit konnte weitgehend ausgeschlossen werden, daß Indianer zu diesen Reaktivierungen beitrugen. Auslöser der Sandreaktivierungen vor der kulturlandschaflchen Entwicklung des Studiengebietes dürften jedoch im allgemeinen klimagesteuerte Prozesse gewesen sein, was in einem Dünenfeld in der Nähe von Estelline, Texas veranschaulicht werden konnte.

Zwei Paläoböden, die von Winderosion freigegelegt waren, wurden auf ein Alter von 200 (± 40) und 340 (± 50) b.p. Jahre datiert, was auf eine erneute Überlagerung dieser Böden während einer Sandreaktivierungsphase zu dieser Zeit hindeutet. Diese beiden Mobilisierungsepisoden ähneln dem Bild zyklisch verlaufender Dürreperioden, das anhand von Baumringdaten in Nordtexas etabliert werden konnte (STAHLE and CLEAVELAND, 1988).

Diese beiden Radiocarbondaten wurden mit dem Juni "Palmer Drought Severity Index", von STAHLE and CLEAVELAND (1988) nachgewiesen an Baumrindendaten von Eichen (*Quercus stellata*), verglichen. Die Ergebnisse von STAHLE and CLEAVELAND (1988) zeigen drei ausgeprägte Dürreperioden seit dem Jahr 1698. Das jüngere Radiocarbonalter (200 (±40) Jahren b.p.) des einen Paleo-B_t-Horizontes im Dünenfeld in den Nähe von Estelline korrespondiert ungefähr mit einer Dürre um das Jahr 1772.

Um die Entwicklung dieses Dünenfeldes genauer untersuchen zu können wurde eine Sand Transport Rose, auf Winddaten basierend, die während einer Trockenzeit in den fünfziger Jahren von JOHNSON (1965) gesammelt wurden, angefertigt. Winde, die Sand transportieren, kommen vorwiegend aus süd-westlicher und westlicher Richtung. Dies bedeutet für das Dünenfeld von Esteline, daß die Herkunftssande vorwiegend aus dem Flußbett stammen.

Diese Hypothese wird von den Daten einer Korngrößenanalyse und dem Vergleich von Luftbildern aus den Jahren 1954 und 1985 unterstüzt. Die Luftbilder vom Dünenfeld in der Nähe von Estelline zeigen, daß Sand während einer Dürre in den fünfziger Jahren vom Fluß auf das Dünenfeld transportiert wurde. Es kann deshalb angenommen werden, daß der Prairie Dog Town Arm des Red Rivers das Ursprungsgebiet der Sande für das Dünenfeld in der Nähe von Estelline ist. Im Dünenfeld befinden sich aber auch einige Ausblasungszonen, die wahrscheinlich während einer Dürre reaktiviert wurden, da durch die Trockenheit die schützende Vegetation zerstört wurde.

Diese Arbeit identifizierte aber auch ältere Bodenbildungsphasen während des Mittel-Holozäns, die zeitlich ins "Altithermal" fallen. Das Altithermal, nachgewiesen von HOLLIDAY (1995) in den Southern High Plains, wies im

Vergleich zu heute größere jährliche Klimaschwankungen und wahrscheinlich auch zahlreichere und ausgeprägtere Dürren auf. Radiocarbondaten von zwei Lokalitäten, die für diese Arbeit untersucht wurden, fallen in den zeitlichen Rahmen des Altithermals.

Die erste Lokalität, der Swenson-Peacock Aufschluß im Stonewall County (Rolling Plains), zeigte zwei Paleoböden und eine rezente Bodenbildung. Diese Paleoböden sind Überreste von Parabraunerden, die im algemeinen ein A-A_h-A_l-B_t-C Profil aufweisen. Die sandige Version dieser Parabraunerden entwickelt im allgemeinen Lamellen anstelle eines durchgehenden B_t -Horizontes in Europa (SCHEFFER and SCHACHTSCHABEL, 1992). An Proben von drei Horizonten dieses Profiles wurde eine Radiocarbonanalyse durchgeführt. Unterhalb des rezenten Bodens ergab die Probe des Lamellenhorizont (Paleosol I.) im oberen Bereich ein Alter von 4,320 (±90) Jahre b.p. und im unteren Bereich 6,090 (±90) Jahre b.p. Der unterste sandige Ton Paleosol II. ergab ein Alter von 7,070 (±160) Jahren b.p.

Das untersuchte Profil der Meyer's Lokalität in Hutchinson County, wies eine rezente Bodenbildung und einen darunterliegenden Paleoboden auf. Der unterste Horizont aus sandigem Ton hat eine braune Tönung und besitzt einige wenige Kalkkonkretionen und kleinere Steinchen. Dieser Horizont ist von einem 1 cm breitem Streifen von Kalkkonkretionen und ebenfalls kleineren Steinchen, überlagert, die von einer Ausblasung des darunterliegenden Horizontes stammen. Als sich dieser Deflationsrückstand aus Kalkkonkretionen und kleineren Steinchen mit zunehmender Ausblasung verdichtete, bildete er eine Schutzschicht und bewahrte das unterlagernde Material vor weiterer Erosion. Eine C^{14} Datierung im oberen Bereich des braunen Horizontes dieses erodierten Paläosols ergab ein Alter von 5210 (± 80) Jahren.

Diese Akkumulationsphase des braunen Horizontes mit anschließender Bodenbildungsphase vor 5210 (± 80) Jahren fällt damit zeitlich auch ins "Altithermal", das von HOLLIDAY, (1995) und Ferring (1990) zwischen 7,000 und 4,000 Jahren b.p. eingegrenzt wurde. Das Deflationspflasters läßt jedoch erkennen, daß ein Großteil dieses Paläobodens erst nach 5210 (± 80) b.p. erodiert worden war, woraus geschlossen werden kann, daß die eigentliche Akkumulationsphase erst danach stattfand und erst viel später bei erneutem Vegetationsverlust und damit erneuter flächenhafter Erosion endete.

Die Ergebnisse dieser datierten Aufschlüsse werden von Daten drei weiterer untersuchter Lokalitäten unterstüzt, die ähnliche Bodenbildungen aufweisen. Dies weist daruaf hin, daß sie wahrscheinlich ebenfalls während des geologischen Zeitabschnittes des Altithermal formten.

In den Rolling Plains haben Paleo-B_t-Horizonte, die während des Altithermals ausgebildet wurden, im allgemeinen rötliche Farben. Böden, bei denen die Ogallala oder Dockum Formation das Ursprungsgebiet der Sande waren und die auch während des Altithermals formten haben stattdessen bräunliche

Farben in den B_t-Horizonten. Dies könnte darauf hinweisen, daß in diesem Gebiet das Ursprungsmaterial vielleicht mehr Einfluß auf die Farbe der Böden hatte als klimatische Faktoren. Rezente Bodenbildungen haben überwiegend bräunliche Farben, was auf eine Sandreaktivierung aus den trochenen Flußbetten hinweist, da die Flußsande aus weitgehend erodierten- bräunlichen Ogallala und Blackwarter Draw Sanden von der Caprock Stufe bestehen.

Die verschiedenen Profile des Studiengebietes zeigen, daß die rezenten Böden im allgemeinen auch im Grad des Stadiums der Bodenbildung variieren. Dies könnte darauf hinweisen, das Dürrezeiten immer mit Sandreaktivierungen verbunden sind, jedoch nicht all Gebiete gleichzeitig von derselben Reaktivierungphase beeinflußt werden. Unangepaßte Viehzucht und Ackerbau Techniken, die große Teile der Vegetationsdecke zerstören, tragen dazu bei Sand-reaktivierungen auszulösen.

Die oben aufgeführten Ergebnisse dieser Arbeit weisen darauf hin, daß Sandreaktivierungenen, zumindest während des Altithermals auf regionaler Ebene stattfanden. Diese Aussage wird von Ergebnissen von HOLLIDAY (1995) unterstüzt, der Altithermal Reaktivierungsphasen auch in den benachbarten Southern High Plains nachweisen konnte. Einige in dieser Arbeit untersuchte Aufschlüsse der Rolling Plains weisen aber auch lokale Ausblasungszonen auf, die während des späten Holozäns, und auch heute noch, formten. Diese Ausblasungen haben wahrscheinlich eine geringere Intensität als die Reaktivierungen während des Altithermals. Die rezenten Bodenbildungen in unterschiedlichen Reifestadien deuten darauf hin, das die Ausblasungen zu unterschiedllichen Zeiten und Stellen im Arbeitsgebiet stattfinden. Zwei datierte Ausblasungen die in den letzten 300 Jahren in einem Dünenfeld in der Nähe von Estelline stattfanden, unterstützen ebenfalls diese Ergebnisse einer lokalen Ausblasung im Untersuchungsgebiet an verschiedenen Stellen.

In dieser Arbeit wurde festgestellt das die Intensität der Reaktiveriungen klimagesteuert ist und von der Dauer und der Intensität einer Dürre während des Holozäns abhängig ist. Trockenere Klimaabschnitte, wie zum Beispiel das Altithermal mit ausgeprägten Dürren führen zu regionalen und großräumlichen Sandreaktivierungen. Ausblasungen und Sandreaktiverung auf lokaler Ebene sind jedoch stärker von der geomorphologischen Lage in Kombination mit kurzlebigen Trockenheiten (~10 Jahre) beeinfllußt. Die Deflationen werden zudem noch durch moderne Techniken der Viezucht und des Ackerbaus verstärkt.

Die zeitliche Abfolge der eolischen Reaktivierungs- und Stabilisierungs-phasen der Texas Rolling Plains wurden mit Ergebnissen von den Great Plains und den Nebraska Sand Hills verglichen. Die Figur 16 im zweiten Kapitel zeigt das Geographen und Geologen (GAYLORD, 1990; MUHS, 1985; FOREMAN, GOETZ and YUHAS, 1992; MADOLE, 1994; ARBOGAST, 1995; AHLBRANDT, et al., 1983; SWINEHART et al., 1995) schon eine große Anzahl an Sandreaktivierungen und bodenbildenen Phasen in der Great Plains Region erforscht haben. Jedoch variieren die Ergebnisse und Daten zwischen den einzelnen eolischen Ablagerungen der Great Plains und Southern High Plains Regionen erheblich.

MUHS (1995), der stabilisierte parabolische Dünen im nordöstlichen Colorado untersuchte, veranschaulichte, daß die älteren zu Grunde liegenden Sande während des Altithermals abgelagert wurden. GAYLORD (1990) erforschte eine 25 m mächtige Abfolge von Dünen- und Interdünenmaterial in Wyoming, wobei er zwei Abschnitte mit eolischem Material zwischen 7,000 und 4,000 Jahren p.b. heraustellen konnte. FOREMAN, GOETZ and YUHAS (1992) fanden zumindest vier eolische Reaktivierungsphasen während der letzten 10,000 Jahre in den High Plains in Colorado. Eine dieser Reaktiverungsphasen fällt zeitlich ins Altithermal.

MADOLE (1995) identifizierte drei Sandeinheiten in einem Zeitraum von 22,500 zu 150 b.p., ausgenommen ist jedoch der Zeitraum von 8,000 bis 9,000 b.p, da das Klima in diesem Zeitraum wahrscheinlich zu naß war um Sand reaktivieren zu können. Das Altithermal fällt genau in eine dieser Perioden die nach Angaben von MADOLE (1995) von 8,000 bis zu vor 1,000 Jahren dauerte.

ARBOGAST (1995) belegte sechs bodenbildende Phasen in der Great Bend Sand Prairie in Kansas (6,300; 2,300; 1,500; 1,000; 700 and 200 Jahre b. p.), alle mit schwach ausgeprägten A-AC-C Profilen. Sandreaktivierungsphasen wurden von ihm zwischen 5,700 - 4,800, 2,300 - 1,700, 1,600 - 800 und < 200 Jahren b.p. festgelegt (ARBOGAST, 1993). Die erste dieser Sandreaktiverungs-phasen fällt in den Zeitraum des Altithermals.

AHLBRANDT, et al. (1983) begrenzte eolische Reaktivierungen der Dünenfelder in den Great Plains and im Rocky Mountain Basin auf die letzten 7,000 Jahre. PORTER et al., (1995) fand zumindest zwei Phasen der Dünenreaktivierung im südwestlichen Kansas. Die letzte Sandablagerung fand zwischen 1,600 und 1,300 Jahren b.p. statt. Die andere Phase der Dünenreakti-vierung war um 5,570 Jahre b.p., ein Zeitpunkt der ebenfalls in das Altithermal fällt.

Die Nebraska Sand Hills wurden noch einmal gründlich von SWINEHART und AHLBRANDT untersucht, nachdem viele Autoren bereits annahmen, daß sie ein Pleistozänes Alter haben. Die Arbeiten von SWINEHART und AHLBRANDT fanden jedoch zahlreiche Sandreaktivierungen während der letzten 7,000 Jahre b.p. (AHLBRANDT et al., 1983).

Feldarbeiten in den Nebraska Sand Hills vorgestellt von Geologen und Geographen während einer “Geological Society of America” Exkursion zeigten, daß der untere Teil der Dünen an der Red Ranch Lokalität aus Pliozänen Sanden besteht, die wahrscheinlich zwischen 2.5 and 2 Millionen Jahre alt sind. Eolische Ablagerungen, die den Pliozanen Sanden überliegen, wurden mit einer “optically stimulated luminescence” (OSL) Datierung auf ein Mittel- bis Spätholozänes Alter von ungefähr 3,000 Jahren festgelegt (STOKES , 1993, pers. Absprache, zitiert in MAY et al., 1995). Der oberste schwach ausgebildete Boden wurde mit zwei Proben auf ein Alter von 220± 90 und 220± 60 Jahren b.p. datiert und die unterere Bodenbildung auf 450± 90 and 770± 90 Jahre b.p. (MAY et al., 1995).

MUHS und seine Kollegen (MUHS et al., 1995) glauben jedoch, daß die Sande der Nebraska Sand Hills älter sind, da die Sande weniger Feldspäte und wesentlich mehr Quarzkörner aufweisen. Für diese Beobachtung gibt es zwei Erklärungen: entweder sind die Sande schon einmal von einer Bodenbildung beeinflußt worden, wobei die Feldspäte chemisch verändert werden, oder die Feldspäte wurden mechanisch während der Saltation zerstört. Beide dieser Hypothesen deuten jedoch auf eine Wiederverarbeitung älterer Sande hin. Die Lage der Nebraska Sand Hills und deren geologische Umgebung ist der Lage der Dünenfelder der Rolling Plains sehr ähnlich, wo ebenfalls ältere Formationen, wie zum Beispiel das Perm oder die Dockum Gruppe von jüngeren Sanden überlagert werden. Dies konnte ebenfalls auf ein Reaktivierung älterer Sand im Gebiet der Rolling Plains hinweisen.

Eine Arbeit von WOLFE et al. (1995) über die semiaride Great Sand Hills Region (auch als Palliser Triangle bekannt) in Sakatchewan (Kanada), ergab sehr junge Sandreaktivierungsphasen. Dünen dieses Gebietes zeigten zahlreiche Reaktivierungen während der letzten 200 Jahre. Diese Dünen ergaben durch eine "optical stimulated luminescence" (OSL) Altersbestimmung Reaktivierungen 173 (±10), 210 (±12), 940 (±60), 70 (±15), 110 (±10) und 97(±10) Jahre vor heute (WOLFE et al., 1995). Sieben andere Proben aus diesem Gebiet ergaben ein Mittel-Holozänes Alter der Böden (WOLFE et al., 1995), ähnlich der Böden in den Rolling Plains.

WOLFE et al. (1995), der diese eolische Ablagerungen im Palliser Triangle in Kanada untersuchte, zeigte in Ergebnissen dieser Arbeit, daß in den letzten 50 Jahren in diesem Gebiet Dünenreaktiverungen das Resultat von Regen und Temperaturschwankungen waren. Der allgemeine Trend der letzten 50 Jahre scheint jedoch zu einer Stabilisation der Dünen geführt zu haben. Diese Ergebnisse lassen sich mit großer Wahrscheinlichkeit auf das Dünenfeld in der Nähe von Estelline übertragen, wobei mit der Hilfe von Luftbildern von 1954 und 1985 festgestellt wurde, daß sich auch hier die Dünen in einem Stabilisierunstrend befinden.

Im allgemeinen kann man die Reaktivierungs- und Stabilisierungsphasen der Great Plains, Southern High Plains, Kanada and der Rolling Plains nur schlecht vergleichen, da dort jeweils andere stratigraphische Einheiten gewählt wurden und mit einer Vielzahl an Methoden gearbeitet wurde. Faktoren, die einen Vergleich erheblich beeinflußen können sind die verschiedenen Altersdatierungs-methoden, das Ursprungsgebiet der Sande, die geomorphologische Umgebung, zeitlich verschiedene Erosionsphasen, regionale gegenüber lokalen Reaktivierungen und eine unteschiedliche kulturelle Entwicklung der jeweiligen Gebiete.

In diesen drei Regionen gab es eine große Anzahl an Reaktivierungsphasen, was andeutet, daß es wahrscheinlich auch eine große Anzahl an langanhaltenden Trockenperioden während des Holozäns gegeben haben mußte. Es ist jedoch problematisch den genauen Zeitraum dieser Trockenperioden zu bestimmen, da eine Dürre, die im allgemeinen von starken Winden begleitet ist den A- und oft auch einen Teil des B-Horizontes erodiert und dieser Teil nicht mehr datiert werden kann. Dies ist natürlich auch vom Material und dem Stadium der Bodenbildung abhängig. Dies kann man an einem Feld in der Nähe von Post in den Texas Rolling Plains beobachten, da ein Großteil des B-Horizontes (C-Horizont kommt zum Vorschein) in diesem Jahrhundert erodiert wurde.

Wenn sich nun die klimatischen Bedingungen ändern und eine schützende Vegetationsdecke wächst, wird auch wieder neuer Sand abgelagert. Der Beginn dieser neuen Bodenbildungsphase und ebenfalls der Zeitpunkt bis zu dem erodiert wurde kann anhand der Tiefe der Probe im Profil datiert werden. Zwischen diesen beiden Böden, wo Material erodiert wurde, ist jedoch ein Zeitraum verlorengegangen. Dies wird in dieser Arbeit an einem Profil in der Nähe der Stadt Borger veranschaulicht, in dem zwei Böden von einem Deflationsplaster getrennt sind.

Der Grad der Erosion hängt sehr stark von den lokalen Bedingungen des Gebietes ab, wie zum Beispiel von der geomorphologische Umgebung, dem Ausgangsmaterial, dem Stadium der Bodenbildungen und variierenden Windgeschwindigkeiten. Im allgemeinen sind alle diese Faktoren entsprechend der einzelnen Lokalitäten unterschiedlich, und deshalb ist wahrscheinlich auch der Zeitraum und die Intensität der eolischen Reaktivierungsphasen in den einzelnen Gebieten unterschiedlich.

Die Altithermal Trockenzeit kann in der Great Plains Region noch nicht klar abgegrenzt werden wie es zum Beispiel in der Southern High Plains Region möglich ist (HOLLIDAY, 1995). Oben ausgeführte Probleme führen zu einer unterschiedlichen Abgrenzung des Altithermals. Eine anderer mögliche Erklärung ist, daß das Altithermal in den verschiedenen Gebieten unterschiedleich lang dauerte. Es müssen sehr viel mehr vergleichende Studien gemacht werden um Sandreaktivierungsphasen in Kanada, und der Great Plains und Rolling Plains Regionen genauer bestimmen zu können und um paleoklimatsche Bedingungen während des Holozäns in den einzelnen Regionen ableiten zu können.

Die in dieser Arbeit erarbeiteten eolischen Reaktivierungs- und Stabilisierungsphasen in den Rolling Plains of Texas können mit eolischen Studien in der Great Plains und High Plains Regionen verglichen werden. Bis zu diesem Zeitpunkt gibt es noch keine umfassende Arbeit, die diese eolischen Reaktivierungsphasen der einzelnen Gebiete im Midwesten der U.S.A. vergleicht.

Diese Arbeit ist die erste und einzige Studie dieser Art, die Sandreaktivierungs- und Stabilisierungphasen in den Rolling Plains in Texas erarbeitet hat. Diese Studie ergründet ebenfalls die Ursachen fur eine Reaktivierung auf regionaler als auch auf lokaler Ebene während des Holozäns. Die Ergebnisse dieser Arbeit lassen Vergleiche mit anderen Reaktivierungphasen in Gebieten der gesammten Great Plain Region zu, was zur Holozänen Klimaforschung in diesem Gebiet beitragen kann.

Diese Studie bemüht sich außerdem um ein besseres Verständnis der Deflationen der Dünenfelder und Sandebenen als Folgeerscheinung von wiederkehrender Dürren in Kombination mit modernen Techniken des Ackerbaus und der Viehzucht in den Rolling Plains von Texas.

Leider stellt diese Arbeit keine vollständige zeitliche Abfolge aller eolischen Reaktivierungsphasen der Rolling Plains dar. Hierzu sollte bedacht werden, daß erstens die Rolling Plains eine Erosionslandschaft sind, und deshalb auch Material und Zeiträume verlorengingen, wie bereits oben erläutert wurde. Zweitens fanden die Sandreaktivierung nicht überall gleichzeitig statt, was man an den letzten 300 Jahren im Dünefeld von Estelline und OSL Daten von Kanada sehen kann. Drittens, es konnte nur ein kleiner Anteil der Lokalitäten altersdatiert werden, da die Laborarbeiten sonst sehr viel teuerer gewesen wären und die Feldarbeiten außerdem den Rahmen dieser Arbeit geprengt hätten.

0. Introduction

Once again concerns about land degradation were fueled by the most recent Texas drought during the year 1996. Anxiety stems from previous drought disasters during the 1930s and 1950s, which affected vast areas of the Great Plains region. During the year of 1996, international and national magazines as well as American newspapers reported on “desertification” in Texas. Is “desertification” getting worse? Are isolated sand sheets and dune fields turning into a broader desert landscape? This research will investigate if concerns about land degradation hold any truth or are just getting fueled by mass media creating a hysteria.

Across the Texas Rolling Plains there exists ample evidence that the cultural development and human utilization of the area could be inducing the process of desertification. Signs include severely wind-eroded fields, blowouts in vegetated dune fields, dust storms, and vast areas of active dune fields with severe blow-outs. Farming and ranching practices may have caused severe land degradation in an area, which has already experienced several severe droughts during this century.

Since the 1880s European settlers have modified the Texas Rolling Plains prairie through the cultural development of the region. The main sources of livelihood during early times were cattle ranching and some agriculture, depending on the availability of water. Agriculture and cattle ranching destroyed most of the natural vegetation in the area and significantly altered dune fields and sand sheets during this century. Short-term droughts during the 1930s and 1950s in combination with unsound farming practices contributed to a severe wind erosion in the area. MACHENBERG (1986) reported up to 0.8 m soil erosion on a cultivated field on the western edge of the Rolling Plains since 1920. These youngest sand reactivations, as part of the land degradation during this century, are evidence of the anthropogenic landscape alteration, which might be destroying the ecological balance of the natural environment in the region.

The study area is part of the Rolling Plains region and lies in the Texas Panhandle, USA (Figure 1). The investigated area, twenty-six counties, amounts to about half the size of Germany. Adjacent to the study area on the west emerges the Caprock Escarpment, separating the Rolling Plains from the Southern High Plains, the latter being the southern extension of the Great Plains region.

Figure 1. Location of twenty-six county study area in the United States of America.

The area was selected because preliminary research showed that sand sheets and dune fields are widespread, appear on all geologic formations, are different in location and morphology, and have different embedded paleosols These factors suggest differences in the geomorphic history. Most of these dune fields and sand sheets are currently vegetated, however some dune fields have large patches of active dunes and blowout areas under present climatic conditions. Others are densely vegetated with several well-developed paleosols and a modern soil. Sand deposits are located mainly adjacent to the Canadian, Red and Brazos rivers and their tributaries. However, smaller vegetated dune fields can also be found distal to modern rivers in elevated topographic locations covering small watershed areas, mostly on Permian shale, silt and sandstone formations. The least-developed and youngest sand deposits can be found alongside fields currently used for agricultural purposes and/or cattle ranching.

The main goal of this research is to interpret the geomorphic history of dune fields and sand sheets in the Texas Rolling Plains, and to investigate human versus climatic impact on these sand deposits. The Holocene landscape development can then be reconstructed and a stratigraphic sequence of sand stabilization/reactivation phases can be determined. To accomplish this goal eolian assemblages in the Texas Rolling Plains will be identified. Depositional phases, associated with soil development, will be linked to sand reactivation periods with erosional conditions. This research is based on a regional framework focusing on localized factors influencing eolian deposits in their immediate environment.

One aspect of this research tries to answer the following questions: are trigger mechanisms of these eolian reactivation phases climatic or human induced. Did the cultural development of the area cause land degradation and reactivation of these sand dunes and sand sheets? Are these reactivation phases a regional scale phenomenon or are local blowouts with short-term climatic changes predominant? If indeed the cultural development of the area triggered a reactivation of the eolian deposits, would it be possible to exactly determine the onset of the youngest sand reactivation phase?

To find answers to these questions it is important to investigate the development of the eolian sand sheets and dune fields, the geomorphic setting, and agricultural impact on the environment in the area. During preliminary field sessions, ample paleosols were mapped in the study area. These paleosols are evidence of older soil development phases. Many paleosols were eroded in the A or upper B- horizon and were then covered by windblown sand. During the time period of their development they had a protective vegetation cover. Drought conditions and/or agricultural practices destroyed the protective vegetation cover and sand deposits became reactivated.

Research of eolian reactivation and stabilization phases has a long history in the Great Plains region, starting in the early 1900s with KEYE's idea of a great "eoliation" of the region (KEYES, 1911a, b). Many researchers and explorers were drawn to the eolian deposits of the Great Plains region throughout history. They provided information ranging from early descriptive accounts of vast sandy areas, for example by Zebulon Pike in 1810 (Austin American Statesman, June 2nd, 1996) to the first comprehensive study of dune morphology in the region (SMITH, 1965).

Recent progress in eolian research, however, brought a series of new interpretations for eolian deposits and their depositional history in the Great Plains region (MUHS, 1985; SWINEHART, 1990; SWINEHART et al., 1988). Early misinterpretations of the eolian sequences of the Nebraska Sand Hills, originally thought to be Pleistocene in age, show that much has to be done to yet accomplish a comprehensive Great Plains eolian stratigraphic record.

There are ample challenges to combine stratigraphic records of the Great and Rolling Plains regions. Some problems are differences in dating techniques (thermoluminescense, versus optical stimulated luminescense and versus the radiocarbon method). Others are that eroded stratigraphic sections in some areas do not permit correlations to uneroded ones at other locations. Consideration needs to be also given to the possibility of local blowout events triggered by short-term cyclic drought events, only affecting some small areas in the region. However, despite these difficulties there is a need for correlations of eolian stratigraphic sequences in the Great Plains and adjacent regions to identify if reactivation of these deposits is caused by the similar regional versus local climatic changes and/or anthropogenic influences.

Researchers have previously focused mainly on the Great Plains and Southern High Plains regions. The eolian deposits of the Texas Rolling Plains have been previously mapped. They were primarily identified as Quaternary undifferentiated deposits (Qsa) by the Bureau of Economic Geology at the University of Texas at Austin on 1:250 000 geologic maps of Lubbock, Plainview, Amarillo and Big Spring (BUREAU OF ECONOMIC GEOLOGY, 1967, 1968, 1969, 1974) with recent revisions during the 1990s. The mapping was mostly performed from aerial photography interpretation. However, reconnaissance fieldwork for this research suggested that the sand deposits' geomorphic setting and paleosols point to more complex differences in their age and depositional history.

The sand deposits have been also described in the literature by several authors (GUSTAVSON & FINLEY, 1985; MACHENBERG, 1986; FERRING, 1990; HOLLIDAY, 1989a; CARAN & BAUMGARDNER, 1990) but have never been further investigated. So far, interpretation of fluvial deposits holds the primary position in landscape and climate reconstruction in the Rolling Plains of Texas (BAUMGARDNER, 1986; CARAN & BAUMGARDNER, 1990; BLUM et al., 1990). Results from this dissertation on sequences of eolian stabilization and reactivation phases will help clarify previous findings from the fluvial record and will help to delineate interpretations of climatic change in the area.

An interdisciplinary approach was selected for this research. A variety of methods from physical and cultural geography were chosen to study the interactive processes of human impact on sandy areas in the Rolling Plains of Texas. To accomplish the research goals, the emphasis was on three methods: map and aerial photo interpretation, fieldwork, and laboratory analysis.

All sand dune areas and sand sheets were identified, located and mapped with the help of aerial photos. Dune field assemblages and sand dune types were differentiated, with the aid of LANDSAT imagery (1978) and geologic maps, because differences in geomorphic and geologic setting could lead to differences in their depositional history and stratigraphic position. For this research the final selection of sand deposits to be investigated resulted from reconnaissance visits and other factors, such as evidence of paleosols, landowner permission for access, and vehicle accessibility.

In the reconnaissance fieldwork all offices of the United States Soil Conservation (SCS) Agencies of the selected counties were visited. These agencies have mapped soil types and classified them according to their grain size and consistency to assist with the appropriate selection of crops to reduce soil erosion. The sand areas, which were selected with the help of aerial photography before the fieldwork started, were compared to the mapped "Tivoli sands" of the soil surveys, which are equivalent to dune fields and sand sheet deposits. Their location was confirmed and a route was selected to reduce mileage during field research.

In the Rolling Plains of Texas fieldwork can be quite challenging at times. This portion of the state is mainly private property and in some cases a few ranchers own whole counties. Large parts of the study area, especially sand sheets, are very remote, far from cities and residences. It is often not possible to contact the landowner, who usually does not live on the premises. A manager frequently maintains the land. They are often reluctant to give permission to investigate the sandy areas.

Entering property without permission is considered trespassing in Texas. Landowners can be very offended and it can happen that the intruder is threatened with a rifle. However, some of the soil conservation agencies assisted with landowner information and helped establish first contacts.

During fieldwork it was necessary to choose German profile descriptions for the sand outcrops, since a genetic interpretation of paleosols is not accommodated in the U.S. Soil Taxonomy (SOIL SURVEY STAFF, 1975). Paleosols needed to be addressed since they are important evidence of landscape development and highlight the climatic history of a region.

For the investigation of the climatic history of the region paleopedology was found to be a valid method for this research. The stratigraphic position of paleosols, their age, mineralogic content, and their geomorphic setting contributed to the interpretation of the relief history of the area. Other methods used were pollen analysis, primarily to investigate the vegetation history as related to paleoclimatic conditions in the region, and sedimentology, to help delineate sand source areas and wind directions.

The main contributions of this research are, first, to determine physical and cultural trigger mechanisms for sand reactivation phases during the Holocene, their time of onset and if they were occurring on a regional or local basis. Secondly, to define and delineate the "Altithermal", a dry period in the stratigraphic record of the Southern High Plains and third, to compare newly discovered Rolling Plains stabilization/reactivation phases with existing locations of the Great Plains region. These results will aid in future research of eolian deposits in the Great Plains region and are a significant contribution to the eolian literature body of the Rolling Plains region.

From the context of the research goals the following outline was developed. It is oriented towards a comprehensive regional approach in cultural and physical geography. Chapter 1 covers the physiographic setting of the Rolling Plains region including geology, geomorphology, climate and vegetation. Here the prerequisites for eolian activity in the area are explained, followed by the criteria for the selection of the individual study sites. In chapter 2 selected dune fields and sand sheets are introduced. Chapter 3 outlines the methodology as a combination of field research, laboratory analysis and remote sensing techniques, along with a brief interpretation of their application and success rate. Chapter 4 investigates interactive processes between the cultural development and the physical landscape of the region.

The next 4 chapters are focusing on research results and interpretation. Chapter 5 interprets the youngest eolian episodes resulting from the cultural development of the area, including a description and definition of so called "fence-line dunes" and "shinnery motts". Other dunes with very young buried horizons are also described in this chapter, and a comparison with outcrops in the Nebraska Sand Hills is performed. Chapter 6 interprets short-term, cyclic, drought-related sand reactivations several hundred years ago by means of a Post Oak (*Quercus stellata*) tree ring record as established by STAHLE and CLEAVELAND (1988). In chapter 7 older Holocene reactivation cycles are introduced, investigating the idea of the existence of a warmer period, previously named the Altithermal, which so far has only been identified in the Southern High Plains.

The last chapter (8) includes a brief statement of the study’s purpose along with the summary and discussion of results presented. This chapter will end with further implications of this research.

Chapter 1. The Rolling Plains of Texas

1.1. Physiographic setting of the Rolling Plains region

The study area is part of the Rolling Plains of the Texas Panhandle. The Rolling Plains are bordered by the Llano Estacado, or otherwise known as the Southern High Plains to the west, abruptly separated by the Caprock Escarpment. Several rivers drain the area to the southeast.

The land surface of the Rolling Plains slopes eastward to southeastward from approximately 15 m/km near the escarpment to 7.5 m/km towards its eastern margins (CARAN and BAUMGARDNER, 1990: 774). The main rivers from north to south are the Canadian, Red and Brazos River and their tributaries (Figure 2). These rivers originate on the Southern High Plains plateau and drain the entire High Plains and Rolling Plains area to the southeast into the Gulf of Mexico. Their degradational force has eroded extensive canyons into the escarpment, such as Palo Duro Canyon (250 m depth), and dissected the Permian bedrock on the Rolling Plains.

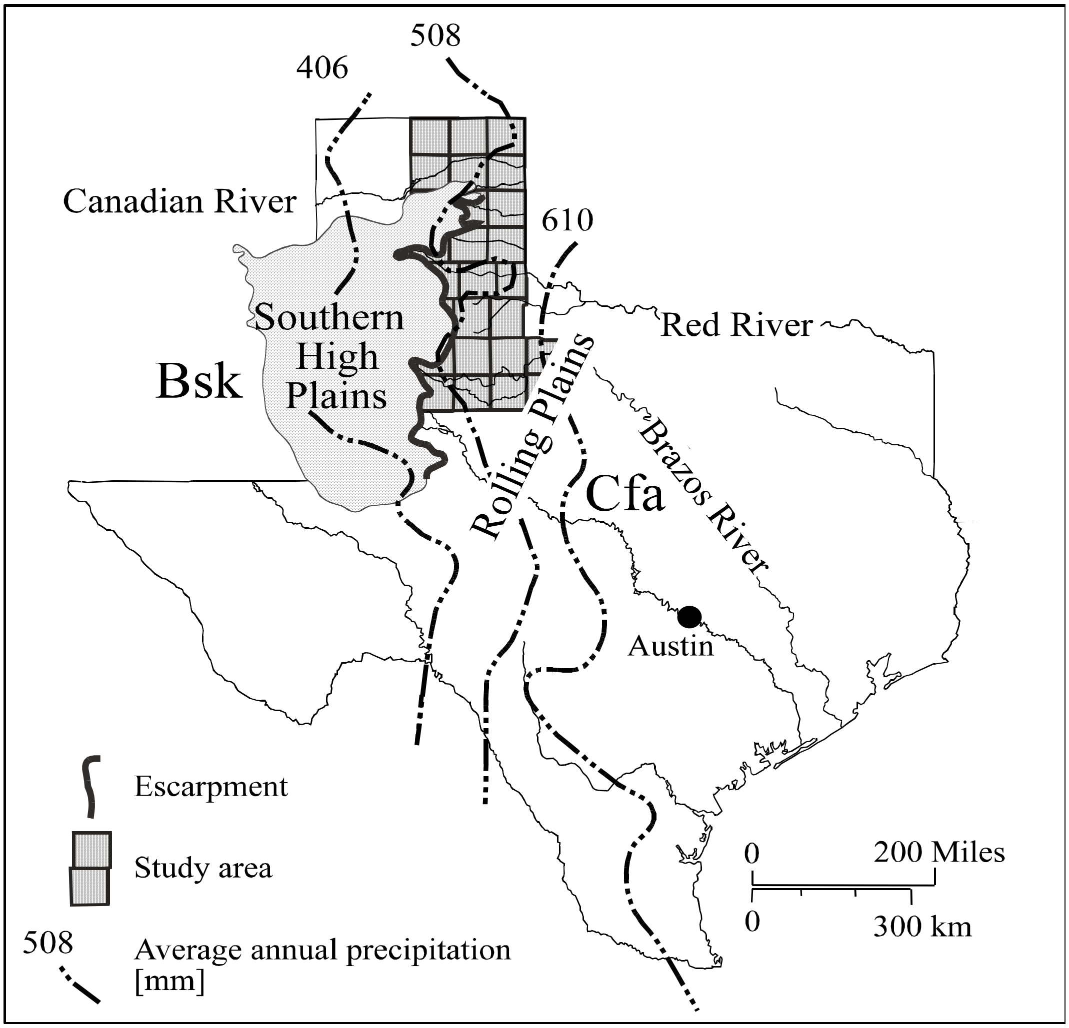


Figure 2. Physiography of the Rolling Plains of Texas and the adjacent Southern High Plains.

The Rolling Plains are dominated by gently sloping hills interspersed with flat areas, which are dissected by river valleys and creeks. The rolling topography of the study area is mainly the result of erosional processes, which will be discussed in detail later this chapter. Erosion was probably greatly enhanced by the poorly consolidated materials of the formations, the hydrologic conditions, the past and present climate and, during the past century, by agricultural practices and man-made changes to the landscape. Today most of the Southern High Plains area is farmland and the Rolling Plains are predominantly used as range land, because the topography is unsuitable for farming. This is due to less productive soils, in-sufficient groundwater availability for irrigation, and a long history of cattle ranching (LEE et al., 1994: 444).

There are ample sand dunes and sand sheets spread across the Texas Rolling Plains overlying different geologic units and with differences in their geomorphic setting. The formation of these eolian deposits is mainly dependent on land surface conditions, such as the availability of source material and vegetation cover. The reactivation of these eolian deposits depends also on the active geomorphic and geologic processes controlled by the climate in the area. Therefore, a description of the geologic history of the Rolling Plains and the adjacent Southern High Plains along with the predominant geomorphologic processes and current climatic conditions is appropriate.

1.1.1. Geology

Major components in the development of eolian deposits are land surface conditions and available source material. A brief description of the evolutionary history of the Rolling Plains and the adjacent Southern High Plains is therefore appropriate, even though eolian deposits are but a small component within the system.

Overall, the structural geology is important for some parts of the evolutionary history of the area (GUSTAVSON and FINLEY, 1985:3). GUSTAVSON (1990:3) discussed the structural geology of the Southern High Plains and the Rolling Plains as follows. The Southern High Plains and the Rolling Plains are underlain by the Palo Duro Basin, which is delineated on the north by the Amarillo Uplift, and on the south by the Matador Arch-Roosevelt Uplift. The Palo Duro and Tucumcari basins lie to the west of the Rolling Plains and are outlined by the Pedernal and Sierra Grande uplifts. The Dalhart and Anadarko basins are separated by the Cimarron Arch further towards the Oklahoma border (Figure 3).

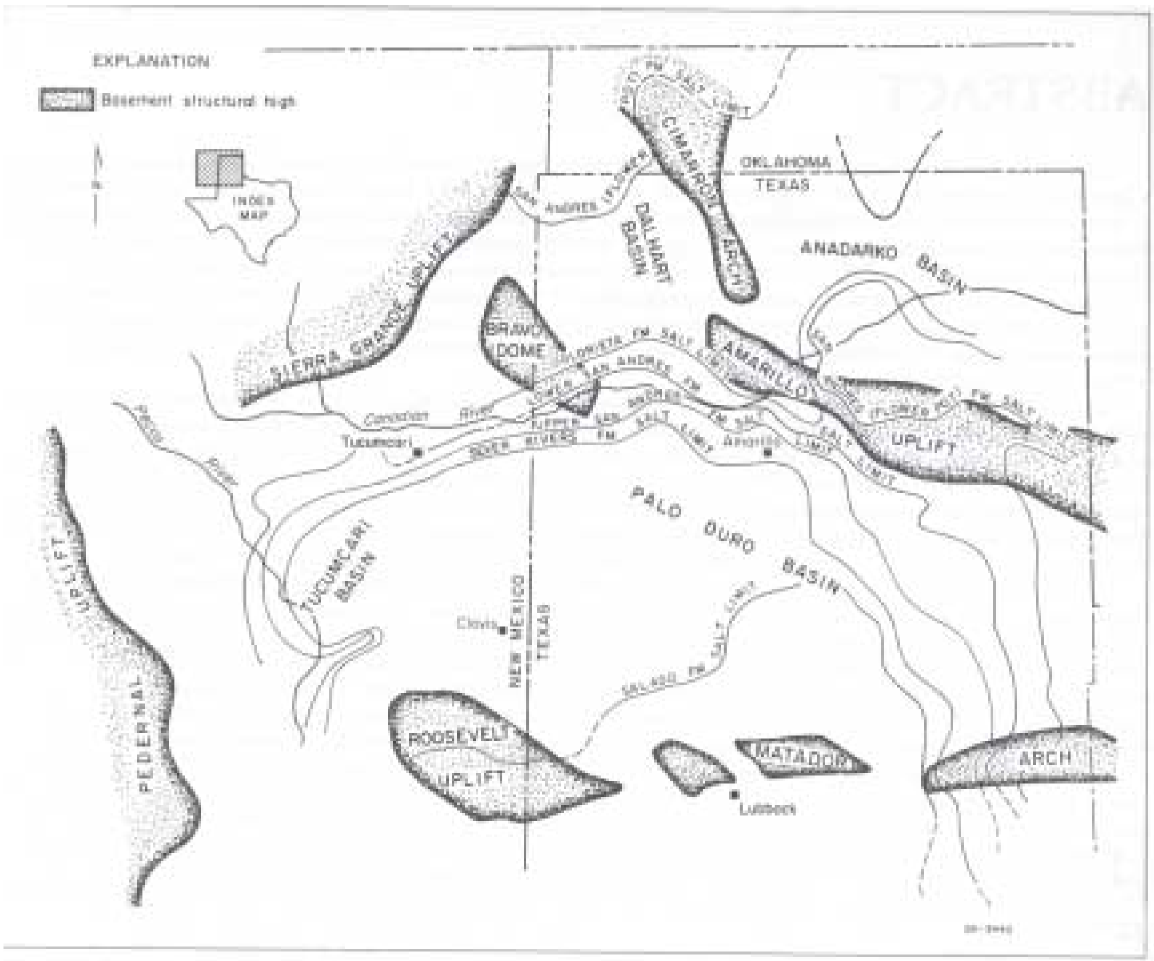


Figure 3. Regional structural geologic elements in the Texas Panhandle, in GUSTAVSON (1985).

The Rolling Plains of Texas are mainly comprised of Permian age strata, which are roughly between 250-280 million years old. The Permian material consists mainly of sandstone and mudstone, dolomite and anhydrite, and several salt bearing units (GUSTAVSON, 1986:3). The Permian strata were deposited in a low relief marine shelf environment. During the late Cretaceous and early Tertiary, the younger Triassic, Jurassic and early Cretaceous formations were mostly eroded (GUSTAVSON, 1990: 3). Therefore Permian “red beds” are unconformably overlain by the much younger Quaternary Paducah Group, which includes the Lingos Formation (Table 1).

Table 1. Stratigraphic units and environment of the Texas Rolling Plains (modified after BUREAU OF ECONOMIC GEOLOGY, 1992).

Age	Stratigraphy	Lithology	Environment
Quaternary	alluvium	clay to gravel	fluvial
	windblown sand	silt to sand	eolian
	Good Creek Formation	clay to gravel	lacustrine, fluvial
	Groesbeck Formation	clay to gravel	laccustrine, fluvial
	Lingos Formation	clay to gravel	eolian, fluvial, lacustrine, fan
	terrace deposits	silt to gravel	fluvial
	surficial deposits	undivided	colluvium ?
	~~ unconformity ~~~~~~~~~~~		
Permian	Quatermaster Formation, Whitehorse Sandstone, Cloud Chief Gypsum, Blaine Formation,	shale, sandstone, siltstone, gypsum, dolomite	fluvial to marine

The newly defined Paducah Group consists of the Seymour, Good Creek, Groesbeck, and as youngest, the Lingos Formation (CARAN and BAUMGARDNER, 1990). The Seymour Formation was deposited to as much as 100 miles east of the Caprock Escarpment in the Rolling Plains and is postulated by MENZER and SLAUGHTER (1971) to be a set of deposits, spared by erosion, marking the easternmost edge of the westward-retreating Caprock Escarpment. The Good Creek and the Groesbeck formations consist mainly of lacustrine and smaller fluvial deposits (DALQUEST, 1962, 1965).

In a more recent study by CARAN and BAUMGARDNER (1990:768), the Lingos Formation is shown to include three distinct lithofacies, originating in different depositional environments. They identify Quaternary lacustrine, eolian, and fluvial and alluvial fan deposits. In the opinion of the authors, these can all be closely linked with the westward retreat of the Caprock escarpment. The gravel-rich, lower Lingos sediments appear to be fanglomerates. The middle Lingos consists of lacustrine silts and clays, including some fossils, deposited in small depressions on the Permian surface. Eolian as well as periodic fluvial sedimentation contributed to the upper Lingos Formation (CARAN and BAUMGARDNER, 1990:784). The dissection of these deposits by modern creeks and rivers reveals the underlying Permian bedrock in some places.

To the west of the Rolling Plains are the Southern High Plains, mostly comprised of the Tertiary-age Ogallala Formation interfingered with the local lacustrine Tule and Blanco formations (GUSTAVSON et al., 1991:479), and topped

topped by the Quaternary Black Water Draw Formation (Table 2). In a position of higher elevation, these deposits all overlay the Triassic Dockum Group and Permian strata, the latter forming the Rolling Plains at lower elevation and to the east.

Table 2. Stratigraphic units and environment of the Southern High Plains (modified after BUREAU OF ECONOMIC GEOLOGY, 1992).

Age	Stratigraphy	Lithology	Environment
Quaternary	Blackwater Draw Formation	clay to sand < 30m thick	eolian, lacustrine
	~~ unconformity ~~~~~~~~~~~		
Miocene to Pliocene	Ogallala Formation	clay to gravel < 250m thick	eolian, lacustrine, fluvial
	~~ unconformity ~~~~~~~~~~~		
Permian or Triassic	Quatermaster Formation, Dockum Group	conglomerate to shale	fluvial to marine

The deposition of the Ogallala Formation was a result of the uplift of the Rocky Mountains during the Miocene and Pliocene, as first suggested by BAKER (1915). The drainage system before Miocene and Pliocene time generally flowed to the east), originating in today's Rocky Mountains (GUSTAVSON and FINLEY, 1985: 21). However, because of the dissolution of salt beds in the underlying Permian strata and resulting subsidence, streams were diverted to the northern and western margins of the present Southern High Plains. This diversion probably occurred during the late Pliocene or early Pleistocene (GUSTAVSON and FINLEY, 1985:1), contributing water to the Pecos and Canadian Rivers. This channel diversion along the northern and western edge of the present Southern High Plains cut off most of the drainage from the Rocky Mountains, limiting fluvial erosion on the Southern High Plains and therefore preserving most of the strata.

GAZDAR (1981) found that the lower parts of the Ogallala Formation consist of base gravel and sorted, pinkish-gray calcareous sands. The upper parts are very fine, reddish-brown silts, clays and coarse gravel representing channel facies. The Ogallala is capped by a calcrete rock, possibly of pedogenic origin, termed "caliche" by BROWN (1956) and also known as 'caprock calcrete'. Overlying the Ogallala is the Quaternary Black Water Draw Formation, which consists mainly of a surficial veneer of reddish-brown Pleistocene and younger sands. Playas are flat depressions on the High Plains surface that seasonally hold small lakes. These playas, associated with sinkholes due to Permian salt dissolution (PAINE,1994) underneath the Ogallala Formation are a common geologic feature on the land surface of the Black Water Draw Formation throughout the Southern High Plains.

The geologic description of the different formations in the study area implies a huge variety of different potential sand source materials. These different formations can all supply sand as a source for the eolian deposits in the study area. It is therefore very difficult to identify the individual source area for each of the eolian deposits. A distinction between the different sand sources would be important for the identification of sand transportation directions during the formation time of the individual eolian deposit. This could explain their history of development and indicate potential age differences and paleowind directions.

The grain mineralogy of these formations and sand deposits ideally can provide a valuable insight where sand is originating. This could then indicate which of the different geologic formations has functioned as source material for the individual sand deposit in the Rolling Plains. However, a distinction between source areas based on mineralogy is difficult in the study area, as will be shown in the following subchapter, because the sand for the geologic formations probably all originated in today's Rocky Mountains and has therefore a very similar mineralogic content.

There are additional problems to distinguish between different sand source materials in the Rolling Plains. The geologic formations of the study area span entire geologic periods and include a variety of units of different climatic and geomorphologic time frames and therefore varying depositional environments (Table 1, Table 2). Sand grains within these units underwent a variety of processes with a difference in duration, complicating the morphological imprint and making a distinction of source area and transportation mode solely by grain shape and morphology impossible.

For example, the Pleistocene Lingos Formation, which is the surficial layer on the Rolling Plains includes a variety of facies, such as eolian, lacustrine, and alluvial fan deposits, from three distinct depositional environments. If windblown sand from an outcrop of this formation is transported over short distances to new locations, the sample will contain a mixture of sands from different depositional environments overprinted by the wind transportation mode. However, sand originating from the Ogallala formation would not be distinguishable from Lingos sand.

One other considerable aspect is the short distance from all source formations to the sand deposits. Most likely, grains were only transported for short distances in one or more transportation modes, thereby further complicating the distinction process. Another problem in the differentiation of grain morphology arises from the proximity of the study area close to an eroding escarpment. The Ogallala, Blackwater Draw, and in parts, the Dockum and Permian formations, are vertically eroded from all their units along the escarpment. The erosive face of this escarpment is approx. 200-300 m high, which means that many sand units of different ages and geomorphologic environments, spanning a time from the Permian to the Holocene, are being mixed in the erosional process.

This outline of the evolutionary history, and geology of the area shows that source material for eolian transportation is abundant. Various sources of sand, such as material from the erosional edge of the Caprock Escarpment, sand from the Quaternary Paducah Group, or even weathered Permian bedrock residues are available.

1.1.2. Mineralogy

The mineralogic composition of sands from different formations in the Rolling Plains and Southern High Plains could provide information on source areas for the eolian deposits. This information can be utilized to decipher the depositional history of the eolian deposits in the area. Sands in eolian deposits may have been combined and mixed from different sources and depositional environments. However, a mineralogic analysis of samples from the different geologic source formations compared to samples from a variety of eolian deposits, could indicate, if a distinction between individual sand source and the different eolian deposits is possible. Additionally, a mineralogy study can provide insights on the reactivation and reworking of older sand deposits.

This was suggested in a recent mineralogy study by MUHS et al. (1995), which indicates that the ratio of feldspar versus quartz in eolian deposits is of importance and shows if older sands have been reworked. MUHS et al. (1995) looked at the mineralogy of sands in the Nebraska Sand Hills in the Great Plains region to determine their source area. Eolian sand from the Sand Hills, which has been reactivated over the past 1,000 years showed to be feldspar-depleted and quartz-rich. They suggested that a process, which occurs with the aging of the sand grains, influence this ratio. Hence, a large amount of quartz and a lack of feldspar indicate that possibly older aged sand (Pliocene?) has been reworked over the past 1,000 years. These results indicate that the older sand (Pliocene?) has been locally reworked, and is providing the source material for recent sand reactivations during the past 1,000 years in the Nebraska Sand Hills.

No similar studies were performed for the present study due to the high cost of such an analysis. There is, however, a resemblance of the study area to the Nebraska Sand Hills region regarding the availability of older Ogallala sand as source material. This could suggest a reworking of older sands in the Texas Rolling Plains as well, since older sand is locally provided for a reactivation from a variety of formations.

A thin section analysis was performed to investigate dissimilarities in the mineralogic content of the geologic formations and evaluate if sand sources originated locally through the reworking of older sands, as in the Nebraska Sand Hills.

Unfortunately, the less expensive thin section analysis does not provide any information on the ratio of quartz-rich versus feldspar-depleted sand. Therefore, iron and clay coatings were used to determine if sand has previously undergone soil development, which would indicate reworking of older sands.

Thin section samples were taken from each of the sand bearing units in the Rolling Plains and adjacent Southern High Plains. Seven samples were collected from the different geologic formations and environments: the Dockum Group, the Permian, the Ogallala and Black Water Draw formations, one sample from the Red Riverbed and two dune sand samples from different dune fields for analysis. The methodology will be discussed in chapter 3.

The first sample, dune sand, was taken within the active area of a dune field near the town of Estelline. This sample (Figure 4) had a significantly higher number of iron oxide and clay coated grains than other samples. This suggests that older sands from a soil unit have been reworked since the sample was not collected from a soil unit, but from the active dune area. Components of this sample include mainly quartz, chert, carbonate rock fragments, metaquartzite, feldspar and granite fragments, similar to the river sample.

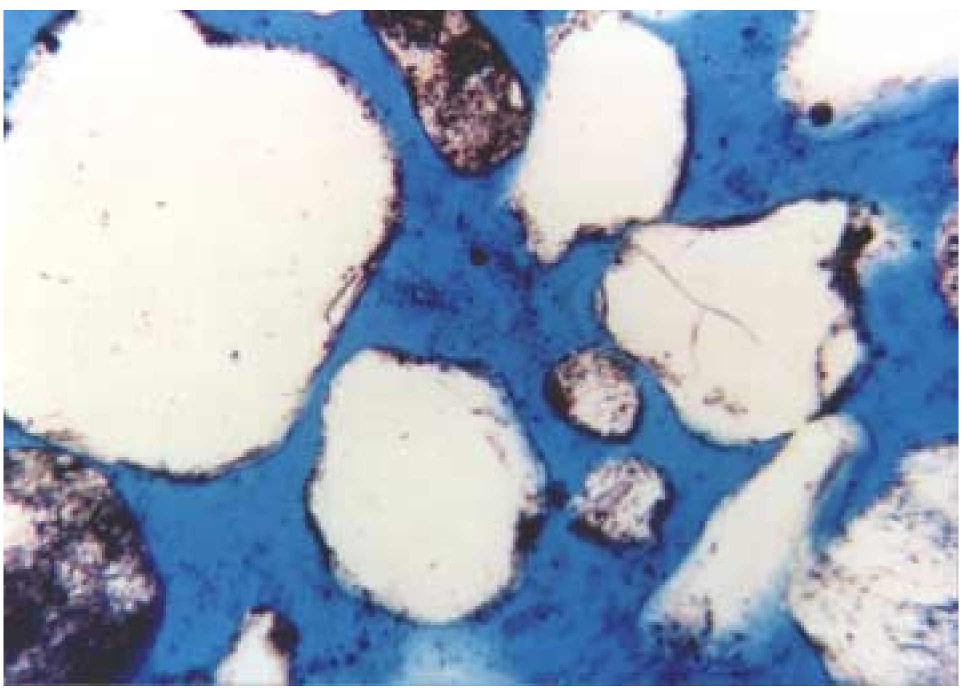


Figure 4. Thin section sample from the Estelline dune field in Hall County, Texas. The actual scale is 1.45 mm.

The river sample was extracted from the Red Riverbed a short distance northwest of the Hall County dune field. The sample (Figure 5) shows an equally high amount of iron oxide and clay coated grains as the sand dune sample. This also suggests reworking of older sands, which had previously undergone soil development and were then only transported for a short distance in the riverbed. It also consists mainly of quartz, carbonate rock fragments, metaquarzite and feldspar (Microcline), which is similar to the dune sand sample.

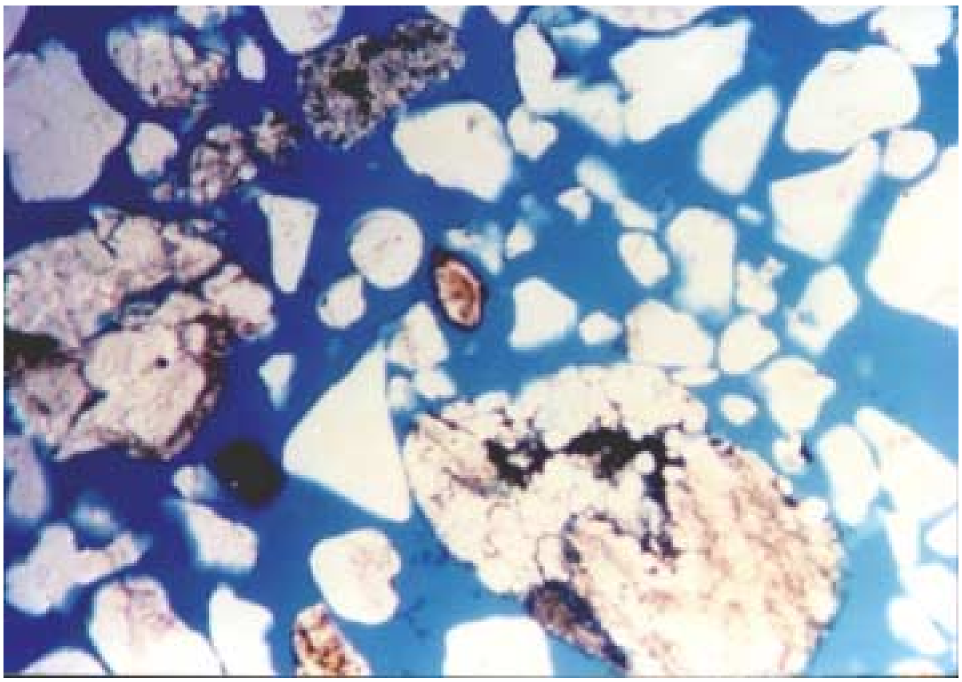


Figure 5. Thin section sample from the Red Riverbed near the Estelline dune field in Hall County, Texas. The actual scale is 5.6 mm.

The third sample was taken from a lighter colored soil horizon, beneath a paleosol. It was collected in a sand sheet stretching between the towns of Swenson and Peacock, near the Salt Fork of the Brazos River. This sample (Figure 6) does not show as many iron oxide and clay coatings as the samples from the Estelline dune field and the Red River locations. The sample has undergone leaching processes as part of an A_l -horizon development, which destroyed much of the clay and iron coatings through time. It, therefore, consists of much older sands as shown by radiocarbon dates of the paleosol above the sampled horizon (between 4,320± 90 B. P. and 6,090± 90 years B. P). This sample consists of mainly quartz, magnetite, feldspar, metaquarzite, chert and zircon fragments. The lack of carbonate fragments in this sample supports the idea of the development of an A_l -horizon, which modifies the sand through leaching processes as part of the soil development. Below the sampled unit is a B_{tk} -horizon where most of the carbonate accumulated.

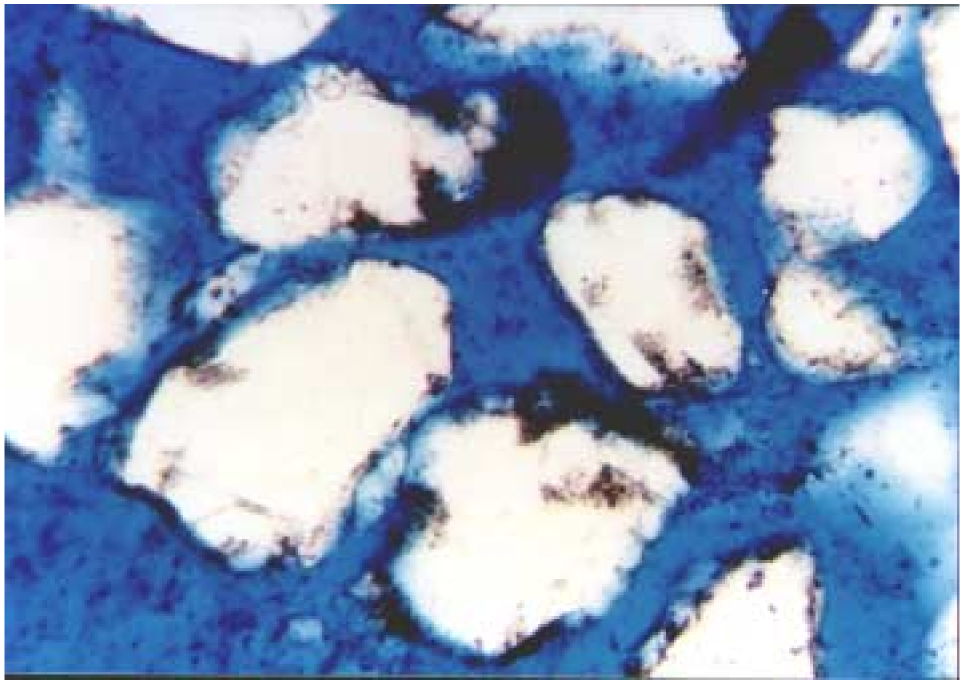


Figure 6. Thin section sample from a sand sheet stretching between the towns of Swenson and Peacock, near the Salt Fork of the Brazos River.

The Ogallala (Figure 7) and Black Water Draw (Figure 8) thin section samples were taken along the escarpment east of the town of McAdoo in Dickens County. The samples show similarities in the amount of calcified sand (up to 95%). Some of the carbonate fragments present in the dune and river samples could have originated from these two formations. Grains in both samples are larger then regular dune sand in the area, but the predominant grain size probably depends on the sampled unit within these formations, since both of these formations span several million years.

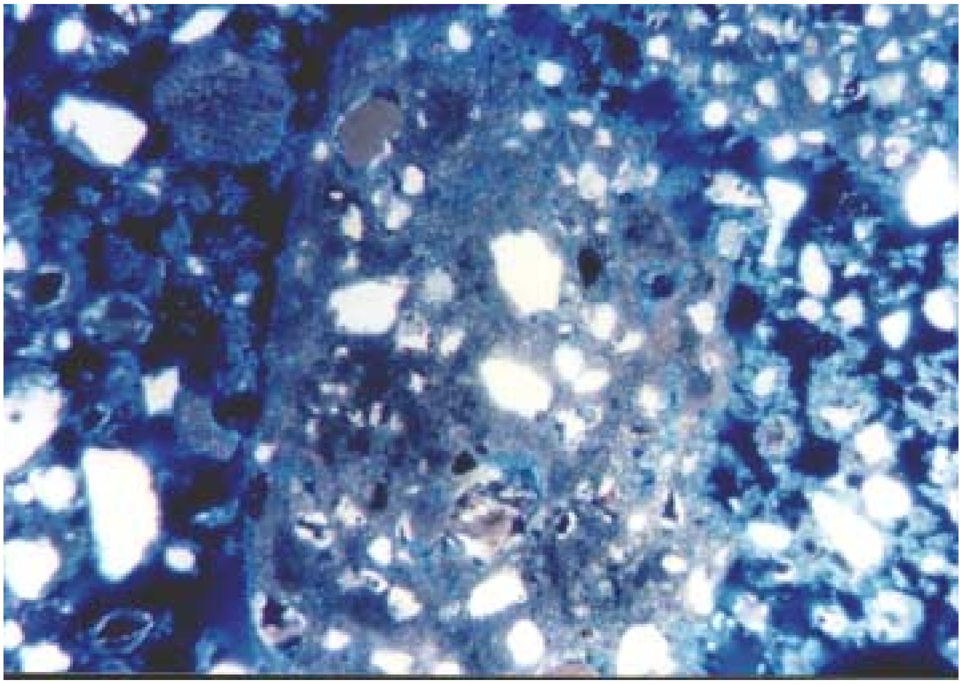


Figure 7. Thin section sample was taken from Ogallala deposits along the escarpment east of the town of McAdoo in Dickens County. The actual scale is 5.6 mm.

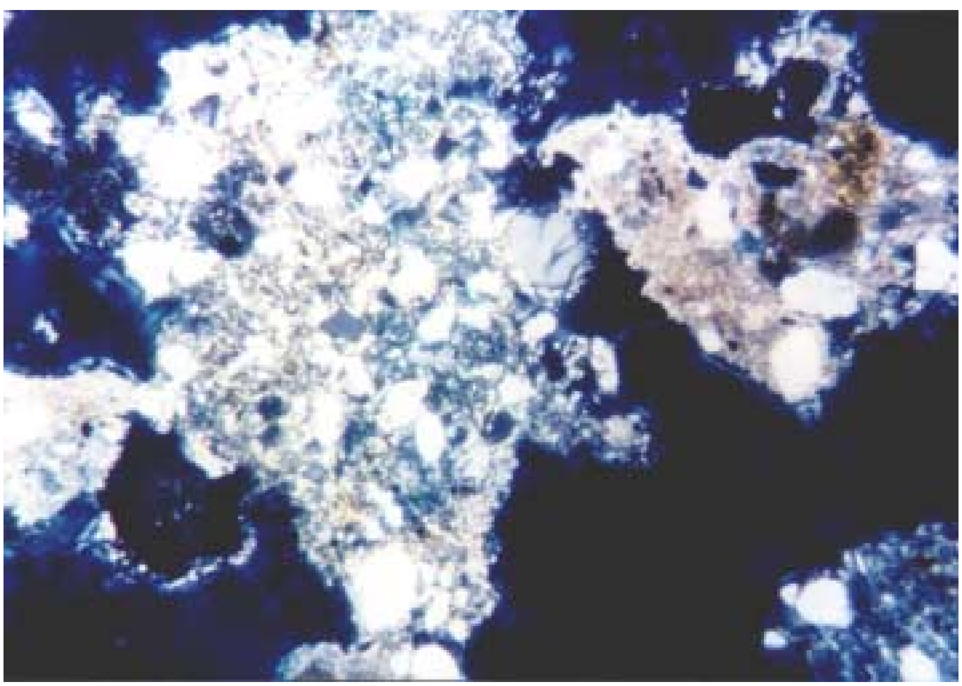


Figure 8. Thin section sample was taken from Blackwater Draw deposits along the escarpment east of the town of McAdoo in Dickens County. The actual scale is 5.6 mm.

The Permian mudstone (Figure 9) was collected near the Salt Fork of the Brazos River in Stonewall County. The piece of mudstone shows very fine-grained material, predominately silts and clays, a common component in dune sands of the study area. The mineralogic content is difficult to determine; some quartz grains are present. The sample suggests that after disintegration the quartz grains, reddish silts and clays can be a source material for eolian deposits in the area. These silts and clays could be the source material for the very fine grained and thick reddish, silty clay bands found in dunes on the Permian strata.

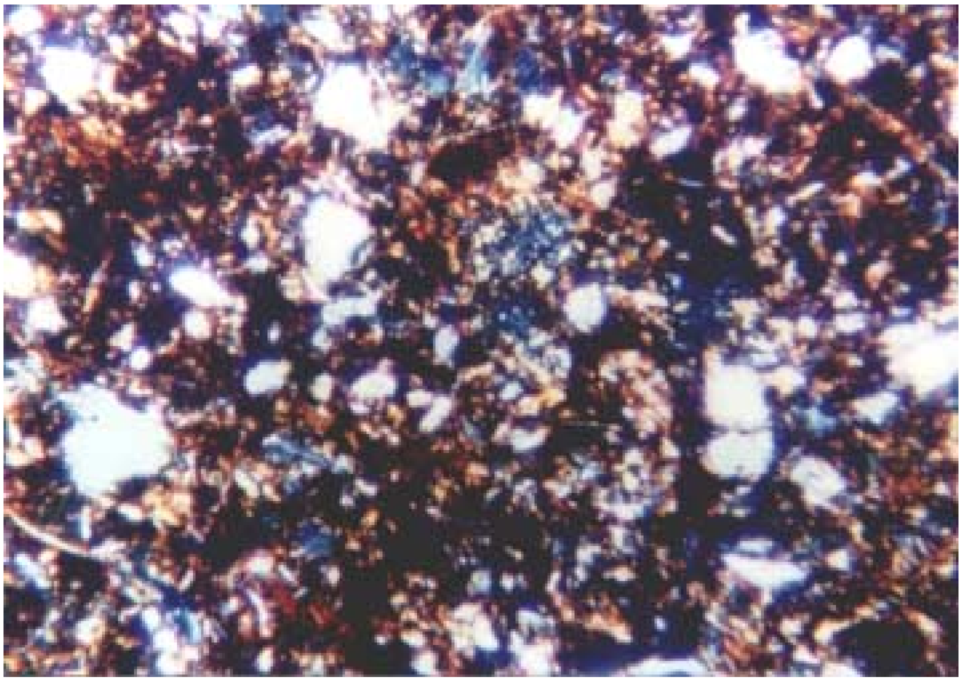


Figure 9. Thin section sample of Permian mudstone collected in the vicinity of the Salt Fork of the Brazos River. The actual scale is 1.45 mm.

The last thin section sample was collected from sandstone of the Dockum Group near the town of Matador in Motley County. A piece of sandstone was used for the analysis. Sand grains in this sample have a similar mineralogic content to the ones in both of the sand dune samples, which suggests that once the Dockum sandstone erodes and disintegrates it probably provides source material for dune sands in the area.

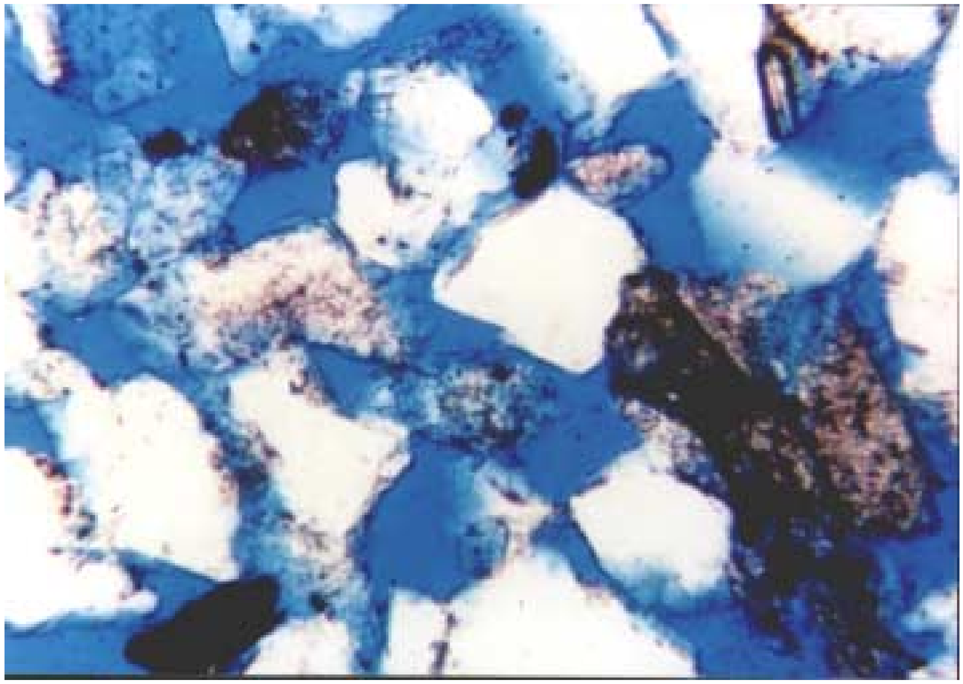


Figure 10. Thin section sample was collected from sandstone of the Dockum Group near the town of Matador in Motley County. The actual scale is 1.45 mm.

Several hundred more samples from each of the formations and dune fields would have to be analyzed before a mineralogic content comparison between sand sheets and formations could be made. The increase of the sample size would have still not been a guarantee to identify the sand sources for each individual sand sheet (pers. comm. Dr. Sue Hovorka).

The presence of grain iron and clay coatings was used as an indicator for soil development prior to eolian deposition in three of the samples. Their presence suggests a short transportation distance, because coatings stayed intact during the transportation by wind and water. This indicates a reworking of older sand deposits, which previously had undergone a soil development, before sand eroded and re-deposited. The above evidence also leads to the conclusion that sands are locally reactivated, since they were only transported for a short distance.

The mineralogic results reported above did not lead to a distinction between the different sand source areas. Part of the reason is probably that the geologic material of the Southern High Plains and the eolian/alluvial cover mantle of the Rolling Plains all originated in today’s Rocky Mountains as already mentioned above.

1.1.3. Geomorphology

Geomorphology is a major component in the evolutionary history of dune fields. In the study area eolian deposits occur in different geomorphic settings which can contribute to their depositional history. Various geomorphic processes deposited and influenced these eolian deposits and are still active under present semi-arid climatic conditions in the Rolling Plains. Active geomorphic processes, most of them erosive, contribute to the reactivation of the sand deposits and must therefore be evaluated in further detail. Geomorphologic processes in the study area include dissolution of several salt beds in the Permian strata with resulting subsidence, erosion along the Caprock Escarpment, eolian deflation, and fluvial processes.

1.1.3.1. Dissolution and resulting geomorphic features

Various sink holes and dolines have developed in the Rolling Plains and are interpreted as collapse features resulting from salt dissolution subsidence in the Permian strata which underlie the Rolling Plains (GUSTAVSON et al, 1982, 454-563). GUSTAVSON (1986:6) identified seven formations in the Permian strata of the Texas Panhandle and eastern New Mexico, which contain salts (Figure 11). He suggests that almost all salt formations are constantly being leached, producing collapse features due to subsidence. He concluded that areas with ongoing salt dissolution have probably influenced local topography through much of the past. His results are in part based on high amounts of soluble salts in rivers draining the Southern High Plains and Rolling Plains, indicating that the process of salt dissolution is still active in the area under present climatic and geomorphic conditions.

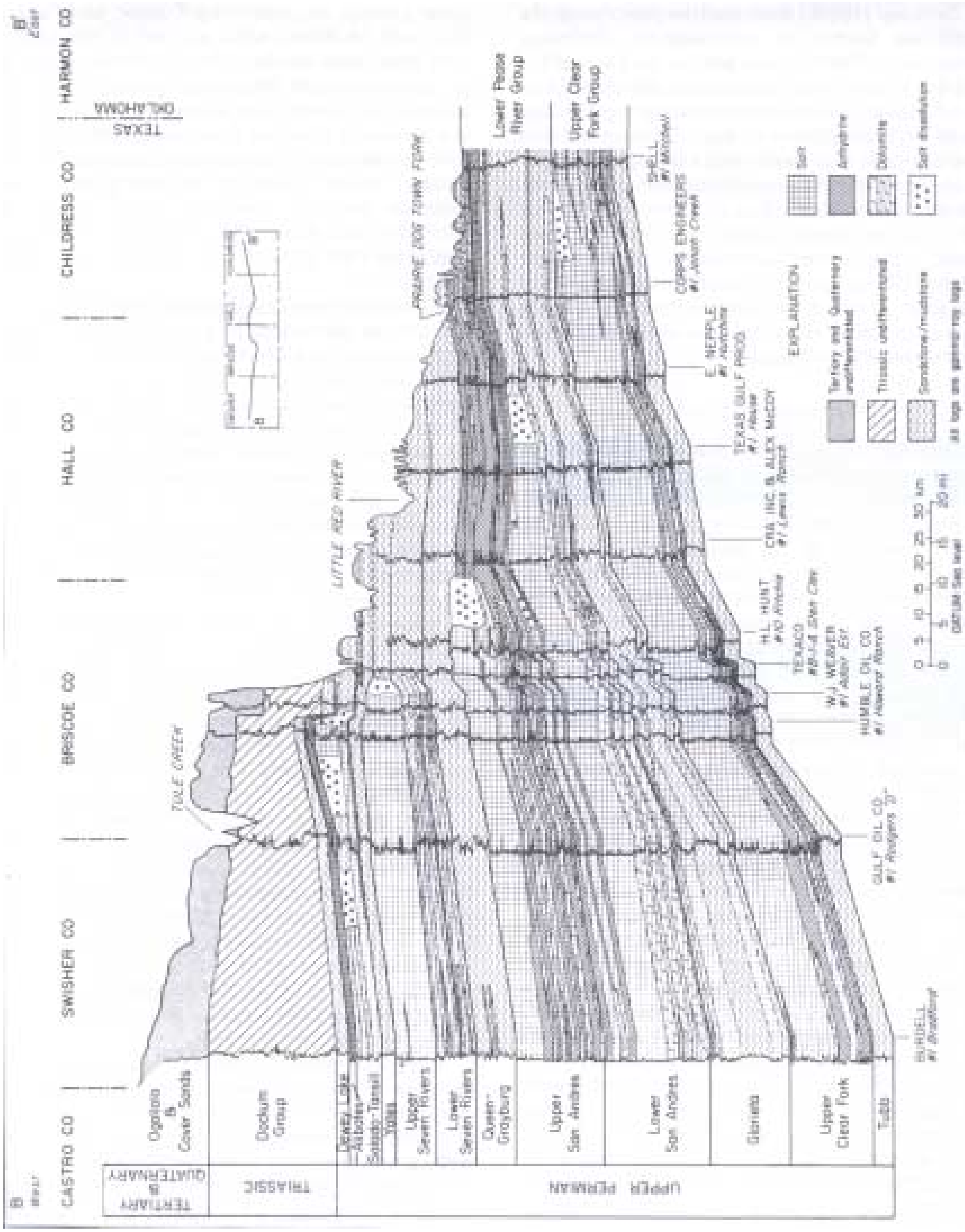


Figure 11. Seven salt bearing units in the Permian strata of the Texas Panhandle and eastern New Mexico, GUSTAVSON (1986).

A recent study by PAINE (1994) using shallow seismic data agrees that salt dissolution and subsidence in several Permian units are important agents for basin formation up to 6 km width in the Southern High Plains of Texas and New Mexico. Playa basins generally range in size from 1 to 13 m in depth and from 100 m up to 6 km in width (pers. comm. Dr. Jeff Paine). Some of the playa basins on the Texas High Plains have sand dunes associated with them that probably resulted from blowouts during the drier season.

Responding to hydrologic pattern, as well as climatic, geologic and geomorphic processes, salt dissolution was active to different degrees, probably since the original salt deposition in a shallow basin during Permian time (GUSTAVSON and FINLEY, 1985). A higher amount of rain due to climatic variations, structural changes in the subsurface, or shifts in the geomorphic drainage pattern may all have contributed to varying rates of salt dissolution within the Permian strata.

The above discussion suggests that the process of salt dissolution and playa development can produce sandy material for deflation, as indicated by sand dunes partially surrounding playas on the High Plains. Playas probably provide the most extensive source for sand deflation during the summer dry period on the Southern High Plains. Apart from salt dissolution, dissolution processes in general can lead to the disintegration of Dockum- and Permian sandstone. This process provides additional source material for eolian deflation in the Rolling Plains.

1.1.3.2. Caprock retreat

Consideration needs to be given to the processes and rates which led to the extensive erosion of the Southern High Plains. The Southern High Plains are presumed to have stretched easterly across parts of the Rolling Plains, therefore influencing the topography and geomorphology of the study area. The geologic history of this erosion is important for the study of eolian deposits, because the erosional processes probably provided source material for eolian deposition at various locations and at different rates depending on the climate through time. Today, erosional processes along the edge of the Southern High Plains probably contribute material for sand deposition in the vicinity of the escarpment.

The history of westward retreat of the eastern Caprock Escarpment of the Southern High Plains and the presumed associated mechanisms of slope erosion has been the subject of interest to several authors (FINLEY and GUSTAVSON, 1980, OSTERKAMP and WOOD, 1984). Most studies agree that the nature and rates of geomorphic processes contributing to the erosion of the Caprock Escarpment changed through time. Erosion conditions and rates probably were dependent on varying climatic conditions and changes in the fluvial systems of the area. MENZER and SLAUGHTER (1971:221) suggested that the Ogallala Formation of the Southern High Plains could have extended approximately 400 km or more east of the present escarpment. Their calculations were based on extrapolated gradients and petrographic analysis of Ogallala deposits. The Southern High Plains were thought to have extended across the Rolling Plains, and thus influenced the topography of the study area during the past.

GUSTAVSON et al. (1981) introduced a model of landscape development in the Rolling Plains of Texas, which postulates a retreat of the Caprock Escarpment. The retreat rates are estimated by GUSTAVSON et al. (1981:419) at about 18 cm per year since the end of the Seymour gravel deposition during the Pleistocene, but retreat rates since the end of the formation of the Ogallala deposition during the Tertiary time period were calculated only at 11 cm per year. These calculations are based on the distance of the Seymour gravel (110 km) to the east of the present escarpment and climatic factors. However, these numbers have to be understood as estimates only, since many factors can influence the processes of scarp retreat. Retreat responds at different rates depending on how many processes operate simultaneously. The main determining factor of the escarpment retreat is thought to be ‘slope slumps’ enhanced by salt dissolution in the underlying sections of the Permian formation alongside the escarpment. GUSTAVSON et al. (1981) see this model of escarpment retreat in combination with surficial erosion and denudation processes with data from 19 drainage basins. These results show surface denudation rates ranging from 0.5 to 2.97 mm/year eroding the Rolling Plains of Texas.

An erosional model proposed by OSTERKAMP and WOOD (1984) claimed that springs and seepage erosion associated with slope slumping at the escarpment outcrop enhanced the escarpment retreat, at least over the last 10,000 years. The pre-Holocene Pecos and Canadian River incisions along the northern and western edges of the Southern High Plains, respectively, cut off the drainage from the Southern High Plains. As a result, runoff from regional rainfall or base flow from the Ogallala and Dockum aquifers may have contributed to erosional processes along the escarpment. FINLEY and GUSTAVSON (1980:33-34) suggest several other slope retreat mechanisms, such as rain splash erosion and surface flow. Enhancing these postulated processes is changing vegetation resulting from grazing impact and agricultural practices along the slopes of the Caprock Escarpment.

The only evidence of Ogallala material is the Seymour gravel some 110 km from today’s escarpment stretching north of Abilene, which are re-deposited Ogallala sediments thought to have been deposited during Kansan time (GUSTAVSON et al, 1981). Escarpment retreat rates based on these deposits are much too high compared to present fluvial sediment yields, which are likely to have increased during this century since they are enhanced by present landuse practices (OSTERKAMP and WOOD, 1984). The erosion rates of a rapidly retreating escarpment front, as postulated by GUSTAVSON et al. (1981), seem grossly overestimated. If the Ogallala extended across the Rolling Plains than only an extensive denudation to a lower relief would explain the erosion of such an amount of material.

No field evidence of Tertiary Ogallala sediments was found on topographic higher-lying surfaces of the Rolling Plains. OSTERKAMP and WOOD, (1984) argue that if the Ogallala formation topped with a hard caliche layer would have extended several hundred kilometers further to the east, then outliers protected by the caprock would have been found as remnant buttes and mesas. Instead, deposits of the Pleistocene Lingos Formation (CARAN & BAUMGARDNER, 1990), and also Holocene sand sheets and dune fields can be found on topographic divides.

The most likely process of erosion seems to be surface denudation across a modestly inclined surface of the Rolling Plains. The rolling topography is the result of hard Permian layers resisting surficial erosion. The Southern High Plains were cut off from the Rocky Mountains during the late Pliocene or early Pleistocene by the formation of the Pecos and Canadian Rivers and left as a plateau (GUSTAVSON and FINLEY, 1985:1). Ever since then only local rainfall can cause erosion on the High and Rolling Plains, probably reducing the force of extensive fluvial denudation processes. More research will be necessary to define the exact mechanisms and time frames for the erosion mechanism or the extent of the Ogallala formation on the Permian surface of the Rolling Plains.

Even though the escarpment erosion processes have not been clearly explained, obviously a vast amount of material was transported from and across the Rolling Plains towards the east. It can be concluded that material from either surficial erosion or slump retreat of the escarpment contributed sand, which was subsequently available for fluvial and eolian transport on the Rolling Plains of Texas - both in the past and present.

1.1.3.3. Eolian processes

Eolian processes are an important mechanism for the investigation of reactivation phases of eolian deposits and thus need to be further investigated. Eolian deposition and deflation have been active processes on the Rolling Plains throughout the Quaternary (CARAN and BAUMGARDNER, 1990; GUSTAVSON 1986; BUREAU OF ECONOMIC GEOLOGY, 1969), influencing dune field and sand sheets. On the adjacent Southern High Plains, eolian deposition occurred locally even during parts of the Tertiary, especially the Miocene and Pliocene, during the deposition of Ogallala sediments. Eolian deposits within the Ogallala Formation provide evidence for eolian processes during the Tertiary. These eolian Ogallala deposits can be found cropping out at several locations along the escarpment.

The present study provides evidence of extensive eolian erosion and deposition cycles throughout much of the Holocene on the Rolling Plains of Texas. A soil profile in a vegetated dune field near the town of Borger in Hutchinson County shows at least two soil development phases. A deflation lag separating these soil units points to extensive soil erosion. The eroded horizon underneath the deflation lag was radiocarbon dated as middle Holocene. Small stones in the underlying eroded horizon are sparsely dispersed in the soil unit, hence a large amount of soil must have been removed locally in this area to produce a solid deflation lag preventing further wind erosion. This profile will be explained in detail in chapter 7.2.2.

There is evidence in the Rolling Plains of Texas of ongoing deflation during every dry season during recent centuries (Figure 12). Due to human activity disturbing the natural vegetation, in combination with semi-arid climate conditions, wind has strongly modified the landscape during historical times (MACHENBERG, 1986:41). Since the beginning of this century, dry farming has disturbed and modified the landscape and vegetation of the Rolling Plains. For example, up to 0.8 m soil loss has been reported on a cultivated field in the vicinity of the Caprock Escarpment (near Caprock Canyon State Park) since the 1920s (MACHENBERG, 1986: 41), as was already mentioned in the introduction.

Figure 12. Dust storm during the month of June 1995 near the town of Swenson, Texas.

Eolian erosion rates varied throughout the past centuries and were probably greatest during a drought in the 1950s and earlier in the dust storm era, the so-called “dirty thirties” depicted in figure 13.

Figure 13. Dust storm cloud near Dalhart, Texas Panhandle, during the 1930s "dust bowl" era.

Eolian erosion was quite severe during the past century in the Texas Rolling Plains due to drought conditions in combination with agricultural practices. Some of this eroded material was found deposited along fence lines and piled up as dunes, a process, which will be discussed in a later chapter. Other material was probably lost being transported by wind into local rivers and thus caused high sediment loads. Some material might have even been blown into higher atmospheric layers and then transported out of the area.

In addition to eolian mobilization resulting from agricultural practices, other sources of sand on the Rolling Plains of Texas are lake beds and the floodplains of braided streams during drier periods of the year, non-vegetated sand dunes, and unpaved roads (MACHENBERG, 1986: 41). MACHENBERG (1986: 41) suggested that the highest deflation rates on the extreme western edge of the Rolling Plains currently occur during the spring, because of dry conditions during the winter months, cultivation activities such as plowing, and frost heaving processes loosening soil aggregates. However, also significant for eolian movement are strong storm winds from the north during the winter and spring months, which will be discussed in the climate section below in more detail.

1.1.3.4. River systems

Rivers draining the Southern High Plains, such as the Red, the Brazos, and the Canadian, are cutting into the Caprock Escarpment, eroding and transporting sand and gravel across the Rolling Plains. This process provides source material for eolian transportation. During the winter dry period, these mostly multi-channeled streams have little or no water. As a result, channel sands can easily be entrained by winds. In addition, rivers tend to abandon channels through time, so that large non-vegetated areas are available during the dry season when such areas are most susceptible to deflation. Abandoned braided stream channels can therefore contribute to or produce sand dune areas along rivers in the Rolling Plains, as in the case of a dune field near Estelline, Texas.

In conclusion it can be stated that most geomorphic processes acting on the Rolling Plains of Texas are favorable for sand transportation. The sand transportation rates, however, are highly dependent on climate and vegetation, which will be discussed in detail below.

1.2. Climate and vegetation

Eolian transport can only occur if wind velocity is high enough to overcome the threshold to mobilize dry sand particles, whereas particles cannot be moved by wind over a wet surface (BAGNOLD, 1941:57-61). Eolian deposits could be affected if high wind speeds coincide with low rainfall periods to trigger sand movement (either deflation or accumulation). Therefore, seasonality and the likelihood of simultaneous wind and precipitation have to be investigated.

The other possibility is the yearly, or multiple-year, effect of climatic conditions on sand deposits. A severe drought, as well as severe dust storm events occurred in the Rolling Plains in this century during the years 1951-1957 (BOMAR, 1983:154, 189-192). Rainfall deficiency over half a decade have destroyed stabilizing vegetation cover to the point where previously fossilized dunes were reactivated, changing the alignment patterns of the dunes (see chapter 6). Seasonal winds and precipitation in the Texas Panhandle result primarily from frontal patterns. In addition, HOLLIDAY (1987:196), and FINLEY and GUSTAVSON, (1980:18) claimed that the topographic effect of the Caprock Escarpment can locally influence wind speeds and precipitation events, however wind speeds and rainfall amounts were not further quantified.

1.2.1. Climate

The present climate in the Rolling Plains can be considered as continental semi-arid, characterized by large seasonal variations in precipitation and temperature (FINLEY and GUSTAVSON, 1980:1). The study area is part of the Cfa and Bsk climate after the KOEPPEN/GEIGER climate classification. Rainfall varies with season and location and ranges between 200 - 610 mm/y. The observed average annual precipitation is around 508 mm/y for the period of 1951 to 1980 (BOMAR, 1983: 55, 220). However, as one farmer remarked: “It doesn’t sound like a lot of rain, but you should have been here the day it fell”. This quote indicates that most of the precipitation occurs in a few, but strong rainfall events.

In the Rolling Plains the mean annual low temperature during this time period averaged around 9.4 ° C, as measured at Childress. The annual average high temperature is 23.6 ° C (BOMAR, 1983: 212-216), but seasonal weather ranges from snowfall conditions to days with temperatures over 37.8 ° C. Average wind speeds at Abilene in the lower Rolling Plains are between 18 km/h and 22 km/h (BOMAR, 1983: 232). However, the speed and the directions of the wind also vary strongly with season, as do temperature and precipitation. Because of this high degree of variation throughout the year, mean annual values of precipitation, temperature, and wind conditions are not representative for the effects of modern climate on Holocene sand deposits in the region. Seasonal and yearly variations, and extreme events such as droughts and dust storms, have to be examined more closely.

1.2.1.1. Frontal patterns and other precipitation events

The climate of the study area is heavily influenced by mid-latitude frontal patterns. In addition, this portion of Texas is typically affected by four types of air masses: maritime polar, continental polar, maritime tropical, and continental tropical (BOMAR, 1983:29). The interaction of these air masses along frontal boundaries is the predominant feature of the climate of the Rolling Plains.

During the late winter and early spring months cold dry continental air from polar latitudes approaches from the north or northeast and often encounters moisture-laden air from the Gulf of Mexico over the region. Their contact produces precipitation events. Thunderstorms are often initiated by either cold or warm fronts, but the effects of the latter are not as pronounced in the Rolling Plains. However, the amount of precipitation depends on the moisture content and the stability of the air masses involved (BOMAR, 1983:32). There can also be very spotty precipitation events, such as during spring, when localized thunderstorms can produce high, but scattered, rainfall in the region.

A pronounced topographic change in elevation can lead to higher amounts of precipitation along a sharp elevation increase, which is commonly referred to as the orographic effect. This can occur along the eastern escarpment of the Southern High Plains, where warm fronts of maritime moist air are forced to rise. This may trigger summer thunderstorms along the escarpment (FINLEY and GUSTAVSON, 1980:18), also affecting the eastern parts of the Rolling Plains.

1.2.1.2. Seasonal winds

Winds, which are effective for sand transportation, are an important factor for the reactivation of dune fields and sand sheets. For further evaluation of seasonal winds in the Rolling Plains, typical wind conditions will be briefly examined.

Most common on the Southern High Plains and the Rolling Plains are southwesterly winds during the summer, due to the effect of the oscillating Marfa front. The Marfa front is the local term for a seasonally reoccurring front, mainly consisting of warm air. Sometimes during the summer, wind shifts occur in the Texas Panhandle when mild, cool fronts reach southward.

During the winter or early spring months cool, polar northerly air blows into northern Texas and eastern New Mexico. Although northerly winds are common in the Rolling Plains, southerly winds remain the dominant feature (BOMAR, 1983: 176). However, the intensity of those short-term northerly or northwesterly winds is much stronger. Winds intensify when a cold front moves through and can blow in gusts of up to 48 or 64 km/h (BOMAR, 1983:177). Wind speeds during storms that last several hours can be two to three times higher than the average wind speed. Gusts over 96 km/h and up to 120-128 km/h occur on the Texas High Plains (BOMAR, 1983:177), adjacent to the Rolling Plains. Such wind speed over a short time will definitely move sand, if the uppermost sand grain layer is dry before a storm (as cited by DRAGA in STENGEL, 1992). In the next section the season of least precipitation will be identified for a further evaluation of co-occurrence between strong winds and dry periods.

1.2.1.3. Seasonal precipitation

Precipitation data from the Rolling Plains climatic region from 1951-1980 show that the most rainfall occurs during May through August, while the least precipitation comes in December, January and February (BOMAR, 1983:220). Hence the winter months in the Rolling Plains are considerably drier than the summers. March and November precipitation can be considered low throughout the region.

1.2.1.4. Droughts and dust storms

Extreme events, such as droughts and dust storms, can provide additional amplification of conditions already persisting during the drier winter months on the Rolling Plains. The predominant factor causing a drought in Texas is the occurrence of a subtropical high-pressure cell which drifts latitudinally with the seasons (BOMAR, 1983:152). Droughts can persist for several years, as shown during the 1951-1957 period in Texas. This period of drought was accompanied by strong winds, which led to soil erosion damage throughout Texas (JOHNSON, 1965: 4).

Dust storms also frequent the Rolling Plains and can cause eolian movement. They often occur in spring after an especially dry winter and in combination with strong westerly spring winds (BOMAR, 1983: 192; ORGILL and SEHMEL, 1976:813), even though a general weather pattern leading to dust storms cannot be identified (HOLLIDAY, 1987:197). Droughts, high wind speeds and dust storms frequently occur together (JOHNSON, 1965:1). Interviews with local residents, who have lived near the Estelline dune field in the Rolling Plains for several decades suggest that sand was only moved during storms with very high wind speeds (Mike Davidson and Jay Warren Cope, 1992, pers. comm.).

1.2.1.5. Wind and dry condition co-occurrence

From the evaluation of modern climatic conditions of the Rolling Plains it can be concluded that the highest wind speeds occur during winter and early spring, coincident with the driest months. This concurrence of dry and windy conditions is critical, since this is when eolian deposits are most susceptible to movement. Therefore the climate in the Texas Rolling Plains is currently favorable for sand transport and local blowout events during the spring months. Vegetation will be discussed in the next subchapter because it functions as protective cover for dune fields and sand sheets and can inhibit sand transportation despite high winds.

1.2.2. Vegetation

The Holocene vegetation can often be reconstructed with the study of pollen analysis to determine species composition at a location. However, pollen are poorly preserved to investigate the “natural” Holocene vegetation in the Rolling Plains of Texas. The pre-settlement vegetation was probably a short-grass prairie during much of the Holocene.

The “natural” vegetation cover, however, was modified by the landscape transformation during this century’s settlement that brought agricultural and ranching practices to the area. Most of the agricultural land was clear-cut and plowed during the fall season to store fall and winter moisture for the next growing season, leaving it highly erodible. The vegetation on ranch land was also strongly modified, first cleared of most brush vegetation and trees and then seeded with high quality grasses such as alfalfa grass used as winter hay for livestock production.

One of the most comprehensive and earliest studies on vegetation regions in Texas was performed by THARP (1939). However, at the time of THARP’s study the vegetation was already influenced by farming and ranching practices. He described the vegetation of the Rolling Plains as a mesquite-savanna.

THARP (1939) observed that tree species include predominantly mesquite (*Prosopis* sp.). Mesquite can either appear as a thorny shrub or a small tree up to 10 m tall. It has drooping branches and a rounded crown, small dark green deciduous leaves, and legumes of 8 - 14 cm length (VINES, 1987). Mesquite grows in small stands and is often shrubby in the drier parts of the Rolling Plains. Other species are cedar (*Juniperus* sp.), oak (*Quercus* sp.), and also cottonwood trees (*Populus* sp.) usually in areas where the ground water can be reached.

Thorny brush vegetation includes species such as Condalia (*Condalia sp.*), Jujube *(Ziziphus sp.)*, Mimosa *(Mimosa sp.)*, Texas Prairie Acacia (*Acacia texensis)*, Mesquite *(Prosopis sp.)* (THARP, 1939). Non-thorny brushwood includes *Quercus* species, such as for example shinnery oak, which is widespread in sandy areas. Shinnery oak is the vernacular name for *Quercus havardii*, which grows as a low shrub, rarely over 1 m, forming thickets by underground rhizomes in deep sands, in the Texas Panhandle (VINES, 1987). Other brushwood in sandy areas are wild plum (*Prunus* sp.), hackberry (*Celtis* sp.), and sagebrush (*Artemisia* sp). *Artemisia filifolia*, a sand sagebrush, is for example a dominant brush on sandy soils in the Texas Panhandle.

Several types of prickly pear (*Opuntia* sp.) from the cactus family can also be found in the study area. Prickly pear is a heavily-bodied cactus with a cylindrical trunk, usually producing a small edible fruit during the summer month (VINES, 1987).

The native grassland is largely composed of Buffalo (*Bulbilis dactyloides*), Love (*Eragrostis* sp.) and wild Bermuda (*Capriola dactylon*) grasses, various other gramas (*Bouteloua* sp.), and fox-tail grasses (*Chaetochloa* sp.). Little bluestem (*Schizachyrium scoparium*) can be often found on dry sandy soil. Other bunch grasses (*Agropyron* sp.) grow in moister areas (THARP, 1939). Cacti and wildflowers are plentiful, such as the Torrey Yucca (*Yucca torreyi*) found on dry sandy or upland soils or the Mexican Hat flower (*Ratibida columnaris* sp.), which grows from May to July over much of the Panhandle, depending on summer rains.

Overgrazing practices are mostly caused by the unwillingness to reduce livestock during drought years where less food is available. Overgrazing leads to an abundance of mesquite and prickly pear (*Opuntia* sp.) vegetation. Mesquite seed pods are eaten by livestock and lead to a rapid spread of the species throughout the ranchland. Overgrazing can generally lead to a denser vegetation cover, which would therefore protect the soil from erosion.

However, due to overgrazing current ranching practices often include a chemical treatment of the fields for brush control and burning or uprooting of the mesquite trees, destroying some of the protective vegetation cover. The land is cleared from mesquite trees because the deeper roots of the mesquite are competing for water and the leaves shade the ground from sunlight, which restricts grass growth.

Prickly pear is also wide-spread on ranch land, however it is not as unwelcome as mesquite trees. Farmers use prickly pear as food supplement for their livestock during drought years when grasses become extremely scarce. However, they have to first burn the individual plant colonies, so the prickly pear thorns will become soft and the plants can be eaten by cows.

Uncultivated and ranched dune field and sand sheet vegetation cover can be classified into three different degrees of density. First, dense shinnery oak vegetation with small trees are on some of the uncultivated eolian sand sheets. This dense vegetation cover probably spared some sand sheets from agricultural usage, since clearing was difficult and after clearance the soil was highly erodible and proved to be not very fertile.

Second, other ranched sandy areas, such as a dune field near Estelline in Hall County, are more sparsely vegetated with some grasses, and different types of brush vegetation, such as wild plum, hackberry, and trees species such as cottonwood, and mesquite, the latter especially along the edges of dune fields (BLÜM, 1994). An interview with a landowner indicated that the Estelline dune field was seeded by a previous owner, who went riding through the active dunes, while throwing grass seedlings out at the turn of this century (pers. comm., Mike Davidson, see chapter 2.3). Third, other parts within larger dune fields or sand dunes in dry riverbeds are not vegetated or only have a thin and patchy grass cover and are, under current climate, classified as active dune areas.

The combination of dry periods with high wind speeds and sparse vegetation cover can foster desertification processes, especially on overgrazed ranch land or cultivated bare, plowed fields, thus in turn leaving the soil even more vulnerable. Therefore the cultural development and the influence of agricultural and ranching practices on vegetation cover, which influences sand transport, will be further investigated in chapter 4.

1.3. Criteria for study site selection

The primary criteria for the selection of the study site within a twenty-six county area of the Texas Rolling Plains was the distribution and geomorphologic setting of the sand sheets and dune fields. A variety of sand deposits were chosen, based on their location on different geologic formations, variability in the morphology of dunes and sand sheets. Another guideline was differences in the occurrence of paleosols within these sand deposits. These criteria point to differences in age and formation, which therefore portray different genetic histories.

Sand dunes and sheets are located on all different geologic formations and in all geomorphologic settings on the Rolling Plains of Texas. Sand deposits can be found on the Lingos formation, several sand sheets are located on the Permian strata, dunes are found on the alluvium, and some active dunes are located along the river or within the riverbed. Sand deposits are located close to but also distant from rivers and tributaries. Some sand sheets are located on topographic highs. These differences in their location could suggest a variety of sand sources and time frames for the depositional cycles of dune fields and sand sheets in the study area.

Sites were pre-selected from each of the above-described geologic settings with the help of geologic maps and LANDSAT imagery (1978) (Figure 14). However, not all of these pre-selected locations were possible study‘sites, because they were restricted by other factors. These limiting factors were 1.) dune field access and landowner contact/permission; 2.) sand deposit located in a restricted hunting area; 3.) the enormous driving distance between some locations and legal camping places; 4.) the availability of maps and aerial photography; 5.) the suitability of outcrops with paleosols for radiocarbon dating, and 6.) a very dense vegetation cover on the eolian deposits. These restrictive factors had to be evaluated for each deposit before each final site was selected.

Figure 14. LANDSAT imagery from 1978 for the determination of eolian deposits in light gray.

Most helpful with the first four selection criteria were the Soil Conservation Service (SCS) Agencies in the study area. These agencies are part of the U.S. Department of Agriculture. Counties with eolian deposits identified on geologic maps (1:250,000) were selected for a visit to the SCS offices to assure the accuracy of sand deposit locations at a 1:24,000 scale. The SCS offices' predominant task is to assist farmers in selecting farming techniques and crops that will limit soil erosion. SCS personnel prepared soil surveys during the 1960s and 1970s that described and classified all the soils within a county with the help of aerial photography and ground verification. Each of the classified soil series, which consists of soils with similar profiles, was named after a town or a geographic feature near the place where this soil was first observed or mapped. Soil surveys are also specifying soil types of different soil series based on their texture.

These SCS soil surveys were excellent for verification of sandy areas corresponding to the sandy soils of the Tivoli series, which are deep, sandy soils with immature A-C profiles. The surveys' classification system is, however, neither appropriate nor helpful for determining the genesis or age of soils, because they are not including paleosols in their descriptions, and the classifications were mainly intended to assist farmers and engineers with erosion control.

As mentioned in the introduction, most of the study area is private property. Trespassing is dangerous in Texas and should not be attempted, especially during hunting season. Snake guards should be worn because of the possibility of encountering poisonous rattlesnakes. Hospitals are far apart and strenuous hikes are sometimes necessary to get out of a dune field. It is advised to have snake guards on at all times and a field assistant who can get help or carry the victim to safety.

The outcrop availability, number of paleosols, and vegetation selection criteria were determined at reconnaissance visits and were the last decision factor for the final site selection. Some dunes appeared to be active dunes with no apparent buried soils. Some dunes had one buried soil, especially those along fences, and yet another set had a whole series of paleosols. Other dune fields or sand sheets could not be entered since they had an extremely dense vegetation cover.

It was attempted to use the morphology of sand dunes and sand sheets and different dune types as an additional selection criterion, but difficulties in classifying the dunes arose since they were in different stages of blowouts. Other dunes were mostly vegetated, which can modify dune types. The grain mineralogy, and hence source area for different sand dunes and sand sheets was decided not to be an appropriate selection criterion, since all material originated in the Southern High Plains or Rolling Plains as described above, and probably was thoroughly reworked and mixed prior to re-deposition of sand fields. Chapter 2 will provide an introduction to dune fields and sand sheet in the study area and present associated literature.

Chapter 2. Dune fields and sand sheets

2.1. Description of dune field and sand sheet settings

A variety of sand sheets and dune fields are spread as a thin veneer across the Texas Rolling Plains (Figure 15). As already mentioned in chapter 1, there is no apparent pattern to their location, neither on which geologic surface they appear nor in distance to rivers or seasonal wind directions. Some of the eolian deposits stretch on both sides of the rivers on Holocene and Pleistocene terraces. Others are distant from modern rivers located on small hydrologic divides. The youngest of all sand deposits are found along agriculturally utilized fields.

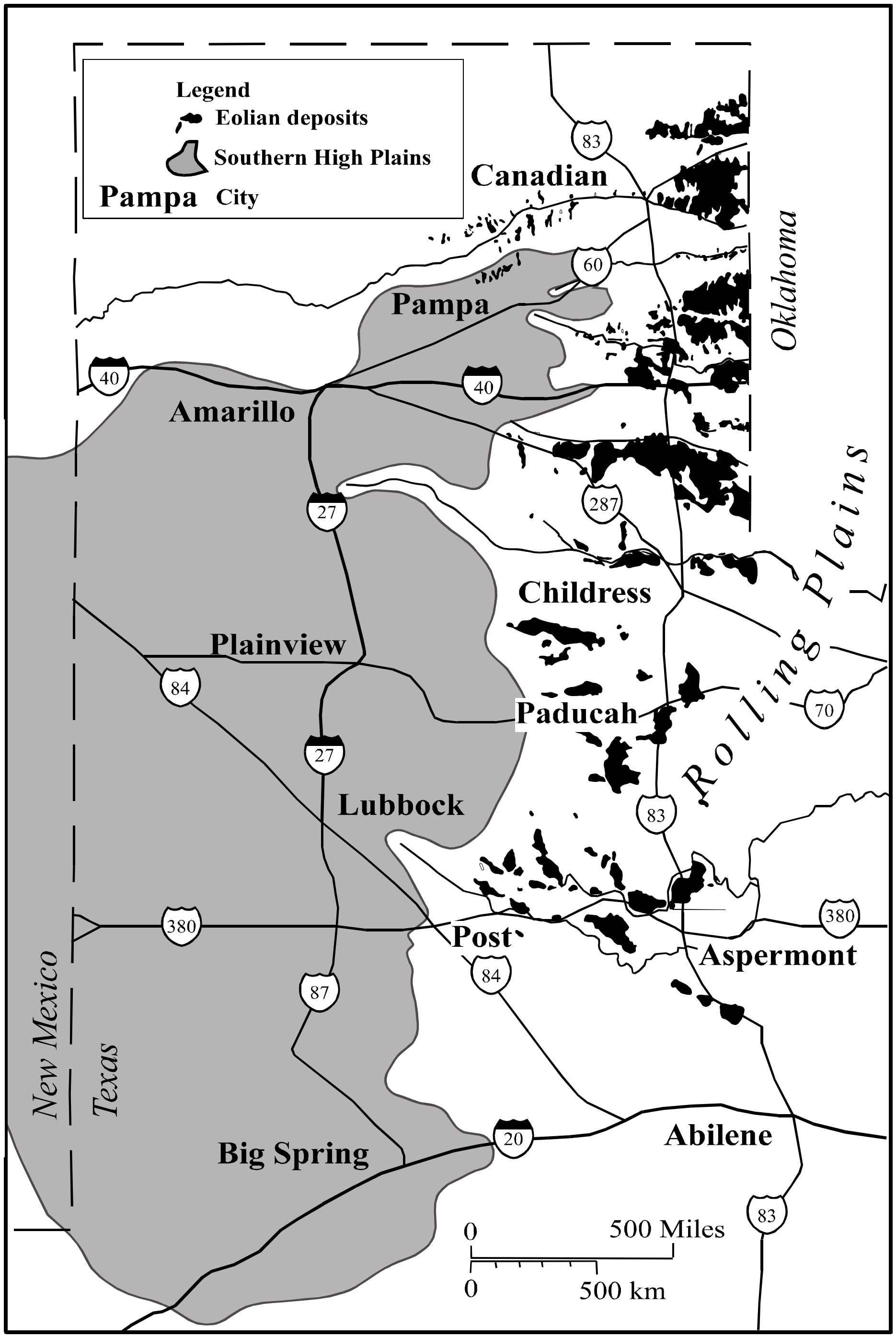


Figure 15. Dune fields and sand sheets in the Texas Rolling Plains.

The distinction between dune field versus sand sheet will generally follow KOCUREK and NIELSON's (1986) definition of sand sheets which are described as areas where dune slipfaces are generally absent. These areas are usually marginal to dune fields, but may also be found in their interior or can exist independently. There is a variety of sand sheets in the Texas Rolling Plains that posses the criteria to fit either one of these three categories.

The abundance of different sand sources from all geologic formations and rivers in the Rolling Plains of Texas and adjacent Southern High Plains, combined with the climatic pattern and different active geomorphologic processes throughout the Holocene, provide a variety of geomorphologic niches for the deposition of sandy material. These factors cause different geomorphologic settings for dune fields and sand sheets. Dune field and sand sheet settings as part of this study will be further described below.

One common geomorphic setting found in the study area is dunes spread alongside river channels, such as the Hall County dune field next to the Prairie Dog Town Fork of the Red River. These channels are generally braided, with a shallow water depth during the drier season. A possible scenario of dune field formation is that dunes form in the braided riverbed during the dry and windy season of the year. Once rainfall increases, the channel bed would be diverted around these higher sand accumulations. This scenario could explain why dune fields are located on either side of the river without even taking seasonal changing wind pattern into account.

Aerial photography of the Hall County dune field, which is nested in a bend of the Prairie Dog Town Fork of the Red River, shows an abandoned channel within this dune field and thus provides supportive evidence of the above theory. There is also field evidence of very young dunes within this type of channeled braided streams throughout the Rolling Plains during the drier part of the year.

One other predominant setting of dunes is closely related to the anthropogenic modification of the landscape. These types of elongated, very young dunes with immature soils appear mostly in a setting with modern fences and are related to agricultural practices of dry-land farming. These features are especially abundant near the town of Post. Hence not only geomorphologic factors are important for dune settings; anthropogenic components of the landscape development also need to be considered, which is a major component of this research and will be further explained in chapter 5.

Other eolian deposits are situated on topographic highs, which are general hydrologic divides away from broader channels, such as the White River Reservoir sand sheet in Crosby County. Some of these eolian features have a smooth topography with contours declining in a circle from the center out, while others are moderately flat.

These sand sheets could have formed some time ago in a semiarid environment of the Texas Rolling Plains. KOCUREK and NIELSON (1986) suggested six favorable conditions for the formation of warm-climate sand sheets. The factors are a high water table, surface cementation or binding, periodic flooding, a significant coarse-grained sediment population and vegetation. Further research beyond the scope of this dissertation needs to be done to determine if the above mentioned sand sheet formation factors apply to the Rolling Plains of Texas semi-arid environment and if they played a role in the formation of these types of sand sheets. It can generally be suggested that the only factor from the listing above which is applicable to the study area, is the vegetation on sand sheets. Generally sand sheets in the study area have a dense vegetation cover, which could have contributed to their development. Other factors suggested by KOCUREK and NIELSON (1986) could not be identified in the field.

Besides having formed as sand sheets, another possible explanation is that these features are erosional surfaces of older and larger dune fields. For this model one indication are paleosols outcropping around the edges of the sand sheet, which was once a dune field, being eroded by creeks and streams around the edges. There are several possible causes for their erosion. They could have been cut off from the local sand supply and were then deflated on the surface. There also were attempts to farm the sandy land during early years of settlement, destroying the protective vegetation cover and thus making the sand sheets vulnerable to the erosional forces. Several agricultural utilized fields near the city of Post show evidence of severe sand erosion as will be further demonstrated in chapter 5.1.3. Some of these sandy fields, which might have been former sand sheets, were utilized to grow peanuts, which thrive well on sandy soils.

Despite theses differences in the geomorphic setting of the dune fields and sand sheets a common relation can be pointed out. The sparser the vegetation cover on the eolian deposit the more likely a reactivation will occur during drought conditions. Dune fields and sand sheets with a dense vegetation cover are currently not being reactivated. Other dune fields with a sparse vegetation cover appear altered after drought events. Active dunes with little or no vegetation are being deflated during every storm/wind shift event as was witnessed in the Estelline dune field in Hall County during multiple fieldwork sessions.

These active dunes in some dune fields and riverbeds can generally not be classified by their dune types anymore, because they represent mostly stages of different blowout phases. Some greatly deflated parabolic and longitudinal dunes, however, were identified in the dune field near Estelline, Hall County. A detailed description of the individual dune fields, sand sheets, their setting, appearance and morphology are presented in chapters 5, 6, and 7.

2.2. Paleosols

Geomorphic setting, appearance and morphology are important factors in the study of sand sheets and dune fields. These factors provide information on geomorphologic processes, wind directions and sand sources. For the investigation of reactivation and stabilization phases in dune fields and sand sheets during the Holocene, however, paleosols are a great indicator. They have been used as an indicator of climatic change throughout the Great Plains region (HOLLIDAY, 1990; PORTER, et al., 1995; ARBOGAST, 1995).

Conditions that currently influence sand transport in the study area determine either a soil development in eolian deposits or their deflation. Factors important for these conditions, such as current geomorphologic environments, current climatic pattern and vegetation cover have already been discussed in chapter 1.

However, older reactivation and stabilization cycles of eolian deposits occurred under the influence of past climatic conditions which may have influenced the vegetation cover and may have drastically altered geomorphologic processes. Past climatic fluctuations influenced the environmental conditions which were responsible for sand reactivation and stabilization cycles throughout the Holocene. Buried soils are evidence of these cycles of landscape stability and instability in dunes and sand sheets.

The period of sand dune formation implies a phase of landscape instability with drier conditions. Such climatic conditions prevent protective vegetation growth and, when combined with strong winds and available sand, favor the formation of sand deposits. By contrast, paleosols found in dune deposits imply a period of moister climate conducive to vegetation, stable land surface conditions, and soil forming processes. Paleosols in sand dunes can be used as climatic indicators. Hence sand deposits of semiarid to arid environments are known for their value in paleoclimatic research (HÖGBOM, 1923; REEVES, 1976; HOLLIDAY, 1985, 1989a,b; BLÜM, 1989; BLEED and FLOWERDAY, 1990).

Although the study of paleosols is still an evolving science in the United States, the information gained is important in the interpretation of past climatic conditions. Scientists in the U.S.A. remain divided as to whether paleopedology is a valid methodology for paleoclimatic studies. BRADLEY (1985) does not include paleosols in his presentation of methods for paleoclimatic reconstruction. He does not furnish any reasoning for the lack of such a chapter in his book, but many other authors concur that the study of paleosols provides a valid methodology for paleoclimatic research (CATT 1986; BOARDMAN 1985; LOWE and WALKER 1987; BIRKELAND 1984; BRONGER and HEINKELE 1989).

Several conditions suggested by BIRKELAND (1984:304) point to the need to use caution with paleosols in past climate research. Soils represent soil-developing intervals in the depositional record, but only the record of certain time intervals remains, since erosional intervals truncate soils, and thus leave no evidence for paleoclimatic research on erosional surfaces. However, this is generally the case for most other paleoclimatic research methods.

BIRKELAND (1984) claimed that only assumptions might be possible in paleopedology, such as higher precipitation rates and surface runoff as major erosional agents, but such assumptions remain unspecified. BIRKELAND (1984:304) stated another dilemma, which is that the effect of a longer interval of soil formation can produce the same pedologic result as a climatic change. He referred to this statement as being "commonly recognized", however, his opinion needs to be carefully evaluated since it is probably based on research using the American soil classification units. These classified soil units do not give very accurate data on weather conditions or paleoclimate. In his research BIRKELAND (1984) seemed to make also no clear distinction between weather conditions and paleoclimate having affected soils during the past. In conclusion, there appear to be great difficulties to conduct paleoclimatic research based on the American soil classification system.

Long-term climatic changes are generally detectable in soils. However, soil development changes slowly in response to climate, hence brief climatic fluctuations, such as short-term cyclic droughts, seem unlikely to be represented in the soil profile. However, as will be shown in chapter 6 in a dune field near Estelline, short-term cyclic droughts are usually integrated in the overall dune field history.

Direct inferences for paleoclimate from chemical and physical properties of paleosols are possible, but require a solid foundation in soil data. The only current method is through comparison with modern processes of soil development, which does not represent a comprehensive approach since genetic soil imprints might be differently represented in soil data. Further research is necessary to evaluate soil processes and their intensity in response to climate, which would provide a closer relationship between soils and past climates.

Despite the fact that physical and chemical properties of paleosols cannot be easily used as paleoclimatic indicators to determine certain climatic conditions, such as temperature or rainfall measurements, the following statement appears to be valid for this research. Paleosols preserved in sand dunes were formed during past landscape stability periods, where wetter climatic conditions or changes to a more stable environmental condition fostered vegetation cover, and hence soil development. These paleosols can be age-dated and correlated with each other to determine periods of stabilization within a dune field or even in a larger setting. At a broad scale, the spatial distribution of paleosols can be used as an aid to determine if overall climate conditions became wetter or if, for example, local environmental or anthropogenic factors were responsible for the reactivation and stabilization of the dunes.

Previous fieldwork (BLÜM, 1994) in the Rolling Plains of Texas and evidence of past climate changes in the Southern High Plains (HOLLIDAY, 1995) suggest Holocene climatic changes in the Rolling Plains of Texas. This research utilizes eolian deposits and their paleosols to determine the extent and time frame of these climatic changes versus anthropogenic factors in sand dune development and modification. To consider anthropogenic factors in the reactivation of eolian deposits it is important to research sightings of sandy hills by first travelers and also interview local settlers about early agricultural utilization of these dune fields.

2.3. Historic sightings of eolian deposits from first travelers

A valuable tool for this research is the exploration of travelers' descriptions who passed through the Rolling Plains region, and also interviews with individuals who settled and were raised in the region. Both of these types of records can be utilized to learn about dune field changes and landscape modification since their first sighting. This will contribute to the understanding of the extent of dune reactivation after Anglo-American settlement of the area in 1875.

There is an abundance of travel literature on the Texas Panhandle prior to Anglo-American settlement in 1875 (KASTEN, 1954). Travelers and explorers who frequented the rough and rugged country mainly described the people, geographic landscape, and the potential for agriculture and mining as a means of contributing to the expansion of the American population and it's colonization in Spanish Texas (ARONSON, 1963). Travelers and explorers of the Texas Panhandle prior to the Anglo-American settlement included Coronado with an expedition in 1541, Conilla in 1583, Onate in 1601, Costillo in 1650, Guadalajara in 1654, Hurtado in 1715, the Mallet Brothers in 1740, Jose Mares in 1787, and Pierra Vial in 1788 (STUDER, 1949).

It is sometimes difficult to get access to these original travel accounts in libraries, since they represent historical documents and are often not made available for the general public. Some information about these above mentioned explorers can be found in documents written by other authors such as for example STUDER (1949). Unfortunately these authors had their own selection criteria for information they presented from the travel diaries which mostly did not include the description of sandy areas.

Zebulon Pike (1779-1813) presented a descriptive account of vast sandy areas with no vegetation in Kansas and Colorado from his 1st expedition published in 1810 (AUSTIN AMERICAN STATESMAN, June 2nd, 1996). He was also sent out to explore the mouth of the Red River, which is now the present Canadian River during his Arkansas expedition (1806). This path along the river would have led Pike through the Rolling Plains of Texas. Unfortunately, Alexander von Humboldt (1769-1859), who created one of the first maps of the "Red River", produced a location error on his map completely misplacing the present Canadian River. Pike used Humboldt's map for his expedition, and thus due to the error on Humboldt's map Pike's actual journey went falsely along the western side around the High Plains region (JACKSON, 1966).

Francisco Vasquez de Coronado, on his expedition in 1541, was one of the early explorers and first European visitor, who made some archaeological observations in the Texas Panhandle (STUDER, 1949). STUDER (1949) made note of an Indian guide named El Turko, who tried to lose Coronado and his Conquistadores in the "desert". The term "desert" probably referred to the vast sandy areas along the Canadian River valley, which were later also mentioned by MONTAIGNES (1845).

MONTAIGNES (1845:101), who traveled the South Fork of the Canadian River in an expedition in 1845, noted on September 1st in his journey diary:

> "we traveled for 6 hours and in passing over a ridge of rough sand hills and rain plowed furrows…"

However, his early travel report, which mentions passing through sand hills near the South Fork of the Canadian River gives a descriptive account of the vegetation, game, travel surface, water and food sources, but is not detailed on geographic or geologic descriptions. We can deduce from his report that vast sand hills with a hard surface and furrows existed along the South Fork of the Canadian River in 1845. This sandy area took about six hours to pass through in his account. With an estimated average travel speed in sand for wagon, horses and men of 3.2 km per hour these eolian deposits would have extended for about 19.2 km.

In conclusion, early explorers, who traveled in the Rolling Plains and adjacent Southern High Plains, described vast sandy areas. These mentioned eolian deposits or "deserts" must have therefore existed before Anglo-American settlement. This indicates that at least some of these sandy deposits could have not been caused by agriculture and ranching practices.

2.4. Description of sand dunes by early settlers

Interviews can be an important instrument in the study of landscape evolution. Two landowners, who own part of the Estelline dune field, were interviewed, because they knew some of the early settlers in Hall County, Texas. The first interview was conducted with Jay Warren Cope, who lived on State Highway 86, south of the Estelline dune field. He was interviewed about his parents, who were among the first settlers in Hall County. The other person interviewed was Mike Davidson, who lives at the southern edge of the Estelline dune field also on State Highway 86. Mike Davidson, who owns presently part of the sand dunes, was interviewed about the previous owner, who was also among the first settlers in Hall County.

Jay Warren Cope, who owned part of the Hall county dune field, came with his father as the first settlers to Hall County, Texas in 1908. His father knew the land since 1880, when the Estelline dune field was already in place. Even though Jay was only a three year old boy moving to the area, he remembered the dune field nearby early on. He was an eyewitness to deflation in the active dune areas within the mostly vegetated dune field. Some of these sand reactivations revealed paleosols and lithic points and will be further discussed in chapters 6.1.2. and 6.1.1.

Another interview conducted with Mike Davidson, who owns also part of the Estelline dune field, showed that the previous owner was going out on horseback across the dunes throwing grass seeds out for stabilization purposes. Mike

Davidson said that the dunes did not move since he had been a little boy and that the initial fence for his property line is still in place and was not covered by dune sand. He said even during the 1950s drought the dunes did not move but seemed deflated, because storms would exhume arrowheads in the active sand areas. He thought that the vegetation has improved over the years and a recent fire in the dunes, which destroyed the vegetation, did not cause the dunes to reactivate.

In conclusion, early settlers, who arrived around the turn of the century in Hall County, Texas, described sand hills near Estelline nested along a bend of the Prairie Dog Town Fork of the Red River. The two above described interviews indicate that some dune fields are older than the settlement of the area, which provides some evidence that they were not caused by agricultural or ranching practices. The two persons interviewed agreed that sand has been deflated since. This was important information for further research. It resulted in an investigation of paleosols within the Estelline dune field and the collection of two radiocarbon samples, as will be further explained in chapter 6.

2.5. Literature

Further aid in this research provides the broad body of literature reporting on eolian deposits and Quaternary environments mostly referring to the adjacent Southern High Plains and Great Plains regions. However, Quaternary eolian deposits in the Rolling Plains have been recognized and mapped by several authors (BARNES, 1967,1968; GUSTAVSON and FINLEY, 1985, 26; CARAN and BAUMGARDNER, 1990; MACHENBERG, 1986; GUSTAVSON et al., 1991), but they have not been studied in detail nor have been described in the literature. The potential information these sands hold on reactivation and stabilization cycles and hence past climatic changes during the Quaternary in the Rolling Plains of Texas remains as yet untapped.

There have been more detailed fluvial studies in the Rolling Plains and High Plains. STRICKLIN (1961), who studied stream deposits of the Brazos River provided some of the earliest work in the fluvial history of the area. More recent research by FREDERICK (1991) described stratigraphic sections of Palo Duro Creek, which aided in the determination of channel aggradation and incision phases useful for the detection of climatic changes. BLUM et al. (1990) studied the evolution of landscapes on the Double Mountain Fork of the Brazos River with respect to the archaeological record in the area. These studies will be a useful asset for the comparison with eolian reactivation and stabilization phases established in this research, climatically corresponding to incision, and aggradation phases of the fluvial record.

Several authors have investigated aspects of Quaternary research in the western Rolling Plains region, including CUMMINS (1893), who presented early aspects of geology, Leighton (1936), who described archaeological horizons and findings near Abilene, FRYE and LEONARD (1957, 1963) and VAN SICLEN (1957), who examined Cenozoic geology. More recent studies include

GUSTAVSON (1986) working on Quaternary stratigraphy, and as already in detail discussed in chapter 1.1.3.2. GUSTAVSON, FINLEY, and BAUMGARDNER's (1981) study, which estimated retreat rates of the Caprock Escarpment, and also a study by BRYANT and HOLLOWAY (1985), which identified pollen and derived some indicators of paleoenvironmental conditions. CARAN and BAUMGARDNER (1990) outlined the Quaternary stratigraphy and paleoenvironments of the Texas Rolling Plains, concentrating on Quaternary alluvial-fan, lacustrine, fluvial, and some eolian deposits. DALQUEST (1962, 1965, 1986) and HIBBARD and DALQUEST (1973) have also documented Quaternary paleofaunas in the region. HUFFINGTON and ALBRITTON, (1941), investigated the Judkins and Monahans formations of the Sand Hills; their research was mainly descriptive in nature. MELTON (1940) who classified sand dunes and investigated their dune history, proposed a tentative dune chronology for the same area. HEFLEY and SIDWELL reported on dune ecology and the sand source of a 200 kilometer-long dune field covering eastern Bailey County and parts of the east central portion of New Mexico (1945).

Most of the paleoclimatic studies, including those of eolian deposits, have concentrated on the adjacent Southern High Plains. More recent and comprehensive literature on eolian deposits in the Southern High Plains includes REEVES (1976), HOLLIDAY (1985,1989a, b, 1990, 1995), and GUSTAVSON (1990). In consideration of escarpment retreat and in view of the close proximity of the Southern High Plains to the study area, these studies are relevant for the characterization of eolian deposits in the Rolling Plains.

There has also been a great deal of recent research and literature generated on various aspects of episodes of eolian activity in the Great Plains region further north of the Rolling Plains. These studies need to be considered for the potential correlation of eolian activity periods between the Great Plains and the Rolling Plains region. GAYLORD (1990) studied Holocene paleoclimatic fluctuations in Wyoming, where he investigated a 25 m thick sequence of dune and interdune strata at Clear Creek. The strata revealed six intervals, four of which showed enhanced eolian activity episodes. MUHS (1985) compared stabilized parabolic sand dunes in northeastern Colorado to sand dunes of the Nebraska Sand Hills. Dunes in the Sand Hills with similar morphological and textural soil properties showed maximum limiting radiocarbon dates of about 3,000 B. P. He found older sands underlying the parabolic dunes in Colorado and proposed their age to be "Altithermal", a warmer and drier time period during the Holocene.

FOREMAN, GOETZ and YUHAS (1992) used the aid of satellite imagery to understand landscape response to Holocene climates in the High Plains of Colorado. They identified at least four sets of eolian reactivation over the past 10,000 years, with dune formations suggesting winds from the northwest.

MADOLE (1994) found stratigraphic evidence of desertification in the west central Great Plains within the last 1000 years. His research is supported by eight radiocarbon dates from five different locales suggesting that episodic eolian activity periods began after 1,000 A. D. and ended some time in the latter part of the 19th century. He furthermore voiced concerns about widespread eolian sand transport under present climatic conditions. MADOLE (1995) also reported on the spatial and temporal pattern of late Quaternary eolian deposition in eastern Colorado. He provided a comprehensive description on source material, dune types and wind-formed direction of the eolian deposits. He recognized three major sand units based on the analysis of bedforms, topographic expression and soil development. These sand units essentially span a time period from 22,500 to 150 years B. P. with the exception of probably wetter conditions without eolian activity or no record shown between 8,000 and 9,000 years B. P.

ARBOGAST (1995) presented his dissertation research on paleoenvironments and desertification on the Great Bend Sand Prairie in Kansas and identified six periods of pedogenesis, hence landscape stability. This indicated wetter climatic conditions during the Holocene, around 6,300; 2,300; 1,500; 1,000; 700 and 200 years B. P. with weakly developed A-AC-C soil horizons. The eolian deposits in his area range from level sand sheets to parabolic dunes. The orientation of the latter suggests their formation under prevailing southwesterly winds. The most intense periods of dune mobilization occurred between 5,700 - 4,800; 2,300 - 1,700; 1,600 - 800 and < 200 years B. P. (ARBOGAST, 1993).

AHLBRANDT, et al. (1983) described dynamic Holocene dune fields of the Great Plains and Rocky Mountain Basins. They limited the time period during which eolian deposits were reactivated to the last 7,000 years, which coincides with most of the other enhanced eolian activity periods in the region. PORTER et al., (1995) found at least two dune reactivation periods among Holocene and older dunes in southwestern Kansas. The most recent deposition occurred between 1,600 and 1,300 years B. P. The other phase of dune reactivation reportedly occurred about 5,570 years B. P.

SWINEHART et al. (1995) presented a paper on the last 1,000 years in the Nebraska Sand Hills and the history of sporadic blowouts versus regional episodes of sand mobilization. This study provides useful insights for discussions, since this is also one of the key questions for eolian deposits in the present study.

The above mentioned researchers outlined different activity time frames and portrayed various aspects of eolian reactivation phases for their study area. Figure 16 shows their spatial distribution and the times of enhanced eolian activity, as well as some soil stabilization periods in the Great Plains region.

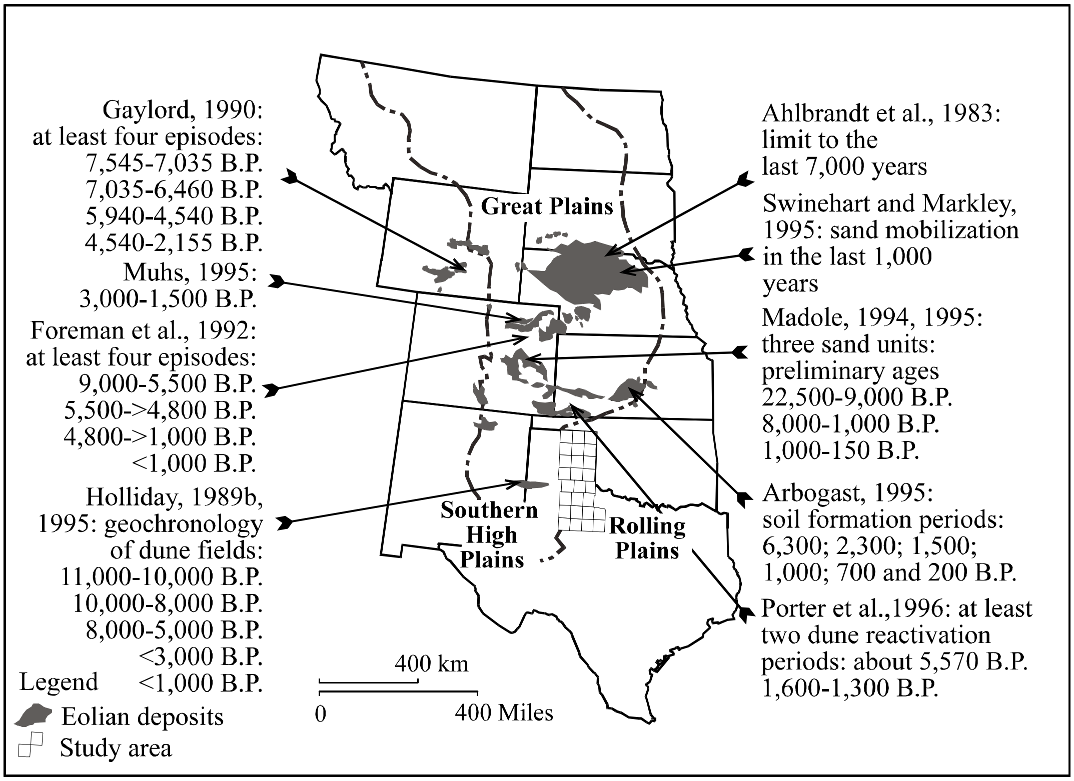


Figure 16. Episodes of eolian activity in the Great Plains Region found by other researchers.

A correlation of these activity periods is very difficult, and it has not yet been attempted. The Great Plains region combines a variety of sand sources similar to the Southern High Plains and Rolling Plains regions, which were discussed in chapter 1.1.1. These different sand sources in combination with differences in the local weather and climate changes through time are providing conditions favorable for a variety of eolian deposits, which may be difficult to correlate. Other challenges combining stratigraphic records are: different dating techniques, eroded sections and local blow-out events, which were already discussed in the introduction. However, studies in the entire Great Plains region show enhanced eolian activity almost everywhere over the past 1,000 years. Even though a correlation seems difficult, comparisons with other studies may help identify overall climatic shifts to drier or wetter condition and need to be investigated.

The literature review presented here discloses that a variety of eolian studies exist for areas mostly further north, as part of the Great Plains region. Ample evidence shows a variety of eolian activity periods throughout the Great Plains region. However, no comprehensive research on eolian deposits exists from the Rolling Plains of Texas. The present study will contribute to this field of study. It will show proof of climatic fluctuations, which are evidenced in reactivation and stabilization phases of eolian deposits in the Rolling Plains. It will also utilize information deduced from short-term sporadic blowouts and identify anthropogenic influences to investigate modifications in the dune fields and sand sheets.

Chapter 3. Methodology

A variety of methods from several disciplines were used to investigate the reactivation and stabilization periods and the environmental history of dune fields and sand sheets in the Rolling Plains of Texas. Some methods were more successful than others depending mostly on the environment, sample size and procedures, and in some cases financial restraints.

The selected methods provided a variety of analyses to examine the different aspects of this study. The geomorphologic part of this study was provided by fieldwork results from outcrop descriptions, soil cores, and laboratory analysis. The laboratory analyses employed radiocarbon dating, pollen and thin section analysis, and the determination of grain size distributions. The anthropogenic component of the methodology is comprised of interviews, museum visits, map and literature work.

Some methods had insignificant results. It is, however, important to report on methodologies that were less useful in the particular type of geomorphologic and climatic setting of the study area. Other researchers can learn from these experiences. Methods are described in detail if the author performed them. In cases where a laboratory was used for the analysis, then the laboratory name and personnel are given along with a short description of the procedures, if available.

3.1. Field research

3.1.1. Visits to Soil Conservation Service offices

As mentioned in chapter 2, interviews are a valuable source of locally gathered information that can provide insights into details of landscape evolution. They are helpful in the detection of archaeological sites and help to gain property access to specific sites, since most residents in the Panhandle seemed to enjoy showing their land.

A variety of settlers, property owners and office personnel working with the Soil Conservation Agencies of the United States Department of Agriculture were interviewed. The Soil Conservation Service (SCS) offices provide soil surveys of entire counties. Their main objective is to support farmers to aid in decisions about agricultural techniques customized for a particular soil type to reduce soil erosion. These soil surveys, however, do not include genetic information of soils and hence are not valuable for paleopedologic research. For the present study soil surveys (1:24,000) helped to locate and confirm eolian deposits, which had first been identified on larger-scaled geologic maps (1:250,000).

These geologic maps (BUREAU OF ECONOMIC GEOLOGY, 1967,1968, 1969, 1974) provided the base information for identifying eolian deposits from different geologic units and in different geomorphologic settings. Once areas had been selected, a visit to the SCS offices of each county followed, to confirm their location with the personnel and the help of aerial photography. The eolian deposits matched in general the Tivoli sands of the soil surveys, which was already discussed in chapter 1.3.

Another reason for visits with the SCS agencies was to gain access to dune fields and sand sheets on private property, which covers most of the study area. Some of these dune fields have up to twelve different landowners. Most of the SCS office personnel were able and willing to provide a contact address or phone number for landowners of sandy areas. Usually this information is not easily available and has to be accessed at each county court house in the particular deed of the easement.

3.1.2. Outcrops and soil profiles, availability and access

In the study area outcrops and soil profiles provided information on anthropogenic desertification, drought-related depositional and erosional cycles, landscape stability periods, and past climate. Nine outcrops were investigated and the soil profiles were recorded at different locations throughout the Rolling Plains.

Some of the landowners did not give permission to access their land, especially if they had cattle on their land, which was often the case on eolian deposits. There was, therefore, often no possibility to search for outcrops in the field. Searches were very time consuming, since as already mentioned some dune fields were owned by as much as twelve landowners, and considerably difficult to actually find outcrops in the field. They were often only inadvertently discovered.

Once access was gained and outcrops were located, soil samples and descriptions were taken from every horizon of these outcrops to identify grain sizes and color. Generally one sample was taken per horizon, but if the horizon exceeded 50 cm in depth, then additional samples were taken from the same horizon.

A hydrochloric acid (HCl) field test was performed on selected horizons to determine if Calcium carbonate ($CaCO_3$) was present. The presence of $CaCO_3$ and the size of the nodules can be an indicator of the age of a deposit (GILE et al., 1966). GILE et al. (1966) defined morphological and genetic sequences of carbonate accumulation in desert soils. They classified the amounts of calcrete in soils and organized this information into different calcrete stages indicating roughly the age of the soil. This information is useful in comparing soils from similar environments as can be seen in chapter 7.2.4. The HCl field test and a comparison with studied soils from the Southern High Plains aided in the selection of soil radiocarbon samples.

Soils were described using European terms since the U.S. classification system of the Soil Taxonomy (SOIL SURVEY STAFF, 1975) cannot be used for buried soils. It does not include a section on paleosols nor is it based on soil genetic criteria. The profiles will be described in the appropriate chapters.

3.1.3. Soil cores

Eleven soil cores were taken by hand with a soil core from Ben Meadows Company (1.9 cm diameter and 76.2 cm length) at different locations in the study area. Soils were cored up to 3 m depth. Coring depth very much depended on the hardness of the underlying material. Higher penetration resistance reflected an increase in clay content.

This method was primarily used to search for buried soils in dunes or sand sheets where outcrop availability was limited, or where an older land surface needed to be traced. Not all soil core profiles were useful for the present study, because they provided only limited information, as will be further discussed in chapter 7.2.1.

The soil extracted was often filled with homogeneous sand and the soil core was not an effective research tool. However, if there was no buried soil discovered up to a 3 m depth it signified that the eolian deposit has a minimum thickness of 3 m, which can still be an important piece of information. However, there still might be a former land surface below 3 m in depth.

Tracing clay bands, also called “lamellas” (see also chapter 7.2.1.) with a core in sandy soils was very problematic since the core has a small diameter of 1.9 cm and the pressure of pushing the soil core into the ground distorted the lamellas. Consequently, one knows that they exist, but nothing can be said about their thickness or at exactly what depth in the profile they occur.

In conclusion, soil cores were not a useful tool for the present study. Most of the cored profiles could not be interpreted if there was no soil outcrop locale in the vicinity for a comparison of the soil horizons.

3.1.4. Museums and libraries

There are several museums and libraries in the study area and some of them have Internet sites. Most of them have some general and also county-specific historic information on Indian cultures and some possess old maps on the cultural development of their region. The information gained from these sources helped mainly during the fieldwork.

3.2. Laboratory analyses

3.2.1. Pollen Analysis

Pollen analysis is a paleoclimatic method that provides information on past plant communities at a specific location. It has provided major contributions to

Quaternary studies in the Southern Great Plains region (HOLLIDAY, 1987; HALL, 1982; BAKER and WALN, 1985. The Texas Rolling Plains, adjacent to the Southern Great Plains are deficient of palynology studies. A possible reason for the lack of palynology research in the Rolling Plains region is that the environment is not suitable for pollen preservation, since pollen in sand can easily oxidize.

Pollen analysis in combination with radiocarbon dating can provide information on assemblages of vegetation communities during a certain time period. Thus long-term climatic changes can be detected, if abundant pollen are preserved and enough clay or organic matter are present for radiocarbon dating. Short-term variations are not recorded in the vegetation because of the reaction lag of vegetation to climatic change (FAEGRI and IVERSEN, 1989:167). Pollen analysis, therefore, does not seem to be a suitable method for short term drought reactivation in the dune areas, but long term climatic shifts to more drier conditions, such as the Altithermal, could possibly be detected.

Four samples were collected from soil horizons at different locations in the Texas Rolling Plains during field research in the summer of 1992. Outcrops in eolian sand deposits were chosen, which were freshly cut and cleaned prior to sampling to prevent contamination. A sampling method adopted from FAEGRI and IVERSEN (1989:53-58) was used. A short description of each location will be presented, followed by the methodology and conclusive remarks about the site selection.

The first sample X2 was collected in a vegetated dune field in Wheeler County. A profile along a roadcut on county road H near County Road 17 was selected as the sampling site. The geologic setting and a profile description can be found in chapter 7.2.4., which describes the Road H outcrop. The sample was taken at a depth of 20 - 30 cm from a transitional A - and weak B -horizon. The sample was collected on 6-13-1992. The color was determined to be HUE 7.5YR 5/6.

The second sample E2 was collected on Tom Cope's property in a dune field located 0.5 miles south of the Red River west of Estelline in Hall County, Texas. Mostly complex blowout dunes, only, some of which are vegetated, combine to form an extensive dune field along the river. The sample was taken approximately 5.4 m below the dune crest at a buried interdune deposit, which outcropped, diagonally for approximately 9 m, dipping north. The sample was taken between 55 - 63 cm in darker colored sand with some lighter colored patches. It was collected on 6-1-92 and the color was HUE 7.5YR 5/6.

The third sample M1 was collected from a dune field locally called "Cash Dunes" on O'Brien's property along the Farm to Market road (FM) 1732 in Donley County, Texas. A roadcut outcrop facing west was selected. The sample was taken between 45 - 54 cm in a brown, sandy B-horizon. The sample collection date was 6-6-1992. The color was determined to be HUE 7.5YR 11/6.

The last sample O1 was collected on Meyer's land east of Borger in a large dune field, with mostly vegetated dunes on FM 1059 in Hutchinson County, Texas. The outcrop, where the sample was taken, is located about 20 m from the FM road on an unmarked road and is facing west. The outcrop description and the geologic setting of the dune field can be found in chapter 7.2.2. The sample was taken between 49 - 58 cm depths from sand with sedimentary structures preserved. The color of the sample is HUE 7.5YR 5/6. The sampling date was 6-9-92. The above discussed sample locations are shown in chapter 7 on figure 44 (p. 113).

Palynologists have developed many different sampling collection methods and laboratory techniques. A technique developed and refined by Dr. Stephen Hall, Geography Department, University of Texas at Austin, was used for the laboratory treatment of the eolian sediments. The laboratory work was conducted at the University of Texas in Austin, Geography Department, in the laboratory GRG 132 from 10-15 to10-24-92 under the supervision of Dr. Stephen Hall.

A small amount of each sample was dried in an oven. Two *Lycopodium* tablets (11,267: 298 spores per tablet, batch 201890) per sample were added as a spike pollen. The sample was then processed with hydrochloric acid (HCl), hydrofluoric acid (HF) and a solution of zinc chloride to dissolve quartz grains and separate the organic material from the clays. The organic flotant was centrifuged with some water and HCl in glass tubes. The *Lycopodium* spike pollen was recognized under a watch-glass in all four samples.

No pollen was recovered from any of the four samples, but spores and fungus were present. Soils are also often not suitable for pollen recovery. A-horizons may have pollen grains, but argillic B - horizons in sand deposits do not preserve pollen grains very well because of the secondary clay and mineral illuviation. FAEGRI and IVERSEN (1989:167) point out that soils at a pH value above six lack pollen. The buried assemblages of pollen grains are vertically and horizontally mixed because of bioturbation processes in a soil profile. This has to be evaluated when choosing a soil as a sampling medium. Inceptisols, young soils with weak pedogenic imprintment, might be a better medium in which to preserve pollen, but older soils lack pollen because of pedogenic processes, which often destroy the pollen grains.

In conclusion, recovery of pollen depends heavily on sampling environment, selected sample site and the material in which pollen is buried. Dunes and eolian sheets are in general not favorable preservation media.

3.2.2. Radiocarbon dating

Seven radiocarbon samples were collected from four different paleosols sites in the study area and were processed at the Radiocarbon Laboratory, University of Texas at Austin, Pickle Research Campus, by Salvatore Valastro and Alejandra Varela. The samples were labeled X-8437, X-8438, X-9000, X-9001, TX-9037, TX-9038, TX-9038 and were pretreated and prepared according to a process dictated by the pretreatment protocol of the laboratory. Two four liter Ziploc bags were required for a full sample.

The objective for this analysis was to date the total humates in the soils. During the pretreatment of the sediment floating particles, sands and carbonates were removed. The remaining sample was dried and then pulverized. The dry powder is the humate fraction, which was then radiocarbon dated.

The analysis report disclosed the following information. Date calculations were based on the Libby half life value for carbon-14 of 5568 years, a modern reference standard from the National Bureau of Standard (NBS) of 74.59% oxalic acid, and an assumed normal 12C/13C ratio of -25%o wrt PDB. The ages are listed to the nearest year, and then rounded to the nearest 10 years. This is customary to acknowledge of the uncertainty between radiocarbon years and calendar years (VALASTRO, 1993).

Radiocarbon analysis is not accurate for the comparison of younger soils, with dates only several hundred years old. Uncertainties in young paleosols are usually 200-300 years (two sigma) (SWINEHART, 1995) and hence a comparison of younger soils is rather difficult. SWINWHART (1995) did not include the comparison of older soils in his discussions, but these uncertainties probably also exist for older soils. In the present study, however, these uncertainties are insignificant, because older radiocarbon dates were more than several hundred years apart.

SWINEHART used a sample from the upper 5 cm of a horizon which yielded a humate date of 450 years B. P. with a one sigma (standard deviation) of ±80 years to explain that this actually represents a much larger age interval than 370 - 530 years. He claimed that for valid comparisons of young soils, two sigma need to be considered, which cover about 95 % of a normal distribution. This then really implied that with a 95% confidence the actual age of the 5 cm interval based on soil humates is between 290 - 610 years (450 ± 2 x 80 years). Comparing this age then to a sample dated at 650 years B. P. with a sigma of ±85 years (2 sigma of 85 years = ±170 years with a 95% confidence) ranging from 480 - 820 years B. P. causes problems, since it can not be stated which of the soils is younger or if they are the same age. Hence it needs to be concluded that these dates cannot be correlated if no other evidence is present to distinguish these young soils (SWINHART, 1996, personal comm.). This creates a challenge for the correlation of short-lived landscape stability and instability cycles, and must be considered when discussing the very young soils that are only 100 years apart in the Estelline dune field in chapter 6.

Fieldwork in an erosional landscape, such as the Rolling Plains of Texas, presents another problem, which can arise with radiocarbon dating. In the Rolling Plains of Texas whole soil sections from a horizon can be missing from a profile.

Two samples very close together in depth could turn out to be far apart in age just because a thick horizon in between these two soil samples was eroded. Generally, there is usually some field evidence to detect unconformities in eolian deposits, for example a deflation lag, a color, or a texture change. However, because local blowout events occur without any long-term climatic changes, missing parts of a horizon may be very much harder to detect. This must be considered at the outcrop on the Meyer's ranch, which is discussed in chapter 7.2.2. A radiocarbon sample was collected from a paleosol B_t -horizon underneath a deflation lag, which indicated some erosion of the younger part of this paleo -horizon.

3.2.3. Thin section analysis

The thin section analysis was performed at the University of Texas at Austin, in the Geology Department by Greg Thompson, who is the head of the petrographic thin section laboratory. As already discussed in chapter 1.1.2., a mineralogic comparison of samples from the different geologic source formations with some samples from a variety of eolian deposits could indicate if the distinction between different sand sources and the eolian deposits is possible.

Seven thin section samples were collected from the different geologic units in the study area, such as the Dockum Group, Permian, Ogallala and Black Water Draw formations. Samples from the eolian deposits included two dune sand samples from different dune fields for comparison purposes and included one additional sample from the Red Riverbed.

The first dune sand sample was collected in a sand sheet, far to the east of non-Permian geologic formations. It was therefore compared to a sample from the Permian (as the possible sand source) strata which was collected in the vicinity of the sand sheet close to the Salt Fork of the Brazos River. The second dune sample was collected in the Estelline dune field along the Prairie Dog Town Fork of the Red River further north. This sample was compared to a sample from the Red Riverbed collected adjacent to the dune field. The samples from the other geologic formations were collected along the escarpment close to a river to see if they can be compared to the river sample. A river generally carries material from the escarpment downstream. Samples were processed in the laboratory and mounted on glass with blue stain.

The thin section analysis was problematic, because not enough samples were processed. The resulting information, therefore, was not useful for drawing a distinction between the sand source areas and the different eolian deposits. A large amount of thin sections would have been required to distinguish between the origin of the sands. Without the analysis of additional thin sections from the different geologic units within a formation it is not possible to determine which geologic section within a formation contributed as a sand source to the various eolian deposits. However, as already explained in chapter 1.1.2., there is such a large variety of sand sources varying in age and location that this method did not seem feasible. Most likely sands from different sources have been already mixed during the different transport modes and thus a distinction with a thin section analysis seems quite impossible.

Another problem arises from SULTAN's (1964) study on variations in heavy minerals downstream along the Brazos River. His research suggested that the mineralogical components in different transport environments behave differently away from the source area This could lead to a different mineralogic composition of the sand grains in dune fields and sand sheets depending on the source area and transport distance. Hence information on mineralogy and sand sources can be quite complex in the Texas Rolling Plains.

As already mentioned in chapter 1.1.1. all the material from the different geologic formations of the study area ultimately originated in the Rocky Mountains and carries similar mineralogical imprints. Hence a distinction of sand sources based on mineralogical components was not possible with only seven samples.

3.2.4. Grain size distribution

Two different laboratories were used for the analysis of two different sets of grain size samples. The first set, thirty-seven samples from two transects, was processed at the University of Texas at Austin in the laboratory of the Bureau of Economic Geology according to the Bureau's protocol. The objective with these samples was to investigate two hypotheses on the formation of the Estelline dune field (Hall County), which will be further explained in chapter 6.

The samples in the Estelline dune field were taken along two transects, north-south and southwest-northeast, which were chosen according to seasonal wind directions. The directions were selected since they have the highest wind speeds during the drier season, coming from the south-west direction, and during the colder season coming from the north. Samples were collected from the luv, lee, top of the dunes, and interdune areas from the top 2 cm.

The sampling procedures in dune fields highly influence the results. Samples taken from different depth may reflect different wind events. The collection location on the luv, crest, lee or interdune area of a dune will reflect grain size accordingly, hence overall wind direction would not be reflected in these samples. Therefore, interpretations have to be prepared cautiously, and results obtained from this particular sampling technique should not be overemphasized.

A detailed description of the standard procedures from the protocol of the Bureau of Economy Geology is given in order to compare the procedures to the second set of grain size samples processed according to German DIN standards.

After field collection, samples were placed in an oven at 105^o C and removed after 24 hours. Close to 100 gm of dry weight were measured to assure a moisture-free basis. Each sample was then poured into a beaker, which was then filled with deionized water. The slurry was placed in a sonic machine to disintegrate the clay and sand fractions. At 50° C the sample was again dried overnight. The following sieves were used: 1,000; 500; 350; 250; 177; 125; and 62.5 µm.

For the analysis of clay and silt the Köhn'sche pipette method was used according to the Bureau of Economic Geology protocol. The pipette analysis depends on sampling a known volume at a particular depth and time. The timing is a function of the temperature of the slurry and is derived from Stoke's law:

$$T= \frac{9\mu L}{2(d_s-d_r)gm^2}$$

where,
T= time in sec
µ= dynamic viscosity dyne-sec/cm^2
L= settling distance in cm
d_s= density of sphere in gm/cm^3
d_r= density of fluid in gm/cm^3
g= acceleration due to gravity in cm/cm^2
r= radius of sphere in cm

The amount of 39.8 gm Na_2CO_3 and 178.6 gm of $Na(PO_3)_6$ soap solution was used per two liters. Fifty ml (5.46 gm) of this dispersing agent were added to 1,000 ml of each slurry. The temperature was measured and a pipette analysis was performed at certain depth intervals with the following pipette withdrawal times, according to each sample temperature in table 3.

Table 3. Depth intervals and withdrawal times for Köhn'sche pipette method at sample temperature

Size	Depth	Temperature		
		20° C	21°C	22°C
53µ	20 cm	<20 sec	<20 sec	<20 sec
4µ	5 cm	60 min 5 sec	59 min 23 sec	57 min 58 sec
2µ	5 cm	4 h 3 min	3 h 58 min	3 h 52 min

Beakers with the remaining 20 ml pipette liquid were dried in the oven at 105 ° C for at least 24 hours. Beakers were then removed and placed into a desiccator for one hour before the silt and clay content were weighed.

The other set of thirteen samples was collected from two soil profiles, the Swenson-Peacock and White River Reservoir sites, as discussed in chapters 7.2.1. and 7.2.3. Mark Waiblinger processed the samples at the Geographical Institut of the Julius Maximiliam University in Würzburg under the supervision of Dr. Barbara Sponholz. The German DIN 19683 standards for the wet sieving and Köhn‘sche pipette method for the clay/silt content analysis were used. The main objective of this analysis was to compare the grain sizes from different paleosols and modern soils at two different locations where radiocarbon samples were also collected.

The samples were prepared with H_2O_2 to eliminate organic material, because the samples consisted of sand from paleosols. Then, after DIN 19683 (page 2), 10 gm dried sample was mixed with 23 ml 0.4n $Na_4P_2O_7$ x 10 H_2O and soaked overnight. After about eight hours the sample was filled with destilled water up to a sample volume of 250 ml and then rotated for two hours, and then the sieving process was started.

For the Swenson-Peacock sand sheet, eight sieves were utilized instead of the standard four to assure a better understanding of the data in the sand fractions. The following sieves were used: 2,000; 1,000; 500; 315; 250; 200; 100; and 63 µm. The White River Reservoir samples were processed according to German DIN standards with only four sieves due to a miscommunication with the laboratory.

Eight soil samples were collected at the Swenson-Peacock sand sheet. Samples 1 - 8 were taken at 5, 20, 60, 145, 185, 200, 215, and 255 cm depth from the following horizons:

0- 10 cm	modern A - horizon, sand
10 -95 cm	modern weak B- horizon, brown colored sand
95 -180 cm	paleosol I. B_t - clay lamellas in white colored sands up to 10 cm thickness (Bänderbraunerde)
180- 200 cm	paleosol II. A_l - white sand, soft, bleached, homogenous, 7.5YR7/4
200- 205 cm	B_{tk}? Calcium carbonate rich, white, harder layer
205- 300 cm	paleosol II. B_t - loamy red sand, clay rich
300- 335 cm	softer, sandy clay, red gravel <3-5 mm, roots

Grain size distribution samples 1-5 were collected at the White River Reservoir at 5, 20, 50, 90, and 110 cm depth from these horizons:

0-10cm	sandy modern A-Horizon
10-40cm	modern, weakly developed B-horizon
40-75cm	paleosol I. or II. ? hard, reddish B_t -horizon, burnt (oxidized) roots
75-95cm	reddish horizon, softer
95-130cm	white-reddish hard layer, non-calcareous, water table?

Different sieve sizes are used in the German grain size analysis DIN standards (2,000; 1,000; 500; 315; 250; 200; 100; and 63 µm) than in the standard's of the Bureau of Economy Geology's protocol (1,000; 500; 350; 250; 177; 125; and 62.5 µm). Therefore, resulting size categories of the finer sand grains include different grain sizes, and the percentages of the amount in these categories cannot be readily compared. This needs to be considered in the interpretation of the data. The results are presented chapters 7.2.1. and 7.2.3 where the soil profiles are described and interpreted.

3.2.5. Grain shape analysis

A grain shape analysis was not performed for this research. As described, the study area has ample reworked sands in the different geologic formations, and an extensive analysis to distinguish between various source areas and rivers seems impossible by means of grain morphology. CAILLEUX (1952) suggested that there are usually differences in percentage of rounded and non shiny and semi-round shiny grains in a sample, which suggests the sequence of transportation mode through wind and water.

However, FRIEDMAN and SANDERS (1978) argued that studies from beach sands show that differences in rounding are often more a result of shape sorting, which they referred to as the most important single process in distinguishing between the roundness of particles (more so than abrasion). This discussion suggests that detailed geologic events that fall within the Quaternary history of the Rolling Plains of Texas are impossible to interpret by means of grain shape alone.

3.2.6. Scanning Electron Microscopy

Grain morphology and grain roughness of sand have been analyzed in past studies for the identification of a transport mode. (CAILLEUX, 1952; VISHER, 1969; SINDOWSKI, 1957). More recent studies are using the Scanning Electron Microscopy (SEM) for a distinction of Quaternary sands (MYCIELSKA-DOWGIALLO, 1992). SEM may be useful to identify eolian deposits from different source environments and deposition cycles (TCHAKERIAN, 1991), depending, however, on the complexity of the environment.

For this study Scanning Electron Microscopy was tested as a tool to distinguish between river and eolian sand. According to FRIEDMAN and SANDERS (1978) SEM provides a valuable tool to show the surface texture of sand particles with particular abrasion forms caused by wind and not by water. These abrasions cause pits and fractures in the grain, and sand saltation, where different grains hitting each other create V-shaped impressions. They suggested that the surfaces of dune sand grains show so-called upturned plates, arranged parallel to each other, with sharp but regular edges.

The SEM of the dune field and river samples was performed under the supervision of Dr. Robert Folk at the University of Texas at Austin Geology Department. Resolution was set in both samples to 30 KV x 200 (1 in = 100 µm), 30 KV x 5,000 (1 in = 5µm).

No upturned plates and V-shaped pits could be identified in the sand dune samples (Figure 17 and 18), probably because of the repeated reworking of the sand grains. The sand dune sample shows in general rounder grains, and a slight surface edging (Figure 18). The river sand (Figure 19) shows large impact depressions, smooth edges, solution and precipitation have resulted in some chemical pits. A distinction between river and dune sand and the mode of transportation was possible with these particular samples, but a distinction is highly dependent on the environment and deposition cycles (FRIEDMAN and SANDERS, 1978). For this study the geomorphic setting of the dune fields and sand sheets adjacent to rivers and on terraces has proven to be a more reliable and less expensive source of information for distinguishing between dune and river sands in the outcrop.

Figure 17. SEM of dune sands collected in the Rolling Plains of Texas.

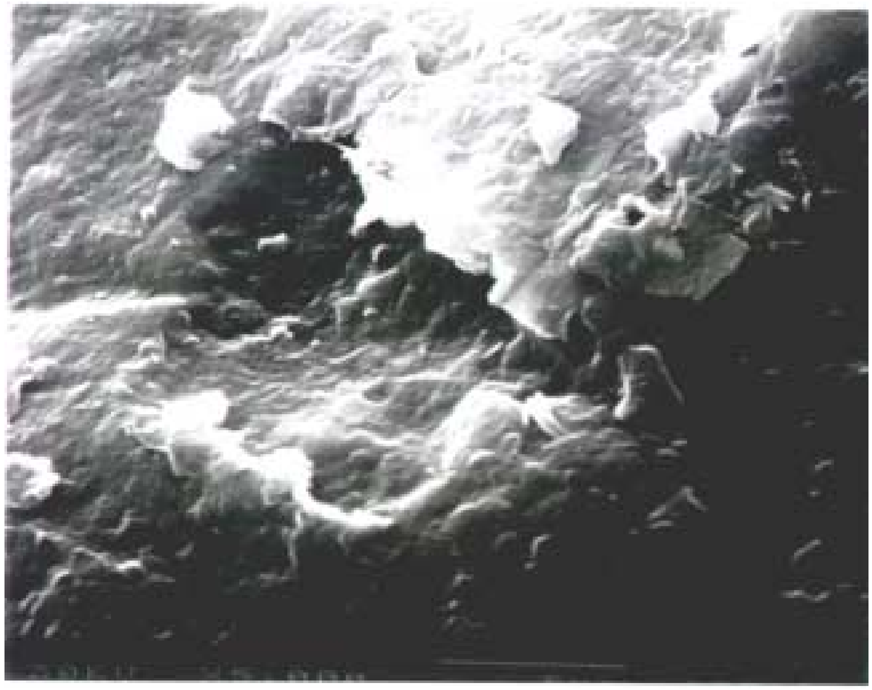


Figure 18. SEM of dune sands collected in the Rolling Plains of Texas (higher resolution).

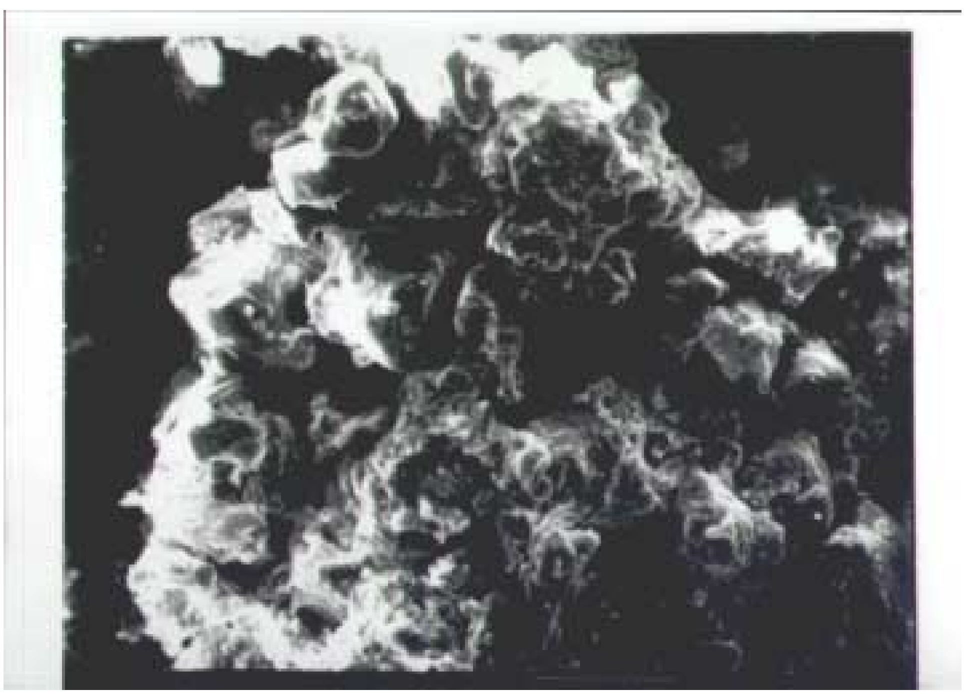


Figure 19. SEM of river sand collected in the Texas Rolling Plains.

Markings on the grain surface show the history of a given particle under the SEM. The grains' surface configuration becomes more complex as the number of transportation cycles increases. In addition, old markings can be obscured during the process of lithification, which involves many different chemical processes (FRIEDMAN and SANDERS, 1978).

This study focuses more on reactivation and stabilization cycles during a time frame and less on the spatial analysis of source areas and wind direction. As described, there are too many sand sources and transportation modes for sand in the Rolling Plains and Southern High Plains region, which are also closely interacting. Therefore sands and transportation mode are hard to distinguish by grain shape or grain surface analysis only, unless extensive research beyond the scope and finances of this work are performed.

3.3. Remote Sensing

LANDSAT imagery (1987) and aerial photography (various years and sites) were a valuable tool for this research. LANDSAT imagery (1978) and older aerial photography were used from the photo library of the Bureau of Economic Geology. The more recent aerial photography 1:40,000 was ordered from the U.S. Department of the Interior, Geological Survey, EROS Data Center from the National Aerial Photography Program (NAPP). The availability of photos ordered was determined prior to ordering by using a microfiche-based E.D.S indexing system, which is based on the 1:250,000 scale maps.

The LANDSAT image was used prior to the fieldwork for the identification of eolian deposits. The image was utilized to identify potential sites, the vegetation cover and land use on the sand sheets, and dune fields.

Geologists from the University of Texas at Austin mostly used LANDSAT and aerial photos in combination with spot-checked ground surveys to identify the geology of the region for mapping purposes at the 1:250,000 scale. A problem discovered in the study area was that the complex Pleistocene Lingos Formation, which spreads as a veneer across parts of the Rolling Plains, and Holocene eolian deposits have similar gray scale colors and vegetation cover, which look identical in satellite imagery and aerial photos. Due to this problem some mistakes in locating eolian deposits were discovered during fieldwork, where areas thought to be dune sand turned out to be Lingos gravel.

The locations of eolian deposits consequently had to be verified with the Tivoli sands from 1:24,000 soil surveys of the Soil Conservation Service (SCS) as was described in chapter 1.3. These Tivoli sands often include paleosols at greater depth. The photos used in the soil surveys were utilized to estimate the vegetation cover, and to identify roads for access possibilities. These aerial photos were a great help in finding sites, and potential locations for outcropping paleosols. They also aided in the identification of property boundaries, so that landowners, who own eolian deposits, could be identified during visits at the SCS offices.

Extensive aerial photography research was also performed for the Estelline dune field in Hall County. Aerial photos were utilized to identify dune relief types in the Estelline dune field. It was soon discovered that a dune classification was generally not possible because the sand deposit consists mostly of blow-out, reworked and deflated dunes as described above (Chapter 1.3.). The photos from the Estelline dune field were used in a time sequence to portray changes in stages of the vegetation cover during drought years. To that end the 1954's photos were compared with photos from the 1985 NAPP program.

Other photos taken near the town of Post were utilized to compare three decades in time to monitor the enlargement of so-called "shinnery motts", which are referred to as nebkhas in the European literature. These dune-like features can be found in agricultural utilized sandy fields. They originate in fields, where a topographic higher area with dense vegetation cannot be plowed and is surrounded. With the deflation from the fields, sand and silt accumulates around these shinnery oak patches, which further pronounces their form. Shinnery motts will be further described in chapter 5.1. Photos from the 1970s, 1980s, and 1990s decades at Soil Conservation Service Office in Post were used for the comparison of the shinnery motts.

Chapter 4. Cultural development of the study area

4.1. Indian cultures

The role of the cultural development of the area is an important factor in the process of recent desertification of the Rolling Plains and adjacent Southern High Plains of Texas. The main question arising is, if human impact, either pre-development or after the Anglo-American settlement of the area, caused irreparable destruction to the ecosystem and thus enhanced drought-related natural desertification processes.

Is it possible that some of the Paleoindian or Indian tribes roaming the area have caused desertification due to their life style? Or is the onset of severe desertification a response to the settlement of the white man? Have the Anglo-American settlers caused such severe alterations and disruptions in the ecosystem that eolian deposits were on a broad scale reactivated?

These questions need to be addressed prior to the further geologic investigation of the sand deposits, because human modifications of the landscape have historically played a leading role in desertification, and hence sand reactivation processes (HAGEDORN, et al., 1977; GLANTZ, 1977; MENSCHING and IBRAHIM, 1976; MENSCHING, 1990). The answer to these questions will help determine if these youngest reactivations are human or climatically induced, and will possibly point to the onset of these youngest reactivations. This chapter will explore the historic aspect of these questions and discuss the possible role of agriculture and ranching in the deflation processes.

There are several Paleoindian sites in the Rolling Plains and adjacent Southern High Plains (JOHNSON and HOLLIDAY, 1985), providing evidence for a chronology of Paleoindian occupation during the Holocene. Findings include projectiles and bison butchering sites.

Paleoindian impact on the environment was probably very low because of their small numbers, their transient lifestyle and their reliance on hunting and gathering for subsistence. Their occupational periods were not further investigated for this research, because it seems unlikely that Paleoindians substantially altered their environment and actively enhanced sand reactivations.

The occupational periods of Indians might have had a higher impact on the environment, since, as STUDER (1949) reported, some of these cultures had a sedentary lifestyle and practiced agriculture. He pointed out that the Panhandle Pueblo Indians built their houses along the Canadian River to utilize irrigation water; they made pottery, baskets, and lived on hunting and agriculture. However, small-scale farming without horses to loosen the soil probably did not cause severe sand reactivations on a broader scale.

It is more likely that natural decade-long dry-spells caused sand reactivations that drove the Pueblo Indians out of the drought-stricken region. STUDER (1949) reported of tree-ring evidence for droughts at the end of the 10th and 11th century and of a 24 year drought during the years 1276 - 1299. STUDER (1949) remarked that it is known that these settlements were abandoned and buried by the sands of the desert before the Spaniards came, probably referring to dune fields along the Canadian River. This Pueblo Indian culture was followed by a period in which nomadic tribes frequented the area.

The Texas Rolling Plains harbored two main transient Indian cultures during pre-horse time, the Apaches and the Comanches, each with a variety of tribes. Pre-horse Indians of the Southern Plains were probably Apaches, which were in the 19th century driven out by the Comanches (NEWCOMB, 1993:100). As suggested by NEWCOMB (1993) no sites were found of Apache Indians in the Texas Panhandle. However, he points out that Coronado on his expedition met one or maybe even two Apache tribes on his travels in 1541, the Querechos north of the Canadian River and the Teyas around the Brazos headwaters on the Southern High Plains.

19th century Indian horse cultures in the Texas Panhandle include the Kiowas and Kiowa Apaches to the north around the Canadian River, and Comanche tribes to the south. Small Comanche Indian tribes in a well-defined territory on the Southern High Plains included the Quahadi Band and the Wanderers Band to the east on the Rolling Plains, and the Peneteka Band further to the south (NEWCOMB, 1993).

Most of these tribes were non-sedentary and relied mainly on buffalo hunting, so they probably did not enhance natural desertification. As described in NEWCOMB (1993), hunting buffalo on the Plains pre-horse time was not easy, especially with the erratic and unpredictable pattern to which buffalo were roaming. Therefore, some tribes were also gatherers and fished. Others on the Plains choose a combination of small-scale gardening and bison hunting, which seemed to be the most successful combination of resources for pre-horse Plains Indians.

Hunting for Indians became more successful with the introduction of horses. Texas was the southern edge of the range of bison, especially the Southern High Plains, which hosted large herds of these animals. Grasses such as buffalo, grama, needle and bunch grasses supported a large number of game (NEWCOMB, 1993). Even though bison was their main food resource, Indians also hunted elk, black bear, antelope and deer, and sometimes even ate their own ponies during war times.

Coronado actively tried to convince the Comanche Indians to settle and farm in permanent villages (FLORES, 1991), but some tribes refused to live in the Arkansas pueblos and returned to hunting buffalo on the Rolling and High Plains. Since attempts failed to convince them to a sedentary life style, there is no evidence of larger scale farming in the area.

One of the dune fields in the study area shows signs of Indian, probably non-sedentary, occupation, as was discovered during fieldwork for this study. At the Estelline dune field in Hall County, Texas, Indian hunting and cooking artifacts were found, mainly small lithic points used to hunt birds and some cooking stones. Sites were generally highly disturbed, probably naturally by sand reactivation and also by individuals.

The landowner collected various lithic points himself as a young boy, usually after strong winds, which deflated some areas enough to expose new artifacts. He also referred to groups of boy scouts frequenting the dune field to collect artifacts during earlier decades. However, in recent years, legislation has been enacted to prevent the disturbance of Indian sites. No artifacts were discovered in other dune fields.

Since only two small lithic points were recovered within the dune field, it could not be determined which Indian tribe or possibly even Paleoindians left these artifacts behind. The lithic points were found close to areas with small gravel 1-2 mm in size and some small indeterminable bone fragments. Without further analysis it was theorized that spears with small lithic points attached were used to hunt birds. The gravel discovered was interpreted as having been among the birds' remains, because it is commonly known that birds often eat small gravel to help their digestive system.

Several cooking stones were also found close by within the lower part of a deflated dune. They were not found in any organized form, such as part of a hearth for example. Burnt discoloration of the outer skin of these well-rounded rocks suggested prior use as cooking stones, probably within the dune field, even though no other burnt material was discovered in the vicinity of the artifacts. There are two possibilities for the lack of a hearth close by. Cooking stones were either carried to sand dunes and never used, or more likely the original hearth area was disturbed by deflation and reworking of sands, leaving only the stones behind.

The various artifact locations in the Estelline dune field were not useful for an in-depth archaeology study because of the high degree of disturbance. However, the site was confirmed and registered with the Texas Archaeological Research Lab in Austin Texas at the Pickle Research Campus Facility.

Several lines of evidence suggest that there has been no large-scale farming by Indians in the Rolling Plains of Texas which could have damaged the vegetation and hence caused sand reactivations. If Indians alone did not cause major deflation, perhaps a combination of factors triggered sand reactivation. Drought appears to be one factor for naturally induced sand reactivations in the area, especially in pre-existing dune fields, since damaging the stabilizing vegetation cover in such eolian deposits quickly leads to sand deflation and reactivation.

Another of these contributing factors may have been larger herds of bison stampeding through sandy areas and possibly causing some of the dune movements. During the drier seasons, bison might have concentrated along streams in the search for water, which may have led to enough pressure on a small area to cause vegetation loss on dunes and resultant sand reactivation.

FLORES (1991) makes note of bison moving from the Southern High Plains into the Rolling Plains area during droughts in the search for water. There is a possibility that large herds of bison could have been involved in local sand reactivations by trampling sparse vegetation cover already reduced during drought, allowing wind to deflate sandy areas.

However, large herds of bison might have not had a high impact on the vegetation in areas used infrequently but at high intensity. This was concluded for this study with the help of a study by RICHARDSEN at the University of Texas on present day cow impact on vegetation cover as an analogy. Research by RICHARDSEN showed that generally large herds of cows do less harm to the vegetation if moved through an area at a high intensity, and in high numbers but at a short duration (D. Richardson, personal comm., 1998). This seems to indicate that large herds of cows moving through an area rather quickly are less damaging to the vegetation cover than livestock kept in confined areas, such as in current ranching practice. The vegetation is probably damaged more in the first case, but regenerates faster than in the case of constant occupation.

NEWCOMB (1993) also pointed out that bison do not have a pattern to their movement, which is erratic and unpredictable, supporting the idea that one area does not get frequently overused as in the case with modern ranching practice. Therefore it can be concluded that bison herds alone moving through an area probably did not trigger sand movement, however it is more likely to have occurred close to watering holes that were highly frequented. However there is a possibility for sand reactivations that were triggered by bison in combination with other vegetation damaging factors, such as droughts or possibly fires. Today there are probably also other factors involved in reactivation processes of sand dunes, such as the degree of overgrazing, and today's mechanical re-seeding practice with alfalfa or other forage grasses, some of which are not as drought resistant as natural grasses.

It was possible for this research to observe closely as a case study how sand dunes behaved after a wild fire rampaged through a dune field near Estelline. These dunes are ranched by a farmer who keeps livestock on them, however, who occasionally reduces their number intentionally during droughts to prevent sand reactivations caused by cattle overgrazing the dune field.

An activity contributing to sand reactivations in this particular dune field, however, is the use of motorcycle three-wheelers. These motorcycles are often used to help care for the cattle, hence this activity is quite common on these dunes and can severely enhance sand reactivations by damaging the vegetation cover, especially during times when the vegetation is also recovering from a fire damage.

A fire broke out in this particular dune field after being caused by a lightning strike during July in 1994 (Tom Cope, written comm.). The farmer re-seeded the burnt area quickly after the fire, probably enhancing vegetation growth and preventing some of the reactivation. He reported that cows generally prefer young sprouts growing on previously burnt areas. Therefore cows frequent these areas more often after a fire. However, he did not observe any vegetation loss from cows favoring sprouting areas. Vegetation was fairly quickly restored and the area did not experience any dune reactivations after the fire. Generally during normally wet years the dunes would have also re-vegetated without the having been re-seeded. This particular summer and fall were not part of an extensive drought cycle, with rain missing to restore the vegetation.

This case study could suggest that in the past dunes could have been easily reactivated during a severe decade-long drought. Fires occurred more frequently in combination with drought conditions, where bison could have been more readily attracted to vegetation re-growth in previously burnt areas. All three factors combined may therefore have led to some blowouts and small reactivations in dune fields during the past when bison were still frequenting the Rolling Plains. The same factors are active today, large cow herds mostly replaced the bison and dune reactivations are additionally enhanced by overgrazing and the usage of non drought-resistant forage grasses as already explained above.

In conclusion, pre-cultural utilization of the Texas Rolling Plains alone most likely did not cause sand deposits to reactivate. Large-scale climatic changes or short-term decade-long droughts were probably always the main factor in sand reactivation. Still, the question remains if the cultural development of the American Frontier caused any enhanced reactivation of the eolian deposits in the Texas Rolling Plains and adjacent High Plains.

4.2. White settlers

With the Anglo-American settlement of the Rolling Plains of Texas, severe changes to the landscape took place, altering it forever. Cities grew steadily larger and with the growing number of people flooding the area, agriculture slowly replaced some of the smaller ranching areas during the early part of the 20th century.

The city of Post, founded by C.W. Post, was chosen as an extraordinary example of the cultural development of the area. The city’s history shows how the rugged terrain was utilized, water shortages were overcome, and how inhabitants adapted to their environment with agricultural practices to compensate for climatic misfits and variations. It also illustrates the cause of irreparable changes to the land.

4.2.1. History of settlement

The onset of settlement occurred when the Plains became more suitable for Anglo-American settlement around 1875, probably fostered mainly by railroad lines crossing through the prairies, such as the Fort Worth to Denver City Railroad during 1886-1888 (MORRIS, 1997). Several forts were established to uphold law and order in the Texas Panhandle and also to keep Indian tribes out of the area, making it even more attractive for settlers (HALEY, 1949).

Early settlers were mainly ranchers, herding sheep and cattle trying to compete with large numbers of buffalo for forage. HALEY (1949) provides a comprehensive description of early life in the Rolling and Southern High Plains region. He reported that Col. Charles Goodnight, one of the first settlers, established a home ranch in 1876 at the upper Red River about 250 miles away from any railroad and hence supplies.

Goodnight chose a spacious park-like area in the Palo Duro Canyon with a spring flowing nearby to build a house, corrals and a picket smoke house. Generally buffalo did not like to feed in gorges or canyons, hence food and water were plentiful. Other cattleman joining in were Mark Huselby in Wheeler County and Tom Bugbee in Hutchinson County (STUDER, 1949). With additional cattle and sheep herds being moved into the area, buffalo was now the competing animal for prairie grass and water. This contributed to the slaughter of the bison, which almost completely eradicated them by the early 20th century.

Settlers established homesteads on ranchland merely by unwritten laws until the Texas Rangers arrived during this time. The Rangers brought law and order to the unprotected settlers. The Panhandle Stock Organization was formally organized to protect ranchers from thieves during 1881 in Mobeetie. A $250 fine for cattle rustling was established (HALEY, 1949), which promoted safety for cattle ranchers and probably attracted more and more settlers.

MORRIS (1997) noted that by 1900 only 35,000 settlers had moved to the area. The larger wave of people arrived when colonization firms broke up unprofitable ranches in an attempt to mass market cheap land. Ranch land was then resold for agricultural utilization, and the High Plains were transformed into one of the most productive areas in the United States. In 1906 prospective farmland buyers poured by train into the area. The population of the area increased to 134,885 by 1910, and approximately 58 new towns were founded between 1902-1913.

C.W. Post's city was chosen as an example for the history of the adaptation of settlers to the harsh conditions in the area and their changes to the landscape. Post is a little town about 60 km southeast of Lubbock in the Rolling Plains of Texas (Fig. 5). The town was founded in 1907 by C.W. Post, who wanted to build a hotel in the rough Prairie land with no transportation connection or access to water and still surrounded by Indians (EAVES, 1943). This was viewed by many of his contemporary fellows as impossible, even almost as one of Post's dreams. EAVES (1943) described in great detail the history of Post city and it's growth in an area unfit for any kind of cultural development.

The city was originally planned for the Southern High Plains, but was moved a few miles down the escarpment into the Rolling Plains to secure the county seat of Garza county. A city was only allowed to be 6.4 km from the center of the county to be considered for the county seat (EAVES, 1943).

Post spent most of his energy and money building this city on the prairie without furnishing any transportation to or from the area. He planned little individual 'ready-built' houses, with their own vegetable gardens, fruit orchards, ranch land and fields. The city grew quickly, by 1920, 600 families owned their own houses. The water consumption grew steadily with increasing demand (EAVES, 1943).

The move of the city from the High Plains to the Rolling Plains created substantial problems for the water supply of Post city. The Permian formation has only limited water, often in great depth and of poor quality compared to the High Plains Ogallala Aquifer. EAVES (1943) reported that C.W. Post installed a water tank between Post city and the Caprock Escarpment to divert water from the Ogallala Aquifer to the city to overcome this problem. A two cents per barrel price for water was agreed on in 1909. From then on, for the first time water had to be paid for by the settlers. Despite Post's efforts to secure the water resources to the area, the city experienced an acute water shortage during the year of 1917, triggered by several dry years with only limited rainfall. Several attempts to produce rain with the explosion of dynamite to trigger clouds and rainfall failed (EAVES, 1943).

Forced by the lack of water and the realization of the human inability to influence climatic conditions, Post probably realized early on that only dry-land farming would be appropriate to overcome the harsh weather conditions of the Rolling Plains of Texas. As described in detail by EAVES (1943), Post built several experimental farms near Post city and investigated different agricultural techniques for growing crops, fruits, and vegetables. He tried to find varieties most adapted to the climate and soil of the region. Post researched to find the best conditions to grow crops most effectively with the harsh weather conditions and soil constraints of the Rolling Plains of Texas.

EAVES (1943) recorded Post's discovery that besides the wild rabbit, sandstorms were one of the worst enemies for growing young trees and other vulnerable sprouts. Post suggested that fruit trees should generally be planted at the end of February or beginning of March, but during the spring season there were often sandstorms with high wind speeds, which can kill young tree seedlings. Therefore he had fences built around the gardens, and each individual tree was wrapped with tarp and wire to protect it against potential harm. In addition, hedges were planted to the west of the orchards to protect them from wind damage.

However, EAVES (1943) noted that after the houses were sold to individual settlers most of these hedges and fruit orchards were not watered, since water was a costly resource in the area. Most of them dried up and the land was laid barren to the elements again. Remnants of orchards from the early 20th century are still visible today near the city of Post (Figure 20).

Figure 20. Orchard remnants show intense cultivation initiated by C.W. Post near Post, Texas at the turn of the century.

With the growing number of settlers in an area essentially not suitable for sustaining a large population, agriculture and ranching led to drastic changes in the environment. Adaptations were made without considering future impact. Research was limited to enhance the productivity, but ignored preventative measures to lessen the impact on the environment. Soil erosion took on disastrous dimensions during the dust bowl era and brought with it a great concern about environmental impact; however, it was much too late.

4.2.2. The role of agriculture and ranching in the process of sand reactivation

Agriculture and ranching changed the landscape profoundly and made it more vulnerable to natural drought-related deflation and desertification processes. New agricultural techniques modified the soil density, making it more susceptible to wind erosion processes. EAVES (1943) claimed that the concept of dry-land farming was introduced first in this region. EAVES (1943) remarked that instead of the traditional 21 cm, now 41 cm were plowed to collect more moisture in the loose top. With the same reasoning, fields were plowed again right after the harvest to assure maximum soil moisture collection.

These practices increased the soil erosion tremendously during the dry winter month when fronts accompanied by high winds frequent the area. Seedlings were generally planted after the spring storms to reduce the sand saltation impact and to ensure they did not get completely covered with soil. C.W. Post also introduced the idea of eliminating the corn stubs completely from the fields. Cows would otherwise walk through the fields trying to eat the corn stubs, further compacting the soil and hence reducing the water storage capacity (EAVES, 1943).

All these procedures were performed to increase the water storage capacity of the soil, and to produce a decent harvest without using expensive irrigation water. However, the down side of all these measures was that they led to increased erosion of the soil, which was loosened and exposed mainly during the dry and windy season. This probably led to intense soil deflation during drought years.

In the early years of agriculture, however, nobody seemed concerned about soil erosion and the deflation of the A-horizon, which is generally followed by a decrease in the overall productivity of the soil. However, this changed when an extensive drought during the 1930s, combined with unsound farming practices and new mechanical equipment, brought on the ‘dust bowl era’. With intensive spring storms and a vegetation cover damaged by drought, large clouds of dust were blown into the air (Figure 21), greatly reducing the productivity of the soil. No preventative actions were undertaken to reduce the impact of the drought, and settlers had to watch their livelihood being blown away. The dust-bowl era, which was very hard on settlers, created an intense awareness of soil erosion, and to the loss of fertility and productivity erosion can cause.

Figure 21. Sandstorm intensely reducing the fertility and productivity of the soil near Dahlhart, Texas during 1930s.

Today, research is performed by universities and government agencies to reduce agricultural impact on the environment. Farmers are kept informed by the personnel from the Soil Conservation Agencies about how to reduce soil erosion by using different agricultural techniques and crop varieties.

A recent study on soil erosion by LEE et al. (1994: 442) from Texas Tech University, has revealed that some soils are more susceptible to deflation than others, especially when farmed. Soil erosion is highly dependent on the clay content in the A-horizon. However, differences in land use and farming techniques can either reduce or enhance the erosion of soils greatly. Extremely sandy soils (more than 90% sand) are not used as farmland and are used mostly for ranching, unless there is a great amount of groundwater easily accessible at shallow depth (LEE et al., 1994).

Ranching altered the biodiversity in the region drastically. With the introduction of cows to the area, buffalo and prairie dogs, both thought to be the livestock's forage competitors, were mostly eradicated during the late 19th and early 20th centuries. However, prairie dogs enhance the diversity of the prairie ecosystem by loosening and fertilizing the soil around their towns. They provide shelter with their burrows for a variety of animals. The eradication of prairie dogs from an area has a profound impact on the balance of the ecosystem in the region (WILLIAMS, 1992).

Prairie dogs, a type of ground squirrel, were considered a pest by ranchers, because in prairie dog tunnels cows can trip and break their legs (FEDARKO, 1997). Prairie dogs can also carry the bubonic plague. One prairie dog town in the Texas Panhandle at one time stretched along 400 km and 160 km wide and consisted of 400 million prairie dogs. In 1960, only two percent of the original range of these animals were left (HOLMES, 1996).

Prairie dogs were shot, poisoned, flooded, bombed and killed with germ agents. Most ranchers thought that prairie dogs would compete with cows for food sources; however, a study has shown that the reduction in forage is only 4 - 8 % (HOLMES, 1996). Recent studies by the U.S. Forest Service as reported by WILLIAMS (1992) have also shown that the plant production is higher in areas which were occupied by prairie dogs and cows rather than in areas stocked with cows alone.

Cows also prefer the more nutritious tender new growth stimulated by the prairie dogs and a study has shown that bison actually gain more weight feeding in prairie dog towns (HOLMES, 1996). Most ranchers thought that prairie dogs cause overgrazing by manually clipping grass short around their towns. However, prairie dogs are a symptom of overgrazing since they multiply during droughts, which are usually accompanied by overgrazing (WILLIAMS, 1996). They generally enrich the variety of natural prairie vegetation.

The eradication of prairie dogs led to a reduction in natural tall-grass prairie species and in combination with the ranching environment, overgrazing practices, and suppressed fires, which most likely enabled mesquite to overpopulate the area. Today mesquite is either burnt, poisoned or manually removed from most ranchland since cows do not eat it and mequite competes with grass for water. Uprooting mesquite can loosen the soil, making it more vulnerable to wind erosion.

Overall, it can be concluded that ranching intensely decimated the variety of species in the Texas Panhandle by habitat destruction. In fact ranching completely altered the tall-grass prairie ecosystem, probably causing the ecosystem to be much more susceptible to droughts and deflation. This process was enhanced by the partitioning of the ranchland with fences. With livestock concentrated in certain areas, overstocking and overgrazing can easily occur especially during droughts. This process lead to enhanced soil erosion and deflation, since mostly sandy areas, unsuitable for farming, are ranched. Chapter 5 will investigate human-induced deflation and sand reactivation caused by ranching and agricultural practices, presenting evidence from field research.

Chapter 5. Youngest eolian episodes

The unique cultural development of the study area during the early part of this century, especially in the vicinity of the city of Post, might have triggered some of the youngest eolian episodes during the Holocene. Agricultural practices such as dry-land farming in combination with short-lived drought events left vast sandy areas of the region barren.

Some of the sandy areas are currently used for ranching. Some sandy soils, such as the Tivoli, are too erodable for agricultural usage, hence ranchers raise livestock on the land. The number of cattle is often insufficiently reduced during drought years (Tom Cope, pers. comm.) causing extreme stress on the vegetation cover and ultimately extensive damage to the topsoil, thereby increasing soil erosion in the region.

The factors described above are fostered by current geomorphologic processes, such as wind erosion and the occasional drought cycles as described in the first chapter. These combined factors produce enough material for sand reactivations during the present time, especially around areas with high intensity agriculture such as in the close vicinity of towns and on fertile river terraces.

5.1. Description and definition of fence-line-dunes and “shinnery motts”

Sand resulting from the ongoing deflation and erosion of barren fields or overgrazed ranch land has been collecting along the field edges. There are very young, elongated dune-like features up to 10 m high piled up along field edges in the area around the city of Post. These dune-like features can be identified on topographic USGS Quadrangle maps at a scale of 1:24,000 and lie generally on the north and/or western edges of the fields. This indicates a southwestern wind direction for their origin, which also matches the current local wind pattern during the drier part of the year.

A further investigation of these dune-like features revealed one or more barbed wired fences inside their dune structure, hence for this research they will be referred to as fence-line dunes. Considering the cultural development of the area, where much of the original protecting vegetation cover was destroyed, new agricultural practices such as dry-land farming, and new mechanical farming equipment, it seems likely that sand for these fence-line dunes originated in barren fields close by.

The sandy soil was deflated when fields were without protective vegetation cover, and over time this material collected along the fences and buried them underneath (Figure 22). Plowing is fostering the process of deflation by loosening material for erosion and pushing it mechanically into a pile along the edge of the field close to the fence. This process combined with vegetation that sometimes grows underneath fence lines probably led to the start of the sand trapping (Figure

23). Some of these fence-line dunes have more than one fence within, since whenever one fence was buried the farmer just built a second one on top of the sand pile.

Figure 22. A fence-line dune with buried barbed wire fence post near Post, Texas. These developed as part of the most recent phase of sand reactivation linked to the area's cultural development.

Figure 23. Plowing results in soil erosion and a mechanical compacting of sand along the fence line.

There is generally only a sparse vegetation cover on these fence-line dunes, probably because of the very young nature of these dune-like structures. Soil profiles show only very weak or no A-horizons, and some profiles still have extensive sedimentary structures, which indicate a very young sedimentation of these deposits.

Another form of pseudo-dune, locally called “shinnery motts”, as already described in chapter 3.3, can be found in agriculturally utilized fields. They originate where topographic highs or heavily vegetated areas within these fields cannot be plowed with the tractor (Victor Ashley, pers. comm.). Farmers attempting to maximize the amount of productive land tend to plow very close to these shinnery oak patches. Therefore sandy soil from the field was mechanically piled up around these features. This process pronounced their shape even further by lowering the ground around them, and they grew through time. Wind erosion and the natural trapping of sand in the shinnery oak vegetation of these topographically higher patches further contributed to their size.

This is evidence from aerial photography that was studied at the Soil Conservation Office in Post. Aerial photos from three decades starting in 1970 show fence-line dunes and shinnery motts. In 1970 the shape of these features was very much smaller and less pronounced than in pictures from 1980 and 1991, 10 and 21 years later. These features probably grew more pronounced in the last three decades because of heavier agricultural equipment and an increase in the intensity of farming on these fields. Unfortunately, photos were not available for reproduction and no photos were available before 1970.

If the amount of deflated material from fields actually created up to 10 m high pseudo-dunes, such as shinnery motts or fence-line dunes, then how much of the top soil has already been eroded? Is most of the A-horizon gone and has the soil already lost it's productivity?

5.1.2. Evidence of erosion to the bedrock

The A-horizon of the sandy Tivoli soil mapped in parts of the study area is on the average between 10-30 cm deep. The material is young and very loose, consisting mostly of sand fractions with little humic material. The B-horizon is also described as a loose soil horizon (BLAKLEY, 1967). This type of soil can be easily deflated, especially when utilized agriculturally under the above-described conditions favorable for erosion.

In the area around the city of Post some associated fields are in parts eroded down to the C-horizon, a Triassic sandstone of the Dockum Group (Figure 24). The question then arises of how much of the soil was lost overall and to what average depth in the horizon. This is especially interesting in the area around Post, which has the most favorable conditions for deflation and numerous fence-line dunes.

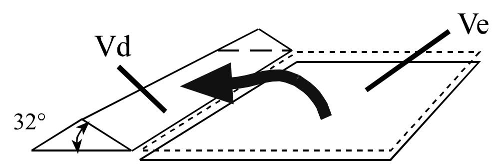
Figure 24. Soil erosion near Post, Texas. A field deflated down to the underlying sandstone.

5.1.3. The modern maximum acceptable loss rate of topsoil

The tolerated upper limit for soil erosion set by the Soil Conservation Agencies is 11.2 t ha^{-1} y^{-1} (Victor Ashley, pers. comm.). At a measured soil density of 1.3 gm/cm^3, this translates to an erosion rate of 0.86 mm/year. Practically, these values could be very different during different years and in different parts of the study area depending on a variety of factors, such as soil type, grain size, agricultural practices and equipment, vegetation cover, climatic pattern, and the depth to the water table.

The 0.86 mm/year erosion rate applied to a one square kilometer area over the 100 year history of farming practices around the city of Post, could actually create a fence-line dune of 22.3 m width, 6.9 m height on 1,000 m length, if 90% of this material had collected (Figure 25). This fictitious dune dimension is much higher than the average dimensions of fence-line dunes in the area, probably because less than 90% of the material accumulated along the fences or not all areas were blown out as severely.

Modern acceptable loss rate of topsoil: 11.2 metric tons per hectare per year (M)



Ve = M / r At soil density r = 1.3 gr/cm^3 --->
Ve = 86,000 m^3 from each sq. km (over 100 years)

Vd = 0.5 h * w * 1000 m and 'angle of repose'
tan32° = h / 0.5 w (idealized triangular dune)

If 90% collected along fences
Vd = Ve * 0.9 = 156.2 w^2 ---> w = 22.3 m, h = 6.9 m

Figure 25. Calculations of sand dune heights and widths based on the tolerated upper limit for soil erosion set by the Soil Conservation Agencies as 11.2 t ha^{-1} y^{-1} at a measured soil density of 1.3 gm/cm^3, calculating to an erosion rate of 0.86 mm per year.

The above calculation assumes an angle of repose of 32°, typical for dunes without vegetation in a semi-arid environment. This also implies that vegetated fence-line dunes could be even taller, since the angle of repose would be higher in a dune with stabilizing vegetation cover. This could create a steeper dune slipface and hence a higher dune.

5.1.4. Windham fence-line dune description

A more closely investigated fence-line dune is located approximately 10 km north of the city of Post at FM Road 651 on Donald Windham's property in Garza County, Texas. The dune was utilized for sand mining and revealed a soil profile of 345 cm depth. The sandy profile describes as follows:

1- 2 cm	no A-horizon, top layer of mulch overlaying sand
2 - 78 cm	sedimentary structures, slightly darker
78 - 120 cm	light colored sand, little reddish, colluvium?
120- 255 cm	ash-colored horizon
255 - 270 cm	buried A - horizon, with plant remains
270 - 290 cm	leached sand horizon, hard cemented
290 - 310 cm	B-Horizon, brown sand
310 - 345 cm	C-horizon, red clay

This particular fence-line dune profile lacks soil in the upper 120 cm pointing to a very recent formation. The profile also revealed at least one buried soil (Figure 26), which appeared about 1 m above today's land surface, showing a humic A-horizon and a brownish B-horizon. The darker upper part has a discoloration due to the high soil moisture content after a rain, also referred to as the wetting front.

Figure 26. Profile of a commercially exploited dune near Post, Texas. The profile shows the original landsurface as a buried paleosol. Today's landscape is approximately 1 m below the paleosol.

This paleosol was interpreted as the original land surface on top of which the dune was once deposited along a fence line before all the material on the field was eroded. This buried fence is visible at another location along the length of the dune (Figure 27), where cows have trampled and eroded parts of the dune.

Figure 27. Barbed wire fence inside the Windham dune, visible through the erosion of cow trampling.

Generally A-horizons of paleosols in sandy material are rarely preserved, since a change to drier climatic conditions will lead first to erosion of the top soil due to the loss of the protecting vegetation cover. However, in the case of fence-line dune development, a natural drought accompanied by vegetation loss was probably simulated by plowing practices accompanied by windy conditions on days with no rainfall. This would actually leave the vegetation on fence-line dunes intact prior to deposition, hence preserving the A-horizon while being buried.

The buried A-horizon in the Windham fence-line dune soil profile appeared approximately one meter above the present land surface. This soil loss of about one meter calculates to a 11 mm per year erosion rate since the beginning of the 20th century, when agricultural practices influenced the landscape. The acceptable soil loss rate value set by the Soil Conservation agency of about 11.2 t ha^{-1} y^{-1} , translates only to a soil loss rate of 0.86 mm per year. Comparing these two values, 11 mm per year is 13 times higher than the acceptable soil loss rate, which translates to quite an extra amount of lost material on agricultural utilized fields.

The approximated soil loss at the adjacent field to the Windham outcrop also compares to similar values reported by MACHENBERG (1986) from a location north of Post in the northern part of the Rolling Plains. She documented 0.8 m of soil loss since the 1920s. A rate of approximately 10 mm per year, very similar to values found in this research at the Windham locale.

Since both of these values are an average over time, it can be assumed that in the last 100 years these values included phases with lower and also much higher erosion rates. The higher rates probably occurred during the dust bowl era of the 1930s and during the drought during the 1950s, which led to extensive erosion throughout the Texas Rolling Plains.

One way of measuring the variations in sedimentation rates through periods of slower and higher soil loss during the past 100 years would be to utilize barbed wire inside the fence-line dunes. This technique can work especially well if several barbed wire fences are buried within one dune. Different barbed wire varieties were used throughout the beginning of the century. THURGOOD (1979) documented 487 different types of barbed wire with a sketch and the manufacturing or patent date.

For this research it did not seem necessary to age-date on such a fine-tuned scale within the dune core itself, since soil loss rates were most likely higher during the two droughts of this century. Overall, it was important to find the origin and source material of these fence-line dunes and to determine that they are features related to the anthropogenic development of the area.

5.2. Other dunes with very young buried horizons

5.2.1. Site description

The site is located north of road FM 1321 on Bill Gething's property in Gray County, Texas. The soil profile is located within a larger dune field at a deflated dune. An outcrop along FM 1321 on the north side of Gething's property shows older sediments exposed. Beneath the uppermost younger dune sand, older deposits, probably Pleistocene and Tertiary of age, are exposed by a road cut. Lower horizons within this outcrop have calcrete nodules and larger gravel.

The dune field is primarily used for oil exploration and ranching and has a sparse vegetation cover. The investigated profile is located in the middle of the dune field in a deflated dune area. It shows a very young and immature A-horizon, with only a slight gray-brown discoloration, buried underneath very light-colored sand. This points to an older stable land surface that probably experienced only a short period of stability associated with soil development probably only several hundred years ago (Figure 28).

Figure 28. This picture shows a very young and immature A-horizon at the Gething's property near FM 1321. The profile has only a slight gray-brown discoloration, buried underneath very light colored sand. This points to an older land surface that experienced probably only a short period of stability associated with a weak soil development.

At this site the cause of sand reactivation was not easily determined as in the case of fence-line dunes near the city of Post, where agricultural practices on adjacent fields caused much of the deflation and dune accumulations. Causative factors at this site could be short-term droughts with reduced vegetation cover and a possibly lower water table, which can cause sand blow-outs (Figure 29).

Figure 29. Short-term droughts and possibly ranching practices during this century can cause blowouts, which causes vegetation loss and hence sand reactivation.

As can be observed in present-day processes within modern dune fields of the study area, the A -horizon was probably eroded and blown out in some places within the dune field, where the vegetation was sparse. However in other places where soil moisture was higher and vegetation richer, reactivated sand probably accumulated and buried the weakly developed A -horizon.

The A-horizon in the dune setting described above did not laterally extend enough and was too weakly developed to be radiocarbon-dated. However, a visual comparison with other soils of this immaturity level in a similar climatic region and sand dune setting was attempted.

5.2.2. Comparison with outcrops in the Nebraska Sand Hills and Canada

The Nebraska Sand Hills have long been thought to be Pleistocene of age. However, SWINEHART and AHLBRANDT presented in more recent work that the Nebraska Sand Hills are only about 7,000 B. P. years old, suggesting major sand reactivation periods for the last 7,000 years B. P. (AHLBRANDT, et al. (1983).

The following picture (Figure 30) was taken during a Geological Society of America field trip in the Nebraska Sand Hills and shows a flat-bedded eolian sand outcrop of 45 m thickness, which was laterally cut by the Middle Loup River east of Seneca, at the Red Ranch locale. MAY et al., suggested that the lower parts are composed of Pliocene sands, probably dated at about 2.5 and 2 million years old. A sample was taken by STOKES (1993, pers. comm., cited in MAY et al., 1995) from the late Holocene dune sand overlying the Pliocene sands and resulted in a preliminary optically stimulated luminescence (OSL) date of about 3,000 years. The next picture (Figure 31) is an upward extension of the same outcrop showing the highest part of the late Holocene dune sand, which revealed very young and immature soils. The upper soil has been dated with two different samples at 220± 90 and 220± 60 years B. P. and the lower one at 450± 90 and 770± 90 years B. P. (Figure 32) (MAY et al., 1995).

Figure 30. Outcrop at the Red Ranch in the Nebraska Sand Hills. The lower parts are composed of Pliocene sands. A sample with an OSL date of 3,000 years was taken from the part above the Pliocene sands (MAY et al., 1995).

Figure 31. Upward extension of the outcrop at the Red Ranch locale showing the highest part, which revealed very young and immature soils, the upper one dating with two samples at 220± 90 and 220± 60 years B. P. and the lower one at 770± 90 and 450± 90 years B. P.(MAY et al., 1995).

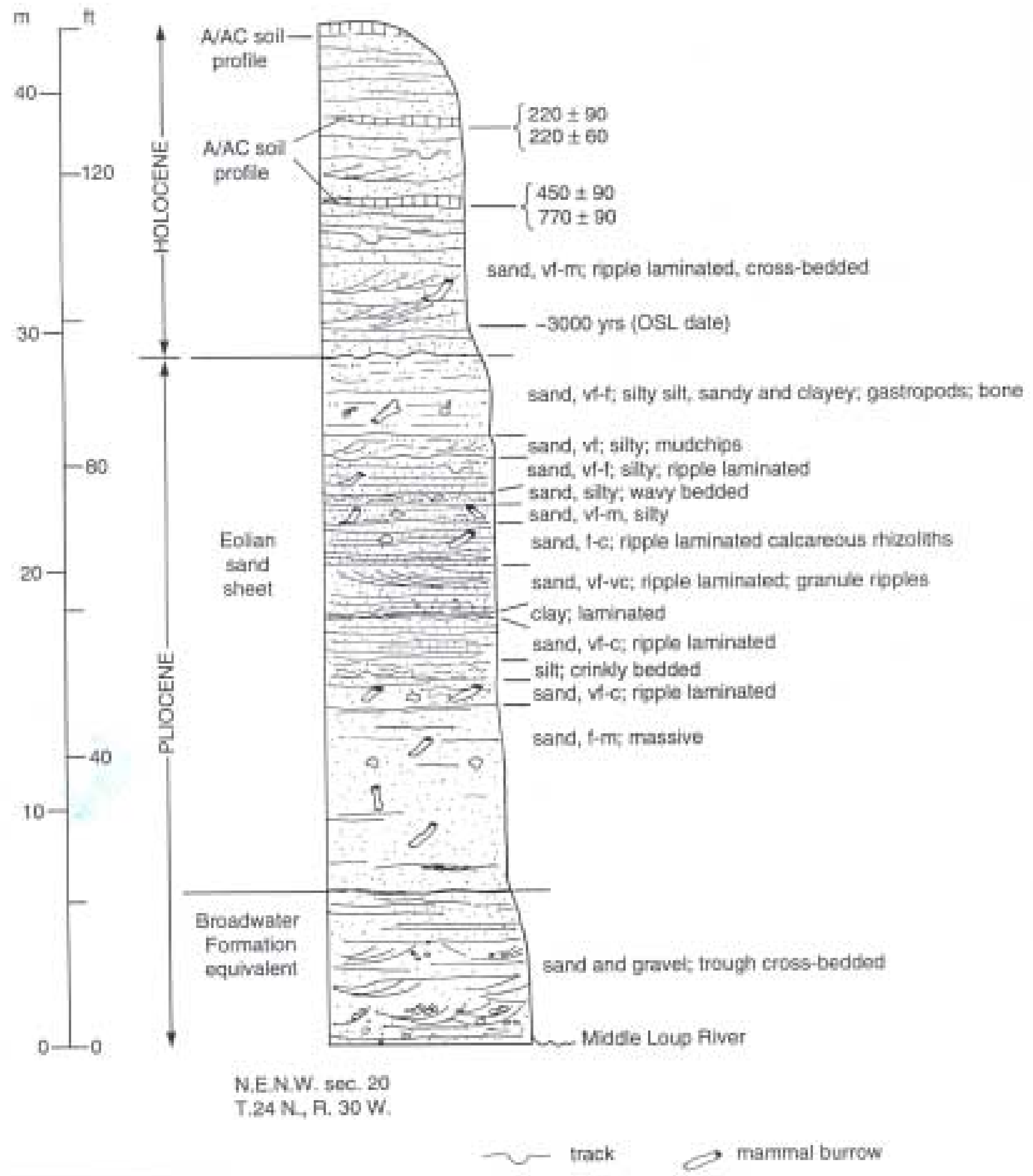


Figure 32. Stratigraphic section at the Red River locale, Nebraska Sand Hills. Comparison with very immature soils at Gething's property in the Rolling Plains of Texas (modified after MAY et al., 1995).

Even though these are very young dates for a soil development phase, MUHS and colleagues (MUHS et al., 1995), as presented in chapter 1, believe that sands are much older in the Nebraska Sand Hills because the mineralogy shows that sands are feldspar-depleted and quartz-enriched. This could mean either that sands already underwent soil development phases prior to reactivation, where feldspars are chemically altered and degraded, or that during the process of saltation feldspar would be mechanically destroyed. Both solutions suggest reworking of possibly older sands.

No mineralogy samples were taken at Gething's property site. However, the setting seems very much similar to the Red River locale, where older formations are overlain by younger buried soils possibly pointing towards younger reactivations of older sediments.

Recent research in the semiarid Great Sand Hills region of Sakatchewan in Canada also revealed very young sand dune reactivations (WOLFE et al., 1995). This region is also known as the Palliser Triangle. Twenty percent of the dunes of the western Prairie Provinces are located in this region and it also showed evidence of dune activity in the past 200 years. These dunes were reactivated from older glaciofluvial, glaciolacustrine, and deltaic sediments, which were deposited with the retreat of the Laurentide ice sheet.

WOLFE et al, (1995) reports that almost all of these dunes in the region are presently stabilized, except for a few parabolic dunes, some small sand sheets, and blowouts, which are currently active. Their research is trying to determine the cause of these recent dune activities with the aid of climate indices of temperature and precipitation. The researched period covers responses to dune activity over the past 50 years. Results from WOLFE et al. (1995) show that in the past 50 years, dune activity resulted from precipitation and temperature variations. The overall trend in the past 50 years seems to be toward stabilization of these active dunes. Their trends and results seem to correspond with a comparison of aerial photography from 1954 (a significant drought) and 1985 of the Estelline dune field in the Rolling Plains, which shows a trend to re-vegetation of some of the active dune patches.

In WOLFE et al. (1995) eolian deposits were additionally optically dated to gain chronological control. Five of these dates revealed very young sand reactivations, all younger than 200 years A. D.; however, no soils were dated with these samples. Seven other samples were part of various mid-Holocene soil development phases (WOLFE et al., 1995). The authors suggest that dunes have recently been active during the past 200 years A. D., but were subdued by high water table levels between 100 and 600 years B. P. During the rest of the past millennium, dune activity was probably extensive but sporadic. Overall, results from this study show a correlation between eolian activity and climate indices for the last millennium in the area of the Palliser Triangle.

Blowout events before the cultural development of the area are probably entirely climatic induced, triggered during drought conditions with reduced vegetation and a lower ground-water table. These blowouts are local events and do not occur over larger areas during the same time interval. The age dates of reactivated sand therefore seem generally spread apart, such as the OSL dates of 173± 10, 210± 12, 940± 60, 70± 15, 110± 10 and 97± 10 years B. P. in WOLFE's et al. (1995) study of recent and late Holocene sand dune activity in southwestern Saskatchewan. The trend of widespread eolian activity events during climatically induced time intervals is therefore important, because it can then reveal drier climatic conditions in that interval at other places.

This chapter presented evidence that anthropogenic desertification combined with climate conditions such as droughts are responsible for some of the recent sand reactivation, especially around the area of the city of Post. In contrast to anthropogenic/drought related dunes of this century, there are also climatically induced sand reactivations and blowouts. Very immature soils from a sand dune within a larger dune field setting were compared to similar ones in the Nebraska Sand Hills. Soils appear to be young, hence the reactivations appear to be even more recent. Optically dated samples from sand dunes in the Canadian Palliser Triangle also show very recent reactivations over the past 200 years A. D. This evidence from three locations, the Nebraska Sand Hills, Canada and the study area for this research, all with semi-arid climate conditions consistently points to enhanced eolian activity at least during the past 1,000 years A. D. Evidence of recent dune reactivations from studies in the Nebraska Sand Hills and the Palliser Triangle are transferable to the Rolling Plains as the next chapter will show.

Chapter 6 will present evidence of sand dune reactivations from a dune field in the Rolling Plains of Texas, which predate anthropogenic desertification and which strengthen the observations and data presented in chapter 5.

Chapter 6. Drought-related sand reactivations several hundred years ago

Chapter 6 will investigate the possibility of short-term droughts causing sand reactivations, probably due mainly to drought-related vegetation loss and subsequent deflation. By contrast long-term climatic fluctuations changing the stability of the entire ecosystem will be discussed in chapter 7.

6.1. Estelline dune field (Hall County)

A dune field near Estelline, Hall County was chosen. Favorable factors in the selection process were access permission, aerial photograph dates available only several decades apart, buried soils within the dunes with enough material to attain a humate radiocarbon date, and buried cottonwood trees pointing towards recent reactivations. Another contributing factor for the selection of this site were wind data records, which were obtained from a weather station in the adjacent county during a drought.

6.1.1. Description

The dune field is located on the south side along a river bend of the Prairie Dog Town Fork of the Red River in Hall County, Texas (Figure 33). It extends for about 16 km east to west and about 10 km north to south. There are active and vegetated dunes within this dune field. The dune field is located on alluvial deposits of the Red River, a braided stream usually with limited water flow during the dry season. The sand source for these dunes probably was the Red Riverbed.

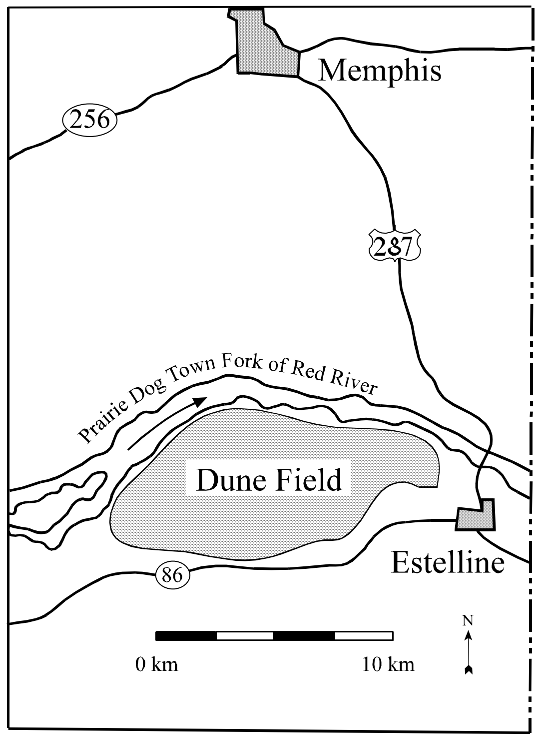


Figure 33. Location of the Estelline dune field on the Prairie Dog Town Fork of the Red River in Hall County, Texas. The dune field stretches 16 km east to west and about 10 km north to south and there are vegetated and active dunes within this dune field. Some deflated areas within the active area revealed several buried B_t -horizons.

Geologic features, such as sinkholes, dolines and surface fractures are common features within and in close proximity to the dune field (GUSTAVSON, 1986:11-16). Several springs are located in the vicinity of the dune field, contributing to salt dissolution and related collapse features that may have contributed to the evolutionary history of the dune field.

The dune field consists of some patches of active dunes, with little or no vegetation cover. In the other areas it has mostly vegetated dunes, with denser vegetation cover. There are mainly two different types of dunes within the dune field. However, due to extensive deflation they are not in their original shapes anymore, mainly now having the form of blowout dunes. Blown-out remnants of parabolic shaped dunes exist at the northern edge of the dune field. They probably formed under north-northwesterly winds and appear to be nested. It was also observed that parabolic-shaped dunes are mostly vegetated. Blown-out longitudinal-shaped dunes can be identified in most other parts of the dune field. A classification of these dunes therefore is impossible because of their extensive deflation.

Dunes have previously been presented as being in one of two categories, either active or vegetated. However, there are also significant qualitative differences in dune and interdune characteristics within the vegetated dunes themselves. Some of these dune forms in various areas are more pronounced, while in other areas the dune forms seem to be more eroded. The areas of less pronounced dunes could be older, suggesting different areas of reactivation within the same dune field at different times and thus different relief stages. This is also in agreement with current patterns of reactivation and stabilization within the dune field.

These different dune relief stages, referring to different sand reactivation phases, can be identified from aerial photos, buried vegetation at the edge of the active patches, and the topography of the dune field. Two sets of aerial photography were taken several decades apart and show how active areas evolved through time. The interpretation of these different dune relief stages will be part of the discussion later in this chapter on how sand transport was started in this dune field.

The dune field is mapped as “Tivoli sands” with active dune areas, by the Soil Conservation Service of the U.S. Department of Agriculture (BLAKLEY, 1967). Large areas of the dune field are vegetated with grasses, different types of brush vegetation (wild plum, hackberry etc.), or cottonwood and mesquite trees, the latter especially along the edges of the dune field. Other parts within this larger dune field are not vegetated or only have a thin and patchy grass cover.

Several cottonwood trees are buried under approximately 7 - 9 m of sand within the active dune area. On different parts of some of the blow-out dunes are grass roots exposed or in other areas plants seem to be shorter than others, pointing towards current shifting of sand from one area of the dune to another. Both of these observations suggest recent sand reactivation, probably during the dry and windy season.

The reason for the lack of deflation inhibiting vegetation cover in such areas has not been identified, but domestic livestock, over-grazing, cyclic droughts or fire could have prevented vegetation growth. Also, motorcycle three-wheelers are now periodically driven through the active dune field areas, for recreational and ranching purposes, as was mentioned in chapter 4. These vehicles probably destroy the vegetation cover and perhaps slow the re-vegetation process.

The Cope family, who has owned part of the dune field since the early 1900s, confirmed that the dunes are older than the dust bowl era of the 1930s. Several artifacts, such as lithic points and cooking stones, already discussed in chapter 4, were found by the Cope family, other residents, and the author. These findings suggest that the dunes were already present during Indian occupation of the area.

The predominant usage of the dune field is ranching, with some parts mesquite-poison controlled. On their part of the dune field the Copes reduce the number of cattle during drought years, and also re-seed fire-damaged areas, both measures undertaken to prevent reactivation of these dunes.

6.1.2. Sand reactivations

Active areas of deflation have revealed underlying clay-enriched B_t -horizons at several locations within the active area of the Estelline dune field (Figure 34).

Figure 34. Active areas of deflation have revealed underlying clay-enriched B_t -horizons at several locations within the active area of the Estelline dune field in Hall County, Texas. This paleosol dated at about 200± 40 years ago, suggesting a stabilization phase, which was followed by sand reactivation.

Soil humate samples for radiocarbon dating were taken from paleosols at two locations. These remnants of paleosols indicate former periods of landscape stability; the one in figure 34 ended at about 200± 40 years B. P. ago and was followed by a sand reactivation phase. The other stabilization phase ended at about 340±50 years B. P. (Figure 35). Both of these young radiocarbon dates (Figure 36) need to be interpreted with caution. Three problems need to be considered, each of which could lead to a misinterpretation of these dates and, when combined, create a much larger possible error.

Figure 35. This paleosol at the Estelline dune field in Hall County, Texas, indicates a former period of landscape stability ending at about 340±50 years B. P.

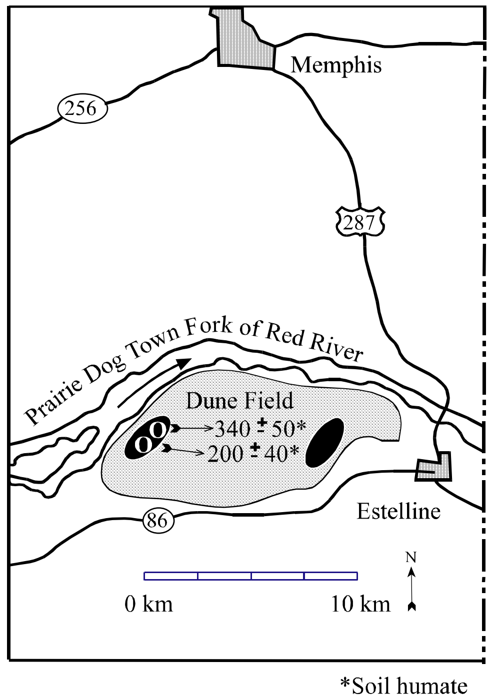


Figure 36. Radiocarbon dates at the Estelline dune field in Hall County, Texas. These dates have to be understood with caution since several types of interpretation errors can occur.

The first problem concerns possibly eroded upper sections from a buried paleosol. This can mean that the stability phase may have ended more recently; however, that section of the paleosol was eroded during the sand reactivation phase. Hence the reactivation phase could be much younger than the radiocarbon date.

Added to this problem comes a challenge when dating very young soils, as already discussed in depth in chapter 3. SWINEHART (1995) explained that radiocarbon analysis is not very dependable in very young soils. Uncertainties in radiocarbon dates of very young paleosols are usually about 80-100 years (2 sigma), in the case of the Estelline dune field. A comparison of these two soils, only 140 years apart, is therefore rather difficult. However, different radiocarbon-dated periods at this dune field will not need to be compared with each other. Instead they point out instability cycles during some time before human settlement.

Another dilemma is that generally the entire organic humate fraction of the clay mineral is dated. Therefore, if a formerly covered paleosol is once again uncovered by sand reactivation and acts again as a soil A-horizon during a second landscape stability phase, then new and younger organic fractions will be worked into the paleosol with the older already existing humate. This error would lead to a much older radiocarbon date than the last landscape stability phase. However, these mixed dates are always older and never younger, therefore it can be also concluded that these dunes were reactivated prior to the Anglo-American settlement of the area.

As determined in above paragraphs and chapter 4, the sand dunes reactivated prior to the settlement of the area. Human utilization of the dunes therefore did not cause these particular reactivations. The question remains: What did trigger sand transport during that time?

6.1.3. Post oak tree ring record

STAHLE and CLEAVELAND's (1988) June Palmer Drought Severity Index record established through Post Oak (*Quercus stellata*) tree ring chronologies in North Texas shows three main droughts indicated by black arrows since 1698. Comparing the two reactivation phases (Figure 36) with the drought record of North Texas (Figure 37), it becomes evident that the younger of the two radiocarbon dates correlates with a drought cycle from 1772.

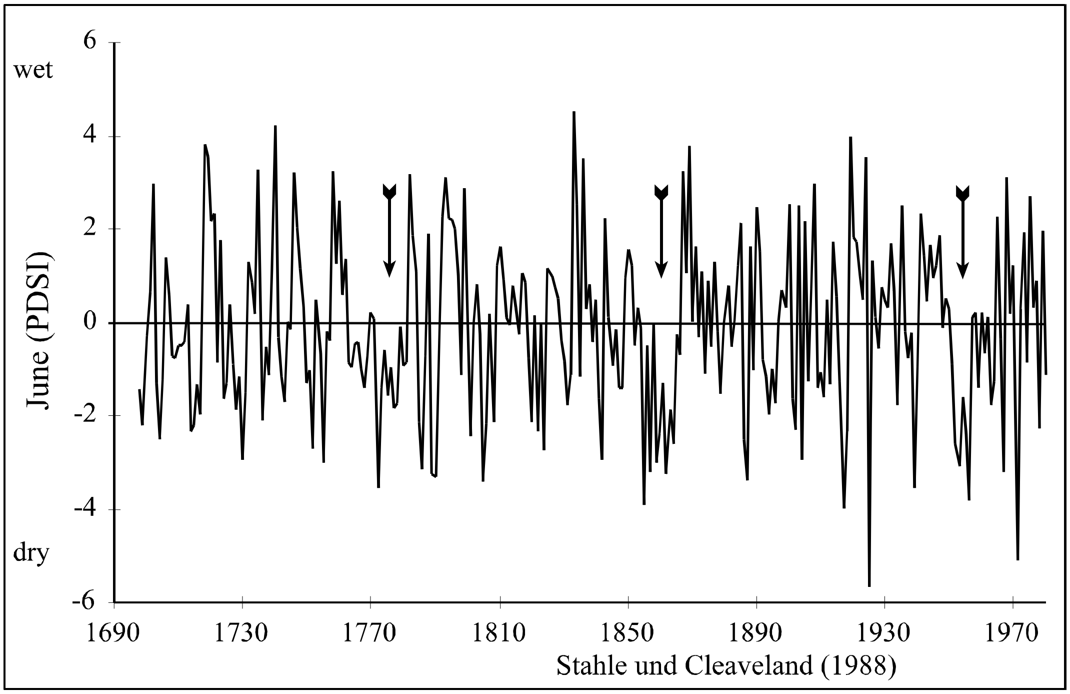


Figure 37. STAHLE and CLEAVELAND's (1988) June Palmer Drought Severity Index record established through Post Oak tree ring chronologies. Three major droughts indicated by black arrows are shown, since 1698. Comparing these droughts with the two reactivation phases (Figure 36), it becomes evident that the younger of the two radiocarbon dates correlates with a drought from 1772.

As already mentioned in chapter 4, settlers arrived in the Rolling Plains in the late 19th century. It can therefore be concluded that these sand reactivations several hundred years ago were not caused by anthropogenic desertification. Before this time, only Indians and large herds of bison inhabited or frequented the area and probably did not cause any desertification. This correlation of the 1772 drought with the younger reactivation phase strongly suggests an environmental response to a historic drought as the trigger mechanism for a reactivation in the Estelline dune field.

Is it possible to activate sand transport without anthropogenic interference in a vegetated dune field? If so, what factors are involved? The buried paleosols are evidence of sand movement within the Estelline dune field only several hundred years ago, before settlement impacted the area. It will have to be investigated if sand movement can be triggered by drought conditions and wind alone. Two theoretical possibilities for initiating sand transportation in the Estelline dune field (Figure 38) are presented below as scenarios:

1.) The riverbed is dry during a drought, exposing it to wind erosion. Vegetation along the river edges dies and predominant south-easterly or strong northerly winds start moving sand onto the old vegetated dune field, reactivating some areas within this dune field.

2.) During a prolonged drought, soil moisture deficits lead to the death of stabilizing vegetation. In some topographic lower parts of the dune field, this can create blow-outs and reactivate sand dunes.

Figure 38. Aerial photo of the Estelline dune field from the year 1985 shows two possible scenarios of sand reactivations starting from 1.) the adjacent dry riverbed or 2.) from within the dune field where drought related vegetation loss can cause deflation.

Both of these hypotheses are probable and will be investigated and discussed in the following sections. The potential rate of sand transport needs to be determined first to analyze wind distributions and proportions in order to see if wind is sufficient to move sand.

6.1.4. Sand transport rose

Wind conditions at the Childress, Texas, weather station were investigated. Since wind velocities higher than the threshold are needed to move sand grains over a rough surface, it is important to consider the Childress County wind rose in detail. March was selected, since it is the month with the highest wind speeds in Childress County.

A wind rose portraying modern drought winds was created, since it is a suitable way of visually summarizing wind data (JOHNSON, 1965:7). The result is a star-shaped diagram (Figure 39) with the length of each arm portraying the overall frequency of wind from that direction. Higher winds are at the outer end of the star. Each arm is usually subdivided into smaller line segments. The length of each line segment on a particular white arm indicates the frequency of occurrence of wind of a certain speed from this direction. Wind speed categories are formed by connecting dashed lines at a certain wind speed to the adjacent arms.

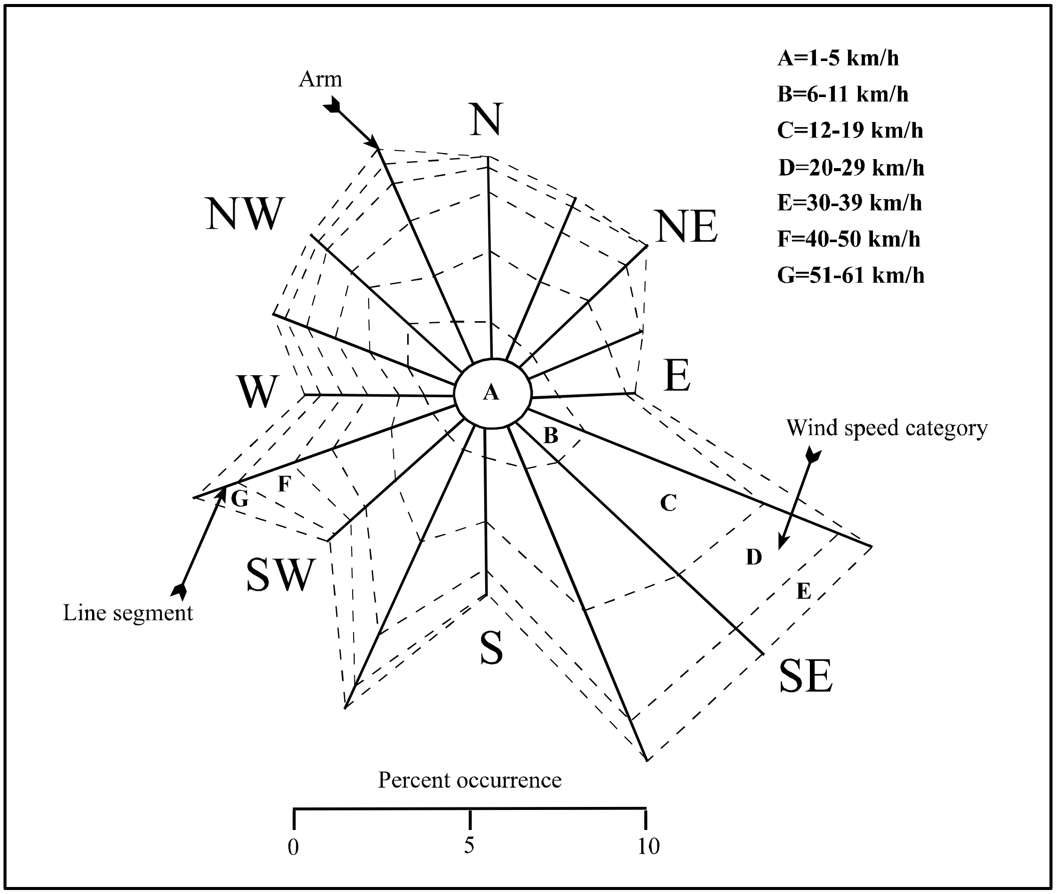


Figure 39. Wind rose for Childress County, Texas based on March winds, 1949 - 1954. Note the high percentage of winds from the southeast, although of low speed. The wind rose also portrays infrequent high north-northwestern winds. Modified from JOHNSON (1965).

High wind speeds, up to 61 km/h, occur from the northwestern quadrant, but these account for less than 2% of the winds. 11% percent of wind occurrence above 40 km/h comes from the north-northwestern direction. The wind speeds of the northeastern quadrant reach velocities of up to 50 km/h, however with less than a 1% occurrence. High wind speeds, up to 50 km/h, are registered from southwestern directions, but are similarly infrequent (1.5% of total). A total of 35% of all winds 40 km/h and higher come from the west-southwestern compass direction. Winds from the southeastern quadrant are all below 40 km/h, but have the highest percent occurrence of approximately 26%of all wind speeds.

A number of useful facts can be derived from the wind rose for Childress County, adjacent to Hall County. First, 12-19 km/h winds blowing from the south-east direction occurred with 4% frequency during March. Second, all winds blowing directly from the east have velocities below 30 km/h. Third, winds in the south-easterly quadrant have the highest occurrence, accounting for 26% of all winds.

In summary, it can be said that the highest wind speeds come from the north and southwestern quadrant. All winds from the southeastern quadrant have velocities below 40 km/h. The highest wind speeds have the least percent occurrence in all compass directions. JOHNSON (1965: 10) calculated the resultant wind for March for Childress as coming from a southwesterly direction, which corresponds with most of the active and vegetated dune alignments.

The combination of seasonal and local winds as portrayed in a wind rose are useful for dune alignment comparison. However, sand transportation does not occur in all winds and generally has a non-linear relationship with wind speed. For a more accurate comparison, a sand movement rose must also be prepared. This can be calculated from wind data, the local sand movement threshold, specific grain size, and the period of time during which a particular velocity of wind blew from one direction (COOKE, et al., 1993:280).

The LETTAU and LETTAU's formula, as simplified by FRYBERGER and DEAN (1979), was used in this calculation. The simplified formula for potential rate of sand transport is,

$$q = k * V^2 (V-V_t)/100 * T$$

Where,
k is a proportionality factor,
V is the wind velocity at 10.8 m height,
V_t is the impact threshold wind velocity estimated for 10.8 m height
$V^2 (V-V_t)/100$ creates a weighing factor
T in % is length of the time during winds blew

From the above formula it can be deduced that the sand transportation rate is proportional to the velocity to the third power. This is portraying a non-linear relationship of sand transportation and wind speed.

As noted by COOKE et al. (1993:280) it is not crucial which of several formulas is used to calculate a sand movement rose, but the choice of threshold velocity seems to be important. Unfortunately, no measurement of threshold velocity exists for the Hall County dune field. Therefore a threshold velocity of 22 km/h, calculated by FRYBERGER and DEAN (1979:146), was assumed.

FRYBERGER and DEAN (1979:146) further assumed the surface conditions to be flat, dry sand without larger bedforms and of medium-sized loose quartz sand without vegetation cover. The dunes in the Hall County study area consist of medium-sized sand under dry conditions, but have medium-sized bedforms and are partly vegetated. These differences mean that the Hall County threshold velocity is probably higher than predicted by FRYBERGER and DEAN (1979: 146), but without exact measurements in the dune field, true sand drift rates cannot be calculated.

The predicted potential sand transportation rose should be treated as a very rough approximation, since it is based on threshold velocity estimates and a period of drought winds during the 50s. However, the derived sand transportation results will yield estimates of wind distributions and proportions, which will be valuable for interpreting the two theories.

A sand transportation rose was calculated (Figure 40), using above formula for the station near the dune field. The wind data were extracted from the U.S. Weather Bureau Local Climatological Data Supplement by JOHNSON (1965). Data were available for eight wind directions. Winds were measured at the Childress station, 585 m above mean sea level and 10.8 m above ground anemometer height. Wind direction and velocity measurements are for the month of March during a five year period (November 1949 to October 1954).

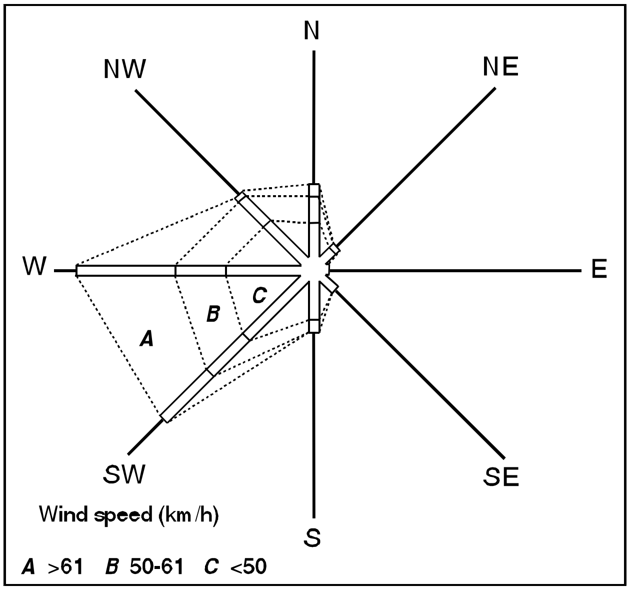


Figure 40. Sand transportation rose for Childress, Texas based on March wind data during 1949-1954. Established with the LETTAU and LETTAU sand transportation formula simplified by FRYBERGER and DEAN (1979). Wind data from JOHNSON (1965) was used for the calculations.

The longer, wide arms at each compass direction indicate higher sand transportation rates. Winds over 61 km/h could not be averaged accurately, since winds of these speeds were extracted from a category with no upper boundary in JOHNSON (1965). An average of 66 km/h was assumed for calculation purposes. The assumption of a higher average would naturally lead to higher sand transportation rates in this category.

A drought period was selected deliberately, since the strongest wind conditions occur during droughts (JOHNSON, 1965: 4). Sand transport was probably greatest during a drought, which would mean maximum sand movement in drought wind direction.

Supporting the first theory, the results derived from the sand transportation rose show that the effective wind distributions and proportions are highest from the west and south-west, meaning from the riverbed during a drought. Therefore it becomes clear that sand transport according to theory one, directly out of the dry riverbed onto the vegetated dunes, with highest sand transport rates from the west and southwest, is very likely (cf. above, figure 38, p. 109).

To investigate the two scenarios further, samples for grain size distributions were taken along two transects in the Estelline dune field. Grain size distributions of the north (Figure 41) and southwest transect (Figure 42) were collected from windward and leeward sides, top of the dunes and interdune areas.

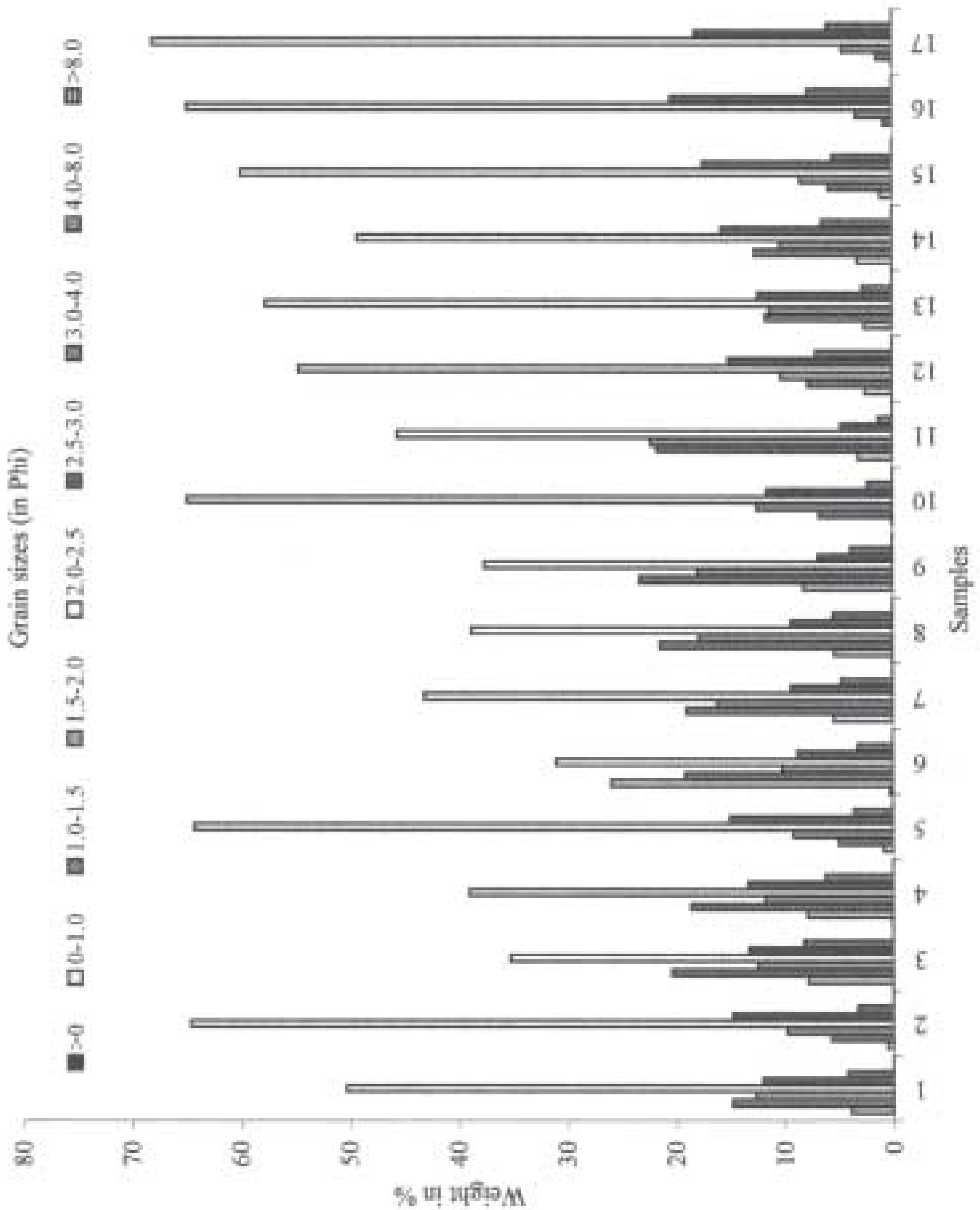


Figure 41. Grain size distribution from a north transect at the Estelline dune field. Larger grains, in the category PHI 0 up to 2, are more predominant in the northern transect.

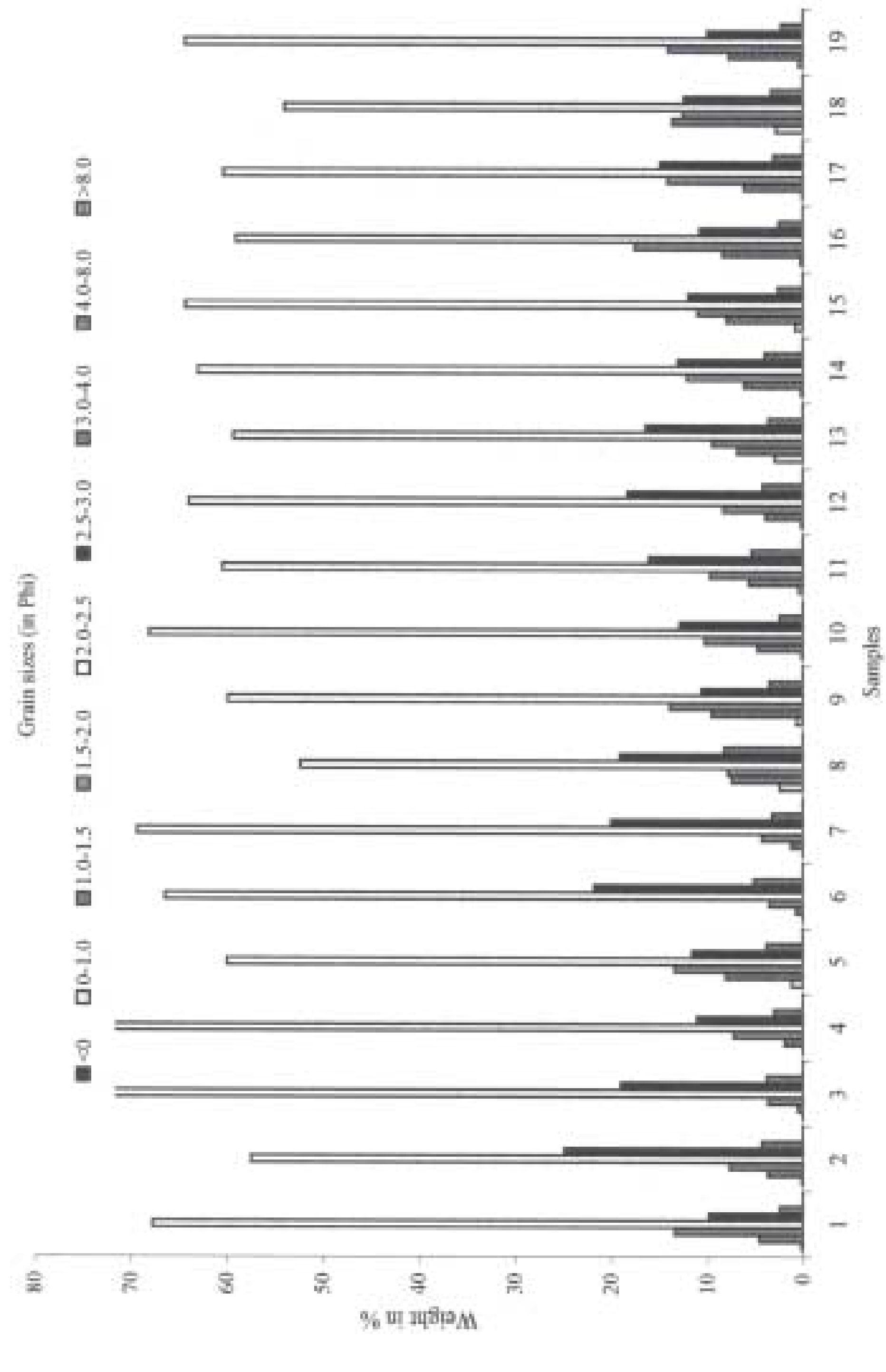


Figure 42. Grain size distribution from a south-west transect at the Estelline dune field. Smaller grain sizes PHI 2 up to 3 have higher percentages in the southwestern transect. The south-west transect went along the south-eastern edge of the dune field furthest away from the river hence smaller grain sizes have higher percentages.

These figures show in all samples that larger grains, in the category PHI 0 up to 2, are more predominant in the northern transect. This could be interpreted as that larger grains are more predominant closer to the sand source, the riverbed. Samples 15,16 and 17 (south, north facing and top of dune), close to the south-eastern edge furthest away from the river, have a decrease in larger grains, maybe pointing to a fining of the sand away from the sand source.

Smaller grain sizes PHI 2 up to 3 have higher percentages in the south-western transect. The south-west transect went along the south-eastern edge of the dune field furthest away from the river, hence smaller grain sizes have higher percentages. Both of these grain size distribution data sets support scenario one.

There was no other pattern evident for a different data interpretation between the two transects. Samples at the different dune locations, such as lee, luv, top of dune and interdune area, did also not show any particular pattern. This can probably be attributed to the sample depth of 2 cm, which represents the last wind event at this particular location. This event might not be the same storm nor the same sand source for all dunes, especially if theory one and two are both active processes. This might suggest that dunes are actually not moving in a regular fashion, which would probably show a pattern in the grain size distribution, but they are rather mainly inactive and being deflated.

Thin section analysis was chosen to support scenario two. A thin section of dune sands (cf. above, p. 32, figure 4) would show that reactivated soils of older vegetated dune sands would have a higher percentage of grains with iron-oxide coatings resulting from the soil formation. On the other hand, a thin section from river sands (cf. Above, p. 33, figure 5) would probably still show a higher percentage of polished grains that have not undergone extensive saltation yet. However, the sample would show less iron-oxide coatings on the grains, which would have eroded from the transport in the riverbed.

The thin section analysis failed to prove hypothesis two, probably because all grains in the Red Riverbed ultimately originated in the Southern High Plains, located only a short distance away. The sand source for the Red River is locally supplied by the Ogallala or Blackwater Draw formations, both of which have multiple buried soils in their sections. The distance from the sand source to the sample location was probably not sufficient to remove iron-coatings and substantially change the mineralogical imprint of the grains.

Even though the thin section analysis did not support theory two, it is still possible that sand transport only occurs through deflation within the dune field. The interpretation of aerial photos from 1954 and 1985 suggests that areas within the vegetated dune field are occasionally reactivated and blown out.

Smaller patches in the center of the 1954 aerial photo suggest the origin of the reactivation of older sand dunes according to the second theory. Sand is locally available through blowouts in the vegetated dune field, but there is no new additional sand provided. Therefore, after moving a certain distance depositing the sand, dunes re-vegetate during wetter years as suggested in the aerial photos from 1954 and 1985 (Figure 43, cf. above, figure 38, p. 109).

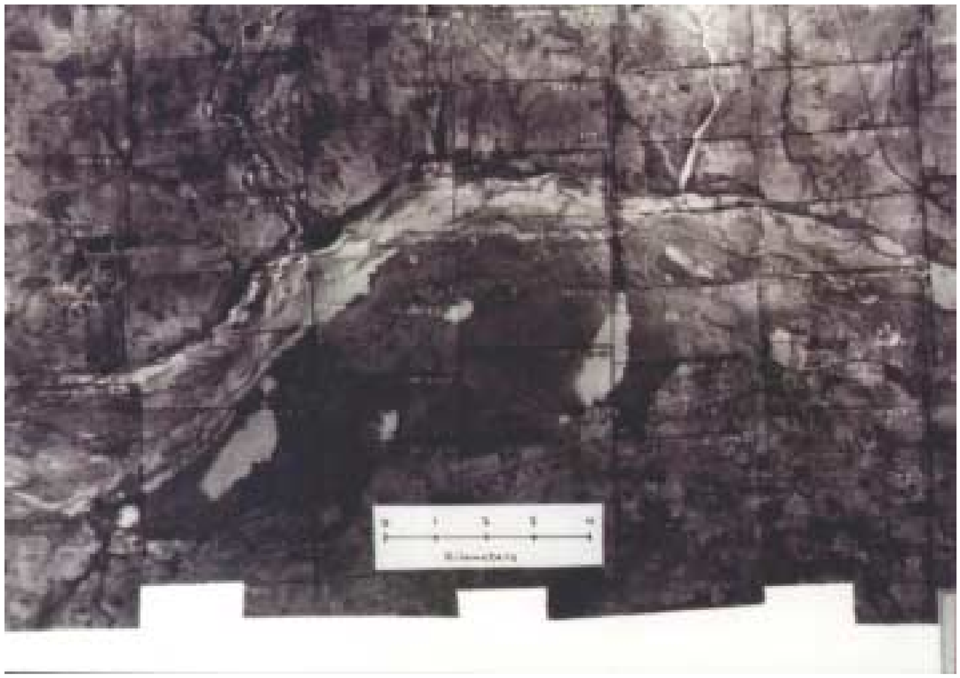


Figure 43. Aerial photography of the Hall County dune field in 1954. The areas of less vegetated dunes in the center of the picture could be of older age suggesting different activation areas within the dune field through time. This agrees with current patterns of activation and stabilization within the dune field, shown by active and vegetated dune areas in the photograph. Photograph courtesy of Dr. Virgil Barnes, Bureau of Economic Geology.

The topographic highs of the larger active patches are at the south-east end, as determined from the USGS topographic quadrangle sheet Estelline at a 1:24,000 scale. There, dunes are encroaching onto vegetated dunes (Figure 43). There is no immediate re-vegetation on the south-east end, because dunes are active and the water table is now too deep. The aerial photo shows several of these active patches at different stages of formation seemingly moving across the dune field from the west, and the riverbed towards the east, thus additionally supporting theory one.

In conclusion, both scenarios seem possible for the reactivation of sand in the Estelline dune field several hundred years ago before human impact. Each of the hypotheses has supporting evidence. However, larger areas in the dune field are probably reactivated under the conditions of scenario 1.

The wind rose at the Childress station shows that there are high frequencies of winds, some of them effective for sand transportation. Several paleosols were investigated showing radiocarbon dates that are corresponding with cyclic drought pattern established by a post oak tree ring record in North Texas by STAHLE and CLEAVELAND (1988).

This shows that sand reactivation does not necessarily only occur with climatic shifts to warmer temperatures and less rainfall over a longer period of time as will be suggested in chapter 7. It supports the idea that sand movement can also be triggered by cyclic droughts sometimes only one decade long, as can be seen in the June Palmer Drought Severity Index established from a post oak tree ring record in North Texas by STAHLE and CLEAVELAND (1988) (cf. figure 37, p. 108). However, STUDER (1949), for example, reported a 24 year drought during the years 1276 - 1299, therefore lasting two decades as evidenced in tree ring records.

Fire ignited by lightning might also have played a role in the triggering of sand movement, but probably only during drought years. This is supported by evidence of swift re-vegetation, during a normally wet year, of a burnt area in the Estelline dune field as reported by the landowner. The fire did not cause any obvious reactivations within the dune field.

The Rolling Plains in the last several hundred years were devastated by reoccurring cyclic drought events, as evidenced in tree ring records. These droughts triggered sand movement, but probably not at every sandy location during the same drought cycle. Different radiocarbon dates for locations in close vicinity to each other, as in the case of the Estelline dune field, are therefore quite possible.

Chapter 7. Older Holocene reactivation cycles

7.1. The Altithermal of the Southern High Plains

The objective for this Chapter was to find evidence for an Altithermal warming trend in the study area. ANTEVS (1948) first defined and pictured the Altithermal as a long, warm age lasting from between 7,000 to 4,500 years B. P. MELTZER (1991) reported that this proposed warm period was probably more variable in time and space as originally thought by ANTEVS. Therefore, one question still remains: is there evidence of cyclic drought events or an overall mid-Holocene warming trend throughout the region or even possibly a combination of both?

A description of evidence for warmer and drier phases on the Southern High Plains from other researchers is followed by several site investigations from the study area in the Rolling Plains of Texas. The chapter ends with a discussion of the Altithermal in the Rolling Plains of Texas and possible correlations with eolian phases during that time frame on the Southern High Plains.

Several researchers have described episodes of warmer climates on the Southern High Plains adjacent to the Rolling Plains of Texas for a period spanning several millennia in the middle Holocene (HOLLIDAY, 1989c; MELTZER, 1991; FERRING, 1990). These researchers used different disciplines, such as geology, paleontology and archeology, to consistently confirm the existence of warmer and drier climatic phases during the Holocene.

MELTZER (1991) found evidence for severe drought conditions at the onset of the Altithermal at Mustang Springs, an archeological site on the Southern High Plains, 32 km northeast of Midland, Texas. MELTZER (1991) reported that Army Captain Randolph B. Marcy mentioned a reliable freshwater spring and an associated pond at the site around 1849, as found in the records. However, with the beginning of irrigation during the 20th century and the decline of the Ogallala Aquifer water table most springs on the Southern High Plains dried up. Well drilling for extensive irrigation practices was responsible for much of the water table decline.

Springs respond in similar fashion to drought conditions with a decline in the water table. MELTZER (1991) showed that the Mustang Springs failed during the Altithermal and that a 3 m drop in the water table occurred at this site. For this decline he found evidence, such as buried well fill deposits in stratum 3, the Altithermal surface at the Mustang Draw valley. These fill deposits were radiocarbon dated with ages 6,599± 35 B. P., 6680± 40 B. P., and 6840± 70 B. P., outlining the onset of the Altithermal (MELTZER, 1991).

MELTZER (1991) also suggested that potholes with centered boreholes, probably hand-dug by Late PaleoIndians or Bitter Creek cultures at the bottom of a draw on the Altithermal surface could be evidence of a fluctuating water table. These pits were dug at during the Altithermal different depth between 0.10-1.65 m, probably to reach the water table, whenever it dropped further.

These climatic fluctuations affecting the water table may have been similar events to decade-long cyclic droughts as reported by STAHLE and CLEAVELAND (1988) for periods during the 17^{th} and 18^{th} century. However these fluctuations could also be part of an overall warming trend.

The idea that cyclic drought events rather than an overall increasing warming trend caused human adaptation is supported by data from JOHNSON (1987:94), who suggested a modern mixed short-grass prairie of fauna and flora during the mid-Holocene with structural similarities to the present vegetation. MELTZER (1991) described the fact that most animal species present in the Southern High Plains today are able to remain at their habitat during short-term droughts.

Some of today's species, however, would not able to remain at their habitat when drastic climatic changes with increasing temperatures and severely reduced precipitation lasting over several thousand years occur. These species include geese, herons and swans, which usually need deeper surface lakes as habitats, or bison, who need to drink regularly (MELTZER, 1991).

The absence of these animals during the mid-Holocene points to more severe drought conditions than today's cyclic drought events reported during this century. However, this still does not provide a persuasive answer to the question of whether or not cyclic droughts were present during the mid-Holocene, or if there was an overall warming trend during the Altithermal, that led generally and continously to drier conditions than before.

In conclusion, the Mustang Springs site shows adaptive strategies of humans to severe drought conditions, either cyclic or more extensive, during the Altithermal. As described, buried fills of hand-dug wells into the Altithermal surface (MELTZER, 1991) preserve evidence of a fluctuating water table during the mid-Holocene on the Southern High Plains.

HOLLIDAY (1989c) in his early work reports also on a mid-Holocene drought on the Southern High Plains. His conclusions are supported by geomorphological, paleontological and archaeological data from a small number of sites, which are widely scattered. HOLLIDAY (1989c) also suggests a regional chronology for mid-Holocene eolian deposition cycles. Eolian sedimentation began locally at least between 10,000 and 9,000 years ago and was episodic but widespread from 9,000 to 5,500 years B. P. He claims that most areas were influenced by 6,500 years B. P. and between 5,500 and 4,500 years B. P. all locations were affected by eolian sedimentation.

In more recent work, HOLLIDAY (1995) investigates dry valleys and their late Quaternary evolution and stratigraphic record on the Southern High Plains. He examines whether the draws formed as synchronous events on a regional basis with similar soil-forming events. Most of his research was performed at tributaries of the Red and Colorado rivers.

His results are based on 53 new radiocarbon ages and 410 cores and exposures at 110 investigated localities. He claims that for the time after 12,000 years B. P., all the draws show a similar stratigraphic record, suggesting that they are regionally synchronous. He also identified 5 lithostratigraphic records, termed strata 1-5, referring from oldest to youngest sediments.

Stratum 4, is an eolian layer, of 1 - 3 m thickness with a moderately to strongly developed soil in loamy to sandy material. Stratum 4, the Lubbock Lake soil, has a calcic or argillic B_t or B_{tk} horizon and generally is dated at 7,000 to 4,500 years B. P., but HOLLIDAY (1995) claims it further developed throughout the rest of the Holocene, except where it was buried. It is assumed that he based this result on the stratigraphic sequence and not on radiocarbon dates of Stratum 4.

According to HOLLIDAY (1995) there was a substantial shift in hydrology from flowing water to standing water, to almost no water, then followed by eolian accumulation during the Holocene. Around 4,500 years B. P., precipitation increased again with brief drought events during the late Holocene. He suggests a drier period during the mid-Holocene with greater seasonality than today, lasting between 7,000 and 4,500 years B. P., with the most extensive deflation between 6,000 and 4,500 years B. P.

The question of whether an overall warm period existed versus episodic droughts was resolved in HOLLIDAY (1995), who suggests that the middle Holocene environment roughly corresponds to ANTEVS' (1955) definition of the Altithermal as a warmer period than before and after. Chronostratigraphic data, however, show that droughts varied in intensity and probably also in extent throughout the mid-Holocene.

FERRING (1990) in his 'Archaeological geology of the Southern Plains' combined paleoclimatologic data from the Southern Plains and the Texas Rolling Plains region. His climatic synopsis of the various paleoenvironments throughout the Holocene is mostly based on pollen data, vertebrate and molluscan faunas, and eolian and alluvial records.

The climatic paleoenvironmental record, as pieced together from studies by other researchers, is generally in agreement with time frames described by HOLLIDAY (1995). Mid-Holocene climates were characterized by drought conditions (8,000 - 4,000 years B. P.). Evidence are vertebrate faunas, eolian activity and very low pollen influx values at a site in the Quachita Mountains to the north of the Rolling Plains (FERRING, 1990).

The existing time frame for mid-Holocene sand reactivations established by other researchers in the adjacent Southern High Plains is useful for the integration, comparison and correlation with localities from the Rolling Plains, since sites here were sparse and widespread due to the nature of the study area. If a drought affected the Southern High Plains during the past and was severe enough to cause sand reactivations there, it would probably also show evidence in paleosol profiles in the Rolling Plains of Texas.

To prove the existence with certainty of this middle Holocene warm period combined with high intensity but widespread droughts in the Rolling Plains, evidence of eolian activity should be found in several different profiles on a regional scale roughly between 7,000 and 4,500 years B. P.

However, a drought that is only a decade long might be strong and severe enough to create several reactivation zones in an active dune field under current climatic conditions, as was shown in the example of the Estelline dune field. Hence, the original dune field might have formed during the Altithermal and was then only recently reactivated during short-term drought conditions. Therefore, localities in the Rolling Plains of Texas need to be carefully evaluated for their usefulness to determine paleoenvironments.

7.2. Site descriptions

In this subchapter several relevant outcrops in the Texas Rolling Plains will be introduced. Five sites and one core (Figure 44) were utilized for evidence of eolian activity during the Altithermal. Six samples from different horizons in three outcrops were radiocarbon dated.

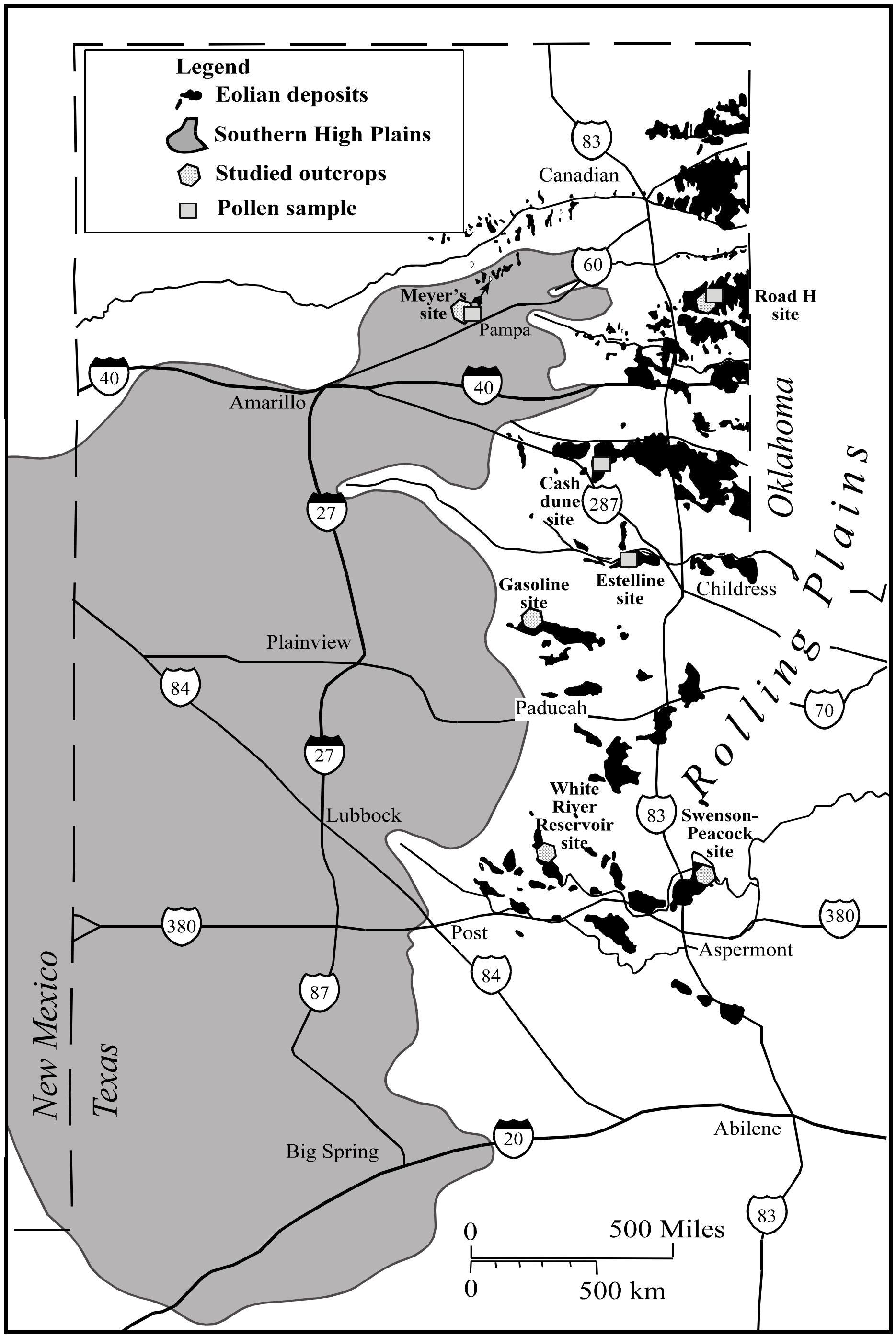


Figure 44. Location of sites in the Rolling Plains of Texas investigated for Holocene depositional cycles during the Altithermal warm phases.

7.2.1. Swenson-Peacock site

The Swenson-Peacock sand sheet can be located on the Lubbock sheet of the geologic atlas of Texas at a 1:250,000 scale (BUREAU OF ECONOMIC

GEOLOGY, 1967) and is marked as Quaternary windblown sand deposits. The sand sheet is nested in a bend of Salt Fork of the Brazos River in Stonewall County. It is bordered on the western margin by Quaternary Lingos Formation deposits. A rise in elevation (about 30 m) and outcrops along the northern edge of the sand sheet suggest that it is also in parts underlain by this formation. The outer areas of the sand sheet, which are located in close proximity to the river, are dissected by intermittent streams.

The sand sheet is mostly used for ranching and agriculture, and some oil production. A huge pit is evidence for former sand mining activity in the western part of the sand sheet. There are some dune-like features in the northwest area of the sand sheet in close proximity to the riverbed. The sand sheet has a typical vegetation cover for this area with various grasses, shrubs and small trees as described in chapter 1.2.2.

There is an outcrop (Lamella outcrop) located on a small dirt road winding west and north along the outer edge of the sand sheet. It can be reached from State Highway 83 turning west onto a dirt road (the last possible road turning west before the river valley), located approximately eight kilometers south of the King County border in Texas (cf. above, figure 44, p. 124). The profile crops out turning the first road north into a topographic low at the eastern side of the dirt road (approximately 500 m south of the road turning west again).

This outcrop revealed several paleosols and a modern soil and was therefore further investigated. One of the paleosols consists of very large clay lamellas up to 10 cm thick interspersed with leached horizons. So far no other reports on similar large-sized lamellas have been made in the Southern High Plains or Rolling Plains. The outcrop profile can be described as follows:

Lamella outcrop (Figure 45)

0 - 10 cm	modern A -horizon, sand
10 - 95 cm	modern weak B -horizon, brown colored sand
95 - 180 cm	paleosol I. B_t -horizon, with reddish-brown clay lamellas in white colored sands up to 10 cm thick (Bänderbraunerde)
180 - 200 cm	paleosol II. A_l -horizon, white sand, soft, bleached, homogenous (7.5YR7/4)
200 - 205 cm	B_{tk}? -horizon, calcium carbonate rich, white, harder layer
205 - 300 cm	paleosol II. B_t -horizon, loamy red sand, clay rich
300 - 335 cm	softer, sandy clay, red gravel <3-5 mm, roots

Figure 45. Swenson-Peacock site in Stonewall County. This profile shows two paleosols and one modern soil suggesting at least two phases of sand reactivation, the upper lamella horizon dating at 4,320± 90 B. P. and the lower part at 6,090± 90 years B. P. The lowest sandy clay was dated in the upper part at 7,070± 160 years B. P.

This sandy profile generally shows an A-A_h-A_l-B_t-C profile. In the German classification system, we call this B_t lamella paleosol I. remnant of a "Parabraunerde". The sandy version of this soil usually develops lamellas instead of a continuous B_t -horizon in Europe (SCHEFFER and SCHACHTSCHABEL, 1992).

This profile shows at least two older paleosols with a modern soil on top. C^{14} dates from the upper and lower parts of the lamella horizon (Paleosol I.), delineate a time frame between 4,320± 90 B. P. and 6,090± 90 years B. P. for the formation of paleosol I. Paleosol II. dated in the upper part at 7,070± 160 years B. P.

The lowest missing A- and B_{tk}\B_t- horizons were first deposited some time ago. As the climate became drier and the vegetation died at the onset of the Altithermal around 7,070± 160 years B. P. , the A-horizon was partially eroded. After that, sand was deposited again, in which the lamellas in the B_t horizon formed, topped by another A-horizon, which eroded again around 4,320± 90 years B. P. Renewed sand deposition with soil formation lead to the recent A- and light-colored B_t- horizons in the modern soil.

At the Swenson-Peacock locale, two major sand reactivations occurred after 7,070± 160 years B. P., with a soil development in between 4,320± 90 years B. P. and 6,090± 90 years B. P. This development is probably comparable to the Lubbock Lake soil in stratum 4 found in the bank profiles of draws on the Southern High Plains by HOLLIDAY (1995). HOLLIDAY (1995) describes that in the dunal facies of the Lubbock Lake soil at Clovis, Midland and Gibson, illuvial clay occurs as clay bands, albeit thinner as described at the Swenson-Peacock site. No new sand reactivation occurred after 4,320± 90 years B. P., hence the climate probably became wetter and encouraged stabilizing vegetation cover, allowing the modern soil to form ever since.

A grain size analysis was performed at the lamella outcrop (Figure 46) to show the size distribution in the different horizons and support pedogenic interpretations. The results will also be compared with an analysis from the outcrop at the White River Reservoir in Crosby County.

Generally, the distribution confirmed eolian material, with the highest percentages in the fine sand category in all eight samples. The modern A- and very weak B-horizons (SP1 and SP2) have no clay fractions. Paleosols I. (SP3 and SP4) and II. (SP6, SP7 and SP8) have the highest amounts of clay, which confirms both B_t- and B_{tk} -horizons of both paleosol. Both red lamella bands, sample SP3 and SP4, have high clay fractions. This would show that the clay accumulates in the reddish layer being leached from the whitish bands, probably similar to processes in the A_l-horizon. This process of illuviation is shown by the absence of clay and fine silt in the A_l-horizon (SP5), beneath the clay lamellas.

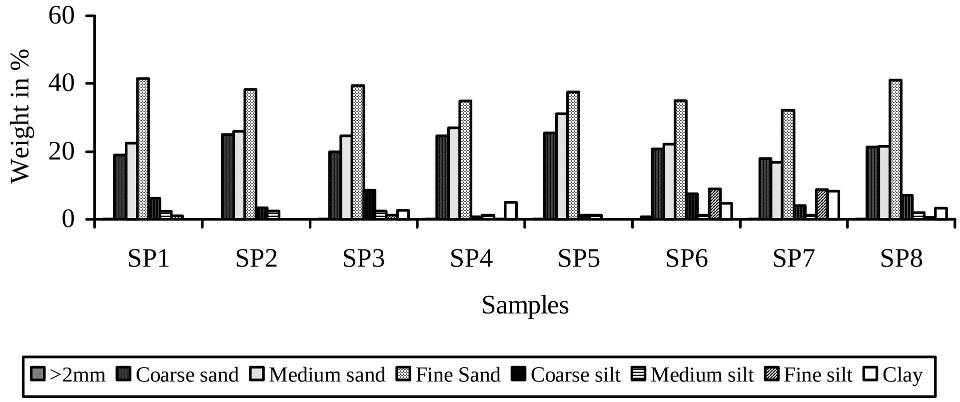


Figure 46. Grain size distribution of the Swenson-Peacock outcrop. Data generally confirmed eolian material and B_t-horizons in paleosols I. and II. Sample depth: SP1=10cm, SP2=50cm, SP3=95cm, SP4=145cm, SP5=185cm, SP6=200cm, SP7=215cm and SP8=270cm.

Additionally, a core was taken about 1.6 km to the southwest of the outcrop at the northwest bend of the dirt road to investigate if both paleosols could be traced as part of a paleorelief on the sand sheet.

Swenson-Peacock sand sheet core:

1- 35 cm	light-colored sand with 20 cm A -horizon, disturbed
35 - 70 cm	reddish sand, slight B_t -development, some clay, roots
70 - 105 cm	reddish sand turning to light-colored sand
105 - 140 cm	turning to light-colored sand, white spots, no reddish color
140 - 175 cm	hard cemented gleyish, reddish sand, plant roots, possibly old water table, carbon
175 - 205 cm	light colored bleached sand, bigger grain sizes, red spots, modern plant roots
205 - 225 cm	fine yellow sand, not cemented
225 - 240 cm	light colored sand, old roots, falls apart easily, no soil development
240 - 250 cm	light colored sand modern roots, hard to core, maybe a root
250 cm	core loss, dry sand

It is difficult to interpret soil cores, because cores taken by hand show only 1.9 cm in diameter of the soil, and no radiocarbon dates can be obtained from such a small amount of soil for comparison to the stratigraphic record. It can generally be stated that lamellas are hard to trace because they become distorted when the soil corer is pushed into the ground. In the above soil core, the red spots could be distorted lamellas. Very dry parts of the core can often not be recovered because they are simply lost, as it happened at the depth of 250 cm in the above core.

The light-colored sand in the lower parts of the horizon has probably not undergone soil development. The core part above 140 cm is part of a modern soil, which, compared to the modern soil in the outcrop, shows also only a weak B_t -horizon development.

The gleyish hardened clay layer between 140 and 175 cm of the core was probably part of an interdune deposit. The gley components may have been infiltrated by a local fluctuating water table. Once the sand reactivated again, the interdune area was covered by sands from the modern soil. This idea is supported by larger grain sizes below the hardened horizon as are commonly found in interdune deposits.

At this point no convincing solution can be supplied which is supported by enough evidence. Nevertheless, this core profile suggests at least one sand reactivation phase. No age estimates can be made at this point other than that the modern soil from the soil core probably corresponds to the modern soil in the outcrop, which has formed roughly during the past 4,000 years B. P. If the soil core horizon between 140 and 175 cm was part of an interdune deposit, the gley points to wetter conditions during its formation, which HOLLIDAY (1995) suggests to be the climate during the past 4000 years up to present. However, short-term droughts have still frequented the area during that time, which would explain why the interdune area was covered again with sand.

The geomorphic location is an important factor in tracing a possible paleosol relief. Reactivated sand on a sand sheet is deposited in varying thickness across a surface, and soil development might not occur at all places simultaneously or correspondingly.

The sand source for this sand sheet is the Salt Fork of the Brazos River, as discussed at the beginning of chapter 7.2.1. Wind from a southwest direction was most likely responsible for the deposition. There is a possibility that some of the deposits stem in part from the Lingos Formation, since the sand sheet overlies part of this formation.

7.2.2. Site on Meyer's ranch

The second site is located in Hutchinson County east of the town of Borger (cf. above, figure 44, p. 124). On FM road 1059 a large, mostly vegetated dune field extends across Meyer's ranch. The dune field is located on the Amarillo sheet of the geologic atlas of Texas, at a 1:250,000 scale (BUREAU OF ECONOMIC GEOLOGY, 1969) and described as Quaternary sand dunes. The sand sheet has variations in elevation of 30 m. The dune field lies between two intermittent streams, both flowing into Spring Creek, a tributary of the Canadian River.

The dune field is underlain by the Tertiary Ogallala Formation. Meyer's property is currently used for ranching purposes (one head per 15 acres) and oil production. The outcrop to be described from this ranch is facing west and can be located approximately 20 m north of FM road 1059 at the entrance to Meyer's oil field access road on his property.

The outcrop (Meyer's outcrop) investigated revealed two major horizons separated by a small band of calcrete nodules and gravel. The lower horizon is comprised of reddish sandy clay. The upper more sandy horizon shows sedimentary structures in the lower parts and a soil development in the upper part. A sample from the sandy horizon with the sedimentary structures did not show any pollen, as was discussed in chapter 3.2.1.

Meyer's outcrop (Figure 47):

1 - 5 cm	sandy A -horizon
5 - 20 cm	sandy B_t -horizon
20 - 60 cm	sand with some sedimentary structures
60 - 61 cm	gravel and calcrete nodules as armored layer, deflation lag (significant erosional unconformity)
61 - 230 cm	paleosol I. B_t -horizon, some calcrete nodules, gravel

Figure 47. Meyer's ranch in Hutchinson County. This profile shows one paleosol radiocarbon dated at 5,210± 80 years B. P. and one modern soil, separated by a deflation lag. This is suggesting at least one sand reactivation phase some time after 5,210± 80 years B. P.

This profile shows at least two soil development phases and one sand reactivation phase (Figure 47). The lowest horizon (Paleosol I.), comprised of sandy clay (HUE 7.5YR 5/8), showed some calcrete nodules and other little gravel, albeit not in great abundance. This horizon is overlain by a 1cm band of calcrete nodules and little gravel, which are most likely a deflation lag from the horizon below.

As this lower horizon (Paleosol I.) was deflated, calcrete and gravel accumulated and produced an armored layer that protected the soil from additional wind erosion. A C^{14} analysis in the upper part of this eroded horizon dated the age of this paleosol around 5,210± 80 years B. P. The prior accumulation and soil development phase for this horizon also falls into the Altithermal time period as framed by HOLLIDAY (1995) and FERRING (1990), lasting between 7,000 to 4,000 years B. P.

HOLLIDAY (1995) suggests that the most extensive erosion was between 6,000 and 4,500 years B. P. This conclusion is based on a stratigraphic record from several draws in the Southern High Plains. This seems to coincide with the erosion of the lower horizon at the Meyer's site. The erosion phase must have happened some time after 5,210± 80 years B. P., the last available date of the uppermost part of the soil development phase of this lower horizon. This soil development phase probably did continue, but the younger parts were deflated as portrayed in the deflation lag. The frequency of calcrete nodules and gravel in this lower horizon suggests that quite an amount of this horizon must have been eroded in order to produce a 1 cm deflation lag, such as found above the horizon.

It is therefore possible that the erosion phase at the Swenson-Peacock sand sheet corresponds to the one at the Meyer's sand sheet, and is part of a more extensive drought cycle towards the end of the Altithermal. The amount of the soil horizon, spanning roughly 1,000 years, would have been eroded from the lower horizon before new sand accumulated.

Consequently, as slightly wetter conditions then returned to the Rolling Plains area, probably around 4,000 years B. P. as shown elsewhere in the region (HOLLIDAY, 1995; FERRING, 1990), the modern soil formed above the deflation lag. This soil is comparable to the modern soil at the Swenson-Peacock location.

The source area for this dune field is Clear Spring Creek, a tributary of the Canadian River. This creek cuts and exposes Ogallala Formation material, and makes it available for deflation especially during drought times.

7.2.3. White River Reservoir site

The White River Reservoir site can located on the Lubbock sheet of the geologic atlas of Texas at a 1:250,000 scale (BUREAU OF ECONOMIC GEOLOGY, 1967) and is marked as Quaternary windblown sand deposits. The sand sheet is underlain by the Dockum Group Formation and is nested along the eastern side of the White River, a fork of the Brazos River, in Crosby, Dickens, Garza and Kent County.

The sand sheet stretches in north-south direction across FM 2794 (cf. above, figure 44, p. 124). The outcrop is at the south roadside about 1.3 km east of the White River Reservoir dam in Crosby County. The elevation of the sand sheet increases roughly between 60 - 90 m from south to north and it is currently used as ranchland.

The outcrop (White River Reservior outcrop) investigated revealed a paleosol and a modern soil underlain by older soft-reddish sands. The profile was located alongside the road underneath a property fence-line. The location under the fence prohibited digging the outcrop back, which would have assured a good quality of the samples. However, this would have undermined the fence and therefore the profile was only carefully shaved and cleaned.

White River Reservoir outcrop (Figure 48):

0 - 10 cm	sandy modern A -horizon
10 - 40 cm	modern, weakly developed B -horizon
40 - 75 cm	paleosol I. or II. ? hard, reddish B_t -horizon, burnt (oxidized) roots
75 - 95 cm	reddish horizon, softer
95 - 130 cm	white-reddish hard layer, non-calcareous, water table?

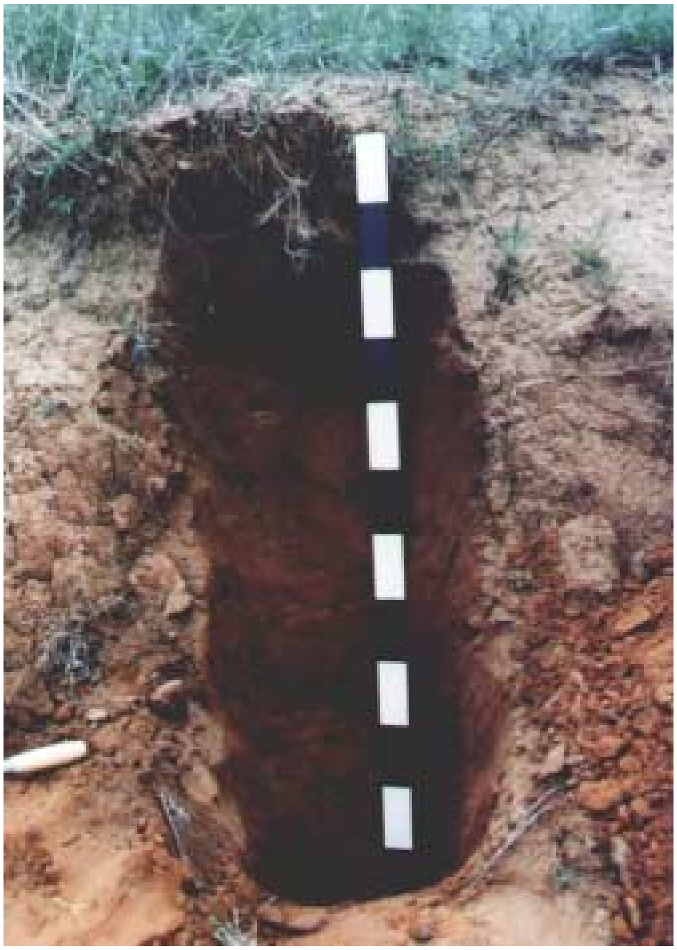


Figure 48. White River Reservoir sand sheet outcrop. Contaminated sampled showed an age much too young. The dated paleosol most likely corresponds to paleosol I. and formed some time between 7,000 and 4,000 years B. P.

One radiocarbon date was obtained from a sample of paleosol I. The date was very young, revealing an age of 470± 30 years B. P. However, there is evidence from the other two sites that paleosol I. probably formed sometime between 7,000 and 4,000 years B. P., whereas paleosol II. probably formed sometime during the beginning of the Holocene.

There is evidence on the Southern High Plains (HOLLIDAY, 1995) that the most extensive droughts were between 7,000 and 4,000 years B. P., during which time frame most of the eolian sand transportation in the adjacent Rolling Plains occurred. Hence the paleosol from the outcrop described above most likely corresponds to paleosol I. and formed some time between 7,000 and 4,000 years B. P.

The very young date probably results from a contaminated sample. The soil was very hard when the sample was collected, and it had to be chiseled from the horizon. Generally, when collecting a radiocarbon sample the top horizons are cleaned off to avoid contamination with younger material. Some material was cleaned off, but the outcrop was underneath a fence, and further cutting back would have undermined the fence, as was already mentioned above. The outcrop was on Texas Department of Transportation property and the adjacent property owner had not been contacted. Undermining the fence would have also presented a danger for cows to trip along the fence and break their legs.

Burnt roots were collected from paleosol I. for radiocarbon dating. After the radiocarbon date of the paleosol turned out to be contaminated, it was considered to use the root for additional radiocarbon dating. Dating the burnt root would have shown when a fire destroyed the vegetation cover and sand was reactivated. The sample was discussed with the lab personnel (Sam Valastro, pers. comm.), he suggested that relatively young roots sometimes become oxidized, which can look like a burn to the root. According to him it was not worthwhile to date the sample.

The source area for this sand sheet was the White River to the west and southwest. The last extensive droughts for the formation of this paleosol occurred between 7,000 and 4,000 years B. P. During this time the effective wind distributions and proportions were probably also highest from the west and south-west as re-constructed by a sand transportation rose for Childress County for a recent drought during the 1950s (cf. above, p. 113, figure 40)

Additionally, a grain size distribution measurement was performed at the White River Reservoir outcrop. Five samples from the different horizons were taken to investigate if the grain size distribution confirms outcrop interpretations and if it shows a similar pattern to that of the Swenson-Peacock site.

The samples WR3, WR4, WR5 reflect clay accumulation in the B_t-horizon of a paleosol horizons. There is also some clay in the A-horizon, but none in the weakly developed B-horizon, pointing to a very young modern soil similar to the Swenson-Peacock grains size distribution results.

Generally, the samples from the White River Reservoir are better sorted than those from the Swenson-Peacock outcrop. Both samples, however, appear to be less well sorted as compared to the modern and active Estelline dune field sands in Hall County. Pedogenic processes during soil development probably modified the size distribution and therefore have an impact on sorting.

In contrast with the Swenson-Peacock outcrop, where the highest percentages are in the fine grains, the White River Reservoir outcrop percentages are higher in the medium grain sizes. This higher percentage is reflected in all five samples and is probably not a result of pedogenic processes. It could show differences in source material, transportation distance, wind speed or depositional environment, such as the difference in dune versus sand sheet development.

The most probable contributing factor is that the sand source material for the Swenson-Peacock sheet has more Permian material incorporated, which generally is high in fine grain sizes, such as fine sands, clay and silts. By contrast, the White River Reservoir sand sheet lies on top of source material from the Dockum Group, generally higher in sands, as can be seen in the thin sections of figure 10.

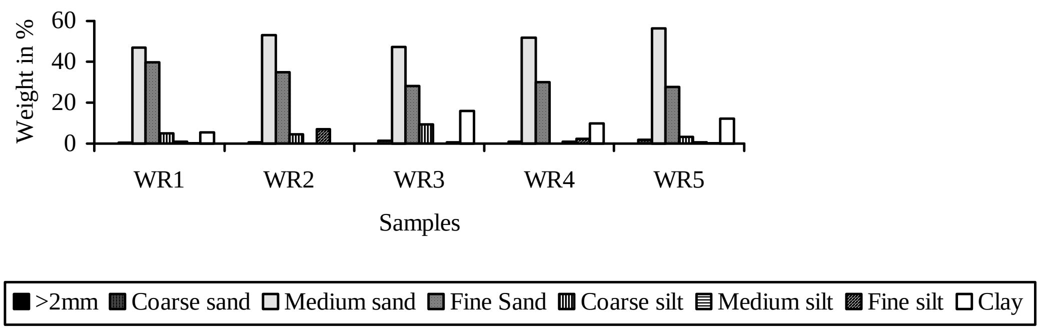


Figure 49. Grain size distribution of White River Reservoir outcrop in Crosby County. The higher percentage of medium size grains reflected in all five samples is probably influenced by the sand source material, the Dockum Group. Sample depth: WR1=5cm, WR2=20cm, WR3=50cm, WR4=90cm, WR5=110cm.

7.2.4. Other sites

Most of these following sites were not suitable for radiocarbon dating and hence interpretations were difficult. The Rolling Plains has a variety of sand sources, which leads to significant differences in the soil profiles. Soils can therefore appear very different from one locale to another.

The first site is in a vegetated dune field located in Wheeler County near County Road 17 on road H (cf. above, figure 44, p. 124). The Quaternary sands here overlie the Tertiary Ogallala Formation as described on the Amarillo sheet of the Geologic Atlas of Texas (BUREAU OF ECONOMIC GEOLOGY, 1969). The dune field lies approximately 3 km north of Sweetwater Creek and stretches east and west between Goodin and Coburn Creek.

The outcrop investigated is located along the road H. The soil profile faces south on the southern tip of the dune field. The profile revealed one or two paleosols and had concrete nodules in both paleosol horizons. A pollen sample X2 taken from a depth of 20-30 cm lacked pollen and showed no results as discussed in chapter 3.2.1.

Road H outcrop (Figure 50):

0 - 50 cm	modern soil, A - and weak B -horizon (HUE 7.5YR 5/6)
50 - 85 cm	paleosol I.? B_t/B_{tk} -horizon, sand, clay, calcrete nodules
85 - 100 cm	light-colored sand, not hardened, very little clay
100 - 130 cm	paleosol II. ? B_t/B_{tk} -horizon, sand, clay accumulation and scattered calcrete nodules

Figure 50. Road H outcrop located in Wheeler County. The two paleosols can be compared to soils in the Southern High Plains by the size of the calcrete nodules. They appear to be at a similar stage I. - II. as identified by HOLLIDAY (1995) in the Lubbock Lake soil of stratum 4 (7,000 to 4,500 B. P.) in several of the investigated draws.

The Road H profile can be interpreted as an A-horizon with a modern B-horizon overlying an older B_t/B_{tk} -horizon. The older B_t/B_{tk} -horizon consists mainly of sand with some clay accumulation and some dispersed large calcrete nodules at a depth of 50 to 85 cm. Between 85 cm and 100 cm lies a zone of light-colored sand with very little clay. Below is another B_t/B_{tk} -horizon with some scattered calcrete nodules and clay accumulation.

The sequence of calcrete and clay accumulation layers can be linked to soil water movement, and hence to climate. Several factors are important for the formation of calcrete nodules. These factors are soil water movement, hence rainfall; the time of soil formation; and the availability of additional calcium carbonate supply, as for example from airborne dust particles, if not provided in the sand source material. GILE et al. (1966) suggested calcic stages for a certain time frame of formation measured by the amount of the calcrete in desert soils.

No radiocarbon dating was performed, therefore no absolute time frame can be established. The only conclusion that can be drawn is that the multiple layers with calcrete and clay accumulations represent various periods of landscape stability. The surface conditions must have been stable, probably with more vegetation cover during a wetter climatic cycle. Soil moisture is essential in the formation of calcrete nodules.

The light-colored sand between the two B_t/B_{tk} -horizon has very little clay and thus indicates a period of dune movement. This horizon represents a drought phase where no soil development took place, between two surface stability cycles, which were fostering soil formation. Paleosol I. and II. probably represent similar climatic conditions.

At this point it is difficult to compare paleosol I. and II. to sites further south in the Rolling Plains, because no calcrete nodules were present for the comparison of calcrete stages as proposed by GILE et al. (1966). However, the two paleosols can be compared to soils in the Southern High Plains by the size of the calcrete nodules, which were similar to stage I.- II., as identified by HOLLIDAY (1995) in the Lubbock Lake soil of stratum 4 (7,000 to 4,500 B. P.) in several of the investigated draws. At this point, without any age control from these paleosol remnants, comparisons can only be made with already dated soils.

Another sand sheet investigated can be located on the Plainview sheet of the Geologic Atlas of Texas (BUREAU OF ECONOMIC GEOLOGY, 1968, revised 1992) and was named Gasoline sand sheet. Sand deposits are marked mostly as Qs (standing for Quaternary sand) on the geology sheet and are covering parts of Briscoe, Motley and Hall Counties.

The sand sheet stretches on both sides along several rivers, including the northern forks of the Pease River, suggesting a western to southwestern wind direction for its formation. The western edge of the Gasoline sand sheet is located less then 16 km away from the Caprock Escarpment, which could have provided additional material as a sand source. The sand sheet is underlain by Permian strata, the Quartermaster Formation, and by Quaternary terrace deposits along the river forks.

The sand sheet is farmed in most parts, suggesting the probability of a higher clay content in the soil than in other sand sheets. There is an outcrop close to the town of Gasoline (Gasoline outcrop) located about 1.6 km south of the eastern turn off to FM road 599 at the southeastern edge of Briscoe county (cf. above, figure 44, p. 124). The opposite road side at this outcrop looks highly modified and washed over, but the side with the outcrop is undisturbed.

Across the road from the Gasoline outcrop, at the highly modified road side, evidence of early 20th century settlement was found. Some charcoal, glass and porcelain pieces, and parts of metal were found in the deflated field along with some more recent items. This could suggest a continuous history of settlement in this area, which could have enhanced deflation at this locale.

Gasoline outcrop:

1 - 35 cm	A -horizon, roots, burrows, coarser white grains
35 - 70 cm	transition of light-colored A_l -horizon and possibly weak B -horizon, burrows
70 - 130 cm	paleosol I.? or modern brownish colored B_t -horizon, clay enriched
130 - 170 cm	paleosol I. or II.? reddish sand, soft
170 - 210 cm	white cemented layer, water table?
210 - 220 cm	sand with gravel and clay enriched

The interpretation of this outcrop is difficult without any age control. It could be interpreted as having two remnants of paleosols, paleosol I, the brownish colored B_t -horizon and paleosol II., the reddish soft sand. The reddish soft sand could correspond to the lowest parts of paleosol II. at the Swenson-Peacock site, which also shows a similar soft red sand at the transition to the hard and red B_t-horizon above. In the Gasoline outcrop the hard red B_t-horizon above the soft red sand could have been eroded with the deposition of paleosol I.

However, no clear unconformity zones are visible for the proposed paleosol I. in the profile, unlike at the Meyer's, Swenson-Peacock and White River Reservoir outcrops. Therefore the most likely possibility is that this outcrop is in the process of developing a leached lower A_l -horizon with a clay enrichment in the B_t -horizon. The red sand, proposed as paleosol II. would then be a remnant of paleosol I., where in a sand reactivation much of a reddish B_t -horizon was eroded. This is the most likely scenario, since brown colors seem to correspond to modern B_t -horizon development in the area, whereas paleosol B_t-horizons seem to have more reddish colors in the Rolling Plains. This points to more Permian material as the sand source for paleosols as compared to dry riverbeds or active dune fields as sand source for sand reactivations today.

7.3. Correlations of depositional phases

Overall, it was shown in this chapter that there are very different sites with mid-Holocene depositional histories in the Rolling Plains of Texas. However, all five sites reflect with some degree of certainty the effects of the Altithermal, a proposed drier period between 7,000 to 4,500 years B. P., where droughts with extensive sand reactivations must have occurred. However, during this time extended soil development also took place, therefore enough soil moisture must have been available during some part of this period to produce profiles such as the Swenson-Peacock site. The climate during the Altithermal had most likely higher effective precipitation, increased temperatures and a greater seasonality (HOLLIDAY, 1995).

A correlation between the sites of the Rolling Plains and the Southern High Plains is possible. Time frames for eolian deposition in the Rolling Plains of Texas correspond to eolian deposition of stratum 4, a 1 - 3 m thick loamy to sandy eolian layer, usually forming the surface soils. This soil is termed the Lubbock Lake soil, and can be found along the sides of the draws (HOLLIDAY, 1995). Stratum 5 includes some eolian sediment (beginning 3,000 years B. P.), which probably corresponds to most of the well developed modern dune soils overlying paleosols from stratum 4, as for example at the Swenson-Peacock and Meyer's sites.

Pre-Altithermal deposition was only found at the Swenson-Peacock site and only dated with an upper limit for soil formation. It is suggested that the eolian deposition occurred at the beginning of the Holocene, perhaps corresponding to stratum C, a pedogenically, strongly modified eolian sand sheet depositing on the Southern High Plains during valley aggradation after 12,000 years B. P. However, since the lower part of paleosol II. was not dated, there is no age control for the beginning of the deposition for this unit.

The investigated outcrops show only two droughts extensive enough to have caused sand reactivation roughly at the beginning and at the end of the Altithermal. However, HOLLIDAY (1995) suggested that the earlier proposed two drought Altithermal is probably incorrect, as he has shown in draws on the Southern High Plains. There is a possibility for other droughts during that time, however, maybe not as severe at the particular sites in the Rolling Plains. Each site has a unique geologic and geomorphic setting and also different sand sources, which probably influence sand reactivations locally. Other locations could very well show additional drought-related reactivations during that time frame.

The investigated sites in the Rolling Plains have supported HOLLIDAY's (1995) findings for eolian sand deposition of strata 4 and 5 of dry valleys in the Southern High Plains. The environmental changes during the Holocene seem synchronous throughout the Rolling Plains region. The time frames for eolian reactivation are regionally similar in the Southern High Plains and Rolling Plains, but there are variations in the stratigraphy because of the geomorphic setting, hydrologic factors and differences in sand sources, which can influence specific sites differently.

Chapter 8. Summary and Conclusions

Chapters 5, 6 and 7 presented results from a variety of locales in the Rolling Plains of Texas. The geomorphic setting and pedogenic interpretation of soil profiles at the sites revealed differences in their depositional histories. With the aid of radiocarbon dating, time frames for their formation or reactivation periods were established. In this chapter, results will be summarized and correlated with reactivation phases identified by other researchers in the Great Plains and Southern High Plains region.

8.1. Conclusions

8.1.1. Brief statement of purpose

The main objective for this research was to identify eolian deposition and reactivation phases in the Rolling Plains of Texas. The site-specific depositional histories were developed and the causes of reactivations were identified at most locations.

An additional goal was to establish a Holocene time frame for sand deposition and reactivations in the Rolling Plains and correlate it with research performed by HOLLIDAY (1995) at draws on the Southern High Plains. In this chapter, eolian phases are compared to reactivations identified by other researchers in the Great Plains region to see if the Rolling Plains eolian deposition phases correspond to a regional climatic pattern during the Holocene.

The last objective was to answer two main questions. First, whether sand reactivations in the Texas Rolling Plains were localized or occurred on a regional scale. Secondly, whether recent sand reactivations were caused and fostered by anthropogenic modification of the landscape or if they were triggered by naturally induced climatic changes.

A variety of methods were used and tested to facilitate comprehensive results. Radiocarbon dates provided reliable results for establishing a chronology, especially for the older reactivations. Other methods used were thin section analysis, grain size analysis, scanning electron microscopy, pollen analysis, soil core analysis, interviews, and remote sensing.

8.1.2. Summary and discussion of results

This study concludes that the youngest eolian activity phase was enhanced by the onset of the cultural development of the area at the turn of the century. This is evidenced in multiple fence-line dunes throughout the Rolling Plains, but especially in the area around the city of Post.

The large amount of sand reactivations was attributed to the unique history of this town. C.W. Post, the founder of the city, introduced dry-land farming to increase the soil productivity and probably without anticipating the devastating consequences this would bear for soil fertility in the area. Large amounts of soil were eroded, in some areas down to the C-horizon (a Dockum sandstone). Soil fertility must have declined drastically with soil depletion culminating in the 1930s dust bowl era.

This study shows that the sandy material partially relocated along fences, creating fence-line sand dunes displaying very immature soil profiles as part of their depositional history. Calculations based on the height of the A-horizon of a paleosol within a fence-line dune and the soil loss from a field corresponded roughly to the height and length of the fence-line dunes.

Other eolian features, such as shinnery motts, simply are topographically higher and heavily vegetated areas in fields, which are being surrounded because the ground is too uneven to be plowed mechanically by a tractor. These dune-like features consequently grow taller every year as evidenced in consecutive aerial photography from 1970, 1980, and 1991.

This study revealed that climatic induced droughts were the trigger for sand reactivations prior to the cultural development of the area and probably still are, even today. This was demonstrated at a vegetated dune field with active patches near Estelline in Hall County, Texas.

Two buried B_t-horizons were radiocarbon dated for this research and revealed ages in the upper part of the horizon for a soil development phase at about 200± 40 and 340± 50 years B. P. These dates suggest that a landscape stability period around that time must have ended and a reactivation must have subsequently occurred, which eroded the A-horizon and buried the B-horizon.

These dates for sand reactivations were compared with recorded data from STAHLE and CLEAVELAND (1988). They established the June Palmer Drought Severity Index record through Post Oak (*Quercus stellata*) tree ring chronologies, which indicates three main droughts since 1698. The youngest of the paleosols (200± 40 years B. P.) corresponded roughly to one of the droughts around 1772.

To investigate the depositional history of the dune field, a sand transportation rose based on drought data during the 1950s, recorded by JOHNSON (1965), was prepared. The calculated sand-transporting winds are from the southwest and western direction; hence sand transportation originates in the riverbed.

This developed hypothesis is supported by grain size distribution data, prepared for this study, and a comparison of aerial photography from 1954 and 1985. Both provide evidence of sand transport onto the vegetated part of the dune field from the riverbed during the 1950s drought. Hence, this study concludes that the Prairie Dog Town Fork of the Red River is the sand source for the Estelline dune field. However, the dune field has also active patches that are local blow-outs and probably were reactivated during a drought, when the protective vegetation was lost.

This research also found older sand reactivations during the Holocene, especially during the mid-Holocene Altithermal. The Altithermal was a drier period with greater seasonality and probably more severe drought events then today. Radiocarbon dates from this study from two sites in the Rolling Plains show evidence of the Altithermal, which was also established on the Southern High Plains by a variety of data (HOLLIDAY, 1995).

The first site investigated, the Swenson-Peacock locale in Stonewall County (Rolling Plains), shows two buried paleosols and a modern soil. These paleosols are remnants of “Parabraunerden”, generally showing an A-A_h-A_l-B_t-C profile, and the sandy version of this soil usually develops lamellas instead of a continuous B_t -horizon in Europe (SCHEFFER and SCHACHTSCHABEL, 1992).A radiocarbon analysis was performed on three different horizons at this locale. Below the modern soil, the upper lamella horizon of the paleosol I. was dated at 4,320± 90 B. P. and the lowest lamella at 6,090± 90 B. P. The lowest sandy clay (paleosol II.) was dated in the upper part at 7,070± 160 B. P.

At the Meyer’s site in Hutchinson County, the studied soil profile shows a modern soil and one paleosol, which was radiocarbon dated at 5,210± 80 B. P. These horizons are separated by a deflation lag. This suggests at least one sand reactivation phase some time after 5,210± 80 B. P. The profile shows two soil development phases. The lowest horizon (paleosol I.), comprised of sandy clay, has some calcrete nodules and other small-sized gravel. This horizon is overlain by a 1cm band of calcrete nodules and small-sized gravel.

The lower soil (paleosol) was deflated, accumulating calcrete nodules and gravel, which resulted in an armored layer protecting the soil from further erosion. This study found that the accumulation and soil development phase for this paleosol occurred during the Altithermal, as proposed by HOLLIDAY (1995) and FERRING (1990), with a duration from 7,000 to 4,000 years B. P.

Three additional sites support this evidence with similar pedogenic imprints in the paleosols, suggesting their formation during a similar time frame. These buried paleosols probably also developed during the Altithermal at these additional locations.

Overall, it can be concluded that in the Rolling Plains buried B_t -horizons, which developed during the Altithermal, generally have reddish colors. However, if the Ogallala or Dockum formations were the sand source for the soil, they developed more brownish colors in the paleo-B_t -horizon. This could indicate that the source material had more influence on the coloration of the soil than pedogenic processes, meaning that source material is probably more important than climate in soil formation processes in the area. Modern B_t -horizons have predominately brownish colors, suggesting sand reactivation from dry riverbeds (mostly eroded escarpment material) as a sand source, rather than eolian deposition from the reddish materials of the Permian Formation.

Profiles in the study area have shown that these modern soils also vary in maturity level, which could suggest that sand reactivations are frequently associated with droughts; however, not all areas will necessarily be affected during the same drought. Other factors influencing sand reactivations today are ranching and agricultural utilization of the land, which destroy the naturally protective vegetation cover.

The above results from this study suggest that eolian deposition and erosion were probably regional during the Altithermal and at the onset of the Holocene. These results are supported by research from HOLLIDAY (1995), who also found evidence of the Altithermal on the Southern High Plains. Some sites, however, show localized sand reactivation during the late Holocene and present times. These reactivations were probably of different intensity than those during the Altithermal and happened during different time frames at several locations, as evidenced in varying maturity levels of modern sandy soils at these locations. Active dune patches and blow-outs in the Hall County dune field area provide evidence of localized sand reactivations during the past several hundred years. Overall results from this study suggest that there were probably no significant dune reactivations during Indian occupation.

In conclusion, the intensity of sand reactivations depends mainly on climatic conditions, such as the duration and intensity of droughts during the Holocene. Drier climates with pronounced droughts lead to broad scale regional sand reactivations. Localized blowouts and eolian reactivations, on the other hand, depend mostly on the geomorphic setting and environmental conditions in combination with short-term droughts during present times, and are additionally influenced by land use.

The chronology from eolian reactivation and stabilization phases in the Texas Rolling Plains can be compared to time frames from the Great Plains, Nebraska Sand Hills, and Canada regions. Figure 16 in chapter 2 shows that researchers in the Great Plains (GAYLORD, 1990; MUHS, 1985; FOREMAN, GOETZ and YUHAS, 1992; MADOLE, 1994; ARBOGAST, 1995; AHLBRANDT, et al., 1983; SWINEHART et al., 1995) have found a variety of sand reactivation and soil development phases.

Other researchers had previously established eolian reactivations at all of the investigated sand deposits in the Great Plains and Southern High Plains region during the Altithermal dry period. However, the boundaries and number of reactivations during the Altithermal that have been established in the Great Plains and Southern High Plains regions between 7,000 - 4,000 years B. P. vary significantly between the deposits and areas.

MUHS (1995) investigated stabilized parabolic dunes in northeastern Colorado and proposed the accumulation of the older underlying sands during the Altithermal. GAYLORD (1990) investigated a 25 m thick sequence of dune and interdune strata in Wyoming, revealing two intervals with enhanced eolian activity episodes roughly between 7,000 and 4,000 years B. P. FOREMAN, GOETZ and YUHAS (1992) identified at least four sets of eolian reactivation in the High Plains of Colorado during the past 10,000 years. One of these episodes falls within the Altithermal time frame.

MADOLE (1995) recognized three major sand units in eastern Colorado that essentially span the time from 22,500 to 150 B. P., with the exception of possibly wetter conditions without eolian activity or no record shown between 8,000 and 9,000 B. P. One of the periods between 8,000 and 1,000 years B. P. covers the entire Altithermal and even expands beyond.

ARBOGAST (1995) identified six periods of pedogenesis on the Great Bend Sand Prairie in Kansas around 6,300, 2,300, 1,500, 1,000, 700 and 200 years B. P., with weakly developed A-AC-C soil profiles. The most intense periods of dune mobilization occurred between 5,700 - 4,800, 2,300 - 1,700, 1,600 - 800 and < 200 years B. P. (ARBOGAST, 1993). The first of these sand mobilization periods occurred during the Altithermal time frame.

AHLBRANDT, et al. (1983) limited eolian activity to the last 7,000 years in Great Plains and Rocky Mountain Basins dune fields. PORTER et al., (1995) found at least two dune reactivation periods in southwestern Kansas. The most recent deposition occurred between 1,600 and 1,300 years B. P. The other phase of dune reactivation occurred around 5,570 years B. P., which is during the Altithermal.

The Nebraska Sand Hills were re-investigated by SWINEHART and AHLBRANDT after they have long thought to be Pleistocene of age. Their study found major sand reactivation periods during the last 7,000 years B. P. (AHLBRANDT et al., 1983).

Fieldwork by other researchers in the Nebraska Sand Hills presented during a Geological Society of America field trip suggests that at the Red Ranch locale the lower parts of the profile are composed of Pliocene sands, probably dated at about 2.5 and 2 million years old. Sand overlying the Pliocene sands shows in a preliminary optically stimulated luminescence (OSL) date of a middle to late Holocene age of about 3,000 years (STOKES , 1993, pers. comm., cited in MAY et al., 1995). The upward extension of the same outcrop shows late Holocene dune sand with very young and immature soils. The uppermost soil is dating with two different samples at 220± 90 and 220± 60 years B. P. and the lower one at 450± 90 and 770± 90 years B. P. (MAY et al., 1995).

Concerning these very young dates MUHS and colleagues (MUHS et al., 1995) believe that sands are much older in the Nebraska Sand Hills because their study showed that these sands are feldspar depleted and quartz enriched. There are two possible interpretations: either that sands already underwent soil development phases prior to reactivation, where feldspars were chemically altered and degraded, or that during the process of saltation feldspar was mechanically destroyed. However, both solutions suggest reworking of older sands. The Nebraska Sand Hill setting seems very similar to some of the settings in the Rolling Plains, where older formations, such as the Permian are overlain by younger buried soils possibly pointing towards younger reactivations of older sediments.

A study by WOLFE et al. (1995) the semiarid Great Sand Hills region (also known as the Palliser Triangle) of Sakatchewan in Canada revealed very young sand dune reactivations. Dunes located in this region showed evidence of dune activity in the past 200 years. These dunes are also reactivated from older sediments such as from glaciofluvial, glaciolacustrine, and deltaic environments.

WOLFE et al. (1995) reports of some re-activated eolian deposits in the Palliser Triangle. Results from this study show that in the past 50 years, dune activity resulted from precipitation and temperature variations. The overall trend in the past 50 years, however, seems to be toward stabilization of these active dunes. Their results correspond with results from the visual comparison of 1954 and 1985 aerial photography of the Estelline dune field in the Texas Rolling Plains, which also shows a trend to stabilization of some of the active dune areas.

As part of their study optical stimulated luminescence dates revealed reactivations all younger than 200 years A. D. (WOLFE et al., 1995). The exact age dates of reactivated sands are 173± 10, 210± 12, 940± 60, 70± 15, 110± 10 and 97± 10 years B. P. Seven other samples show mid-Holocene soil development phases (WOLFE et al., 1995), which is similar to samples from sites in the Rolling Plains.

Overall, there are problems in correlating eolian reactivation and stabilization time frames that have been established by a number of researchers using different stratigraphic units in the Canada, Great Plains, Southern High Plains and Rolling Plains regions with a variety of methods. Factors that can influence the correlations are differences in dating techniques and the laboratories used, source materials, the geomorphic setting, erosional versus depositional environments, regional versus localized reactivations, and differences in the cultural development of the area.

There are ample eolian phases throughout the three regions, suggesting prolonged droughts during much of the Holocene. Dating the start and ending of these drought periods, and thus eolian reactivation phases, is problematic. Usually a sand reactivation period accompanied by high winds erodes the A-horizon and perhaps also part of the B-horizon, depending on the soil development stage and the soil material. This was shown near Post in the Rolling Plains of Texas, where at one location, much of the B-horizon was deflated only during this century.

When climatic conditions change, protective vegetation cover grows and sand begins to deposit again. The beginning of a new soil development phase, and also the depth to which the paleosol erosion took place, can be dated. However, in between these two soils, there is a potential time frame from which material has been eroded and is lost. This is evidenced in a deflation lag and discontinuous paleosol profiles in the study area.

The depth of erosion depends very much on local and environmental factors, such as variations in geomorphic setting, source material, soil development stage and wind speeds. Since these factors are different at various sites, the duration of eolian phases will vary locally.

The variations of the Altithermal boundaries and differences in reactivation phases are probably influenced by the problems explained above. The other possibility is that the Altithermal might have had different duration and drought cycles in the different regions.

No clear delineation of the ending of the Altithermal dry period can be depicted in the Great Plains region, such as was done in the Southern High Plains region (HOLLIDAY, 1995). More comparative research has to be done in Great Plains, Southern High Plains and Rolling Plains regions to correlate sand reactivations and more accurately deduce the paleoclimatic conditions during the Holocene.

8.2. Further implications of this research

The eolian reactivation and stabilization phases in the Rolling Plains of Texas can be compared to well-established and forthcoming eolian research from the Southern High Plains and Great Plains regions. So far there has not been a comprehensive attempt to correlate established eolian reactivation and stabilization phases throughout the mid-western Great Plains section of the U.S.A.

This research is the first to determine eolian reactivation and stabilization phases and their causes on a regional and local scale during the Holocene in the Rolling Plains of Texas. These results will allow the integration of eolian deposition and soil development phases from several sites spread throughout the study area with chronologies from other regions. These comparisons of different chronologies in various adjacent regions are an important tool for determining climatic conditions during the Holocene. The results from this research can be compared to the paleoclimatic record of the Southern High Plains and Great Plains regions.

This research fosters a better understanding and raises awareness of land degradation of sand sheets and dune fields as a result of interactions between reoccurring droughts and land use management practices during this century.

Soil conservation agencies can to some extent help to protect the soil from further erosion through education about soil erosion prevention methods. However, erosion processes are often triggered and greatly enhanced by drought conditions, the uncertain factor in the equation of land degradation, and droughts in turn lead to sand reactivations. An increase in the amount of prolonged droughts will certainly reactivate more sand sheets and dune fields, as will an increase in land degradation. However, a more severe shift to a drier climate is probably necessary to create environmental conditions that will trigger the kind of large scale eolian reactivations that were more common during the Altithermal.

8.3. Restatement of scope

Unfortunately, the presented record of sand reactivation phases does not provide a complete chronology at every location in the Rolling Plains of Texas. First, the study area is part of an erosional landscape. Second, reactivations did not occur everywhere simultaneously, especially not during the last several hundred years. Third, only a relatively small number of sites were investigated and age dated due to financial constraints and the need to not exceed the scope of this research.

Erosion or preservation of sediments are dependent on a variety of factors, such as geomorphic setting, climate, environmental conditions, and human impact. This complicates the analysis of radiocarbon dates and makes comparison with other regions necessary to obtain additional information to depict reactivation and soil stabilization phases more accurately. Hence, research has to simultaneously occur in a larger setting, preferably with a variety of researchers from different fields interacting to enhance results on paleoclimatic conditions during the Holocene.

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Lebenslauf

Ich, Martina Ursula Blüm, wurde am 27.2.1964 in Schweinfurt geboren. Meine Eltern sind Dr. Heinz Blüm und Margarete Blüm. Ich besuchte die Kerschensteiner Grundschule in Schweinfurt von 1970 bis 1974 und wechselte dann auf das Alexander von Humboldt Gymnasium ebenfalls in Schweinfurt und erhielt das Abitur in 1984. Ich besuchte die Bayerische Julius - Maximilians Universität in Würzburg im Fachbereich Geographie von 1984 bis 1989. Ich beendete das Hochschulstudium mit dem Diplom in 1989 mit der Gesamtnote "gut". Das Thema der Diplomarbeit lautete: "Alter und Überformung der Dünen im Stufenvorland, in der Stufe, und auf der Hochfläche des Steigerwaldes am Flächenpaß von Geiselwind und ihre morphologische Umgebung." Meine Nebenfächer waren Verwaltungsrecht und Geologie. Ich bestand außerdem im Juli 1990 die akademische Zwischenprüfung, Lehramt Geographie mit der Note "befriedigend".

Im August 1990 ging ich zu einem Fortbildungstudium an die University of Texas at Austin in den U.S.A. Ich began mit einem Auslandsaustauschprogram der Universität Würzburg von 1990 bis 1991. Nach Ablegen des G.R.E. erhielt ich dann die Genehmigung zur Aufnahme in das 'Graduate Program' in 1991 im Department of Geography, wo ich dann mit dem Master´s Degree (M.A.) in 1994 (Gesamtnote 3.6, wobei im amerikanischen System die Bestnote 4.0 ist) abschloß. Der Titel der Master's Arbeit lautete: Eolian deposits in Hall County, Texas: A geographic information sytems (GIS) evaluation for paleoclimatic research.

Danach wurde ich in das Teacher Certification Program an derselben Universität aufgenommen und beendete es als Lehrerin in Social Science, mit dem Fachbereich Geographie (Gesamtnote 3.3, wobei die Bestnote 4.0 ist). Das Referendariat machte ich an der Austin Highschool in einer 9. Klasse von August bis Dezember 1995, abgeschlossen mit der Referendariatsnote 4.5, wobei die Bestnote 5.0 mit dem 'high degree of excellence' ausgezeichnet ist. Ich bestand die Certification Prüfungen in Texas in Geography und Deutsch.

Zudem habe ich den International Teaching Assistant/Assistant Instructor English Oral Proficiency Assessment Test mit 295 Punkten bestanden (Bestnote 300 Punkte). Dieser Test erlaubte mir an der University of Texas at Austin zu unterrichten. Ich wurde dann im August 1992 als Teaching Assistant im Department of Geography at the Univertsity of Texas at Austin angestellt und unterrichtete die Seminare GRG 301C Physical Geography, GRG 305 Cultural Geography bis zum Mai 1993.

Um mein Studium in den USA zu finazieren arbeitete ich im Bureau of Economic Geology at the University of Texas at Austin als Graduate Research Assistant (März 1991 - Mai 1992, Juni 1993 - September 1997). Ich habe im Bureau of Economic Geology an folgenenden Publikationen und Berichten mitgearbeitet:

Dutton, A., Mace, R., Nance, S., M. Blüm. 1995. Geologic and hydrologic framework of regional aquifers in the Twin Mountains, Paluxy and Woodbine Formations near the SSC site, north-central Texas. (Part II).

Dutton, A., Bennet, P., Tweedy, S. and M. Blüm, 1996. Analysis of the subsurface oil plume and evaluation of remediation alternatives - Chiltipin creek site, San Patricio County, Texas.

Paine, G., Dutton, A., Blüm, M., Boghici, E., Nelson, I., Trembley T., and S. Tweedy. 1996. Airborne and ground-based geophysical screening of potential brine infiltration sites, Runnels County, Texas.

Mullican, W.F. III, Dutton A., Mace, R., and M. Blüm. 1997. Reevaluation of ground-water resources on state lands in eastern El Paso County.

Smyth, R., Dutton, A., Nava, R., Gibeaut, J., and M. Blüm. 1997. Site investigation and evaluation of remedial alternatives for the Vinson site, Jones County, Texas.

Sullivan, J., Dutton, A., Nava, R., Mahoney, M., Gibeaut, J., and M. Blüm. 1997. Site investigation and evaluation of remedial alternatives for the Vernon Briggs site, Matagorda County, Texas.

Mahoney, M., Dutton, A., Sullivan, J., Nava, R., Paine, J., Gibeaut, J., Blüm, M., Choi, W.J. 1997. Site investigation and evaluation of remedial alternatives for the Mandi-Injecto site, Tom Green County, Texas.

Sullivan, J., Dutton, A., Nava, R., Mahoney, M., Gibeaut, J., Blüm, M., 1997. Site investigation and evaluation of remedial alternatives for the Post Oak site, Lee County, Texas.

Ich habe außerdem bei wissenschaftliche Tagungen folgende Vorträge gehalten:

Eolian features in the Texas Rolling Plains and their implications for past climates. 1993. Association of American Geographers annual meeting, Atlanta, Gorgia, U.S.A..

Eolian deposits in Hall County, Texas: A GIS evaluation for paleoclimatic research. 1993. Southwestern association of American geographers meeting, Fayettville, Arkansas, U.S.A.

Eolian Deposits of the Geiselwind gap at the Steigerforest escarpment, Germany. 1994. Association of American Geographers annual meeting, San Francisco, California, U.S.A.

History of ground-water production from cretaceous sandstone aquifers of north-central Texas. 1994. Southwestern association of American geographers meeting, Little Rock, Arkansas, U.S.A. Zusammen mit Robert Mace als coreferent. Bureau of Economic Geology, University of Texas at Austin.

Episodes of sand mobilization and stabilization in the Rolling Plains of Texas. 1996. Geological Society of America, south - central meeting, Austin, Texas, U.S.A.

The Texas Rolling Plains: Anthropogenic desertification? 1996. Association of American Geographers annual meeting, Charlotte, North Carolina, U.S.A.

Außerdem wurde ich zu einem Symposium als Vortragende zum Thema 'Eolian deposits in the Texas Rolling Plains' eingeladen. (Symposium der 29th annual meetings, north-central and south-central sections of the geologic society of America, 1995, Lincoln, Nebraska, U.S.A.. Session: Quaternary eolian deposits of the midcontinent: loess, sand, and ash (II))

Ich erhielt als vortragende Studentin die folgenden Auszeichnungen. Den 2. Preis für meinen studentischen Vortrag bei der Southwestern Association of American Geographers Tagung (1993), in Fayettville, Arkansas, U.S.A. mit dem Thema ‘Eolian deposits in Hall County, Texas: A GIS evaluation for paleoclimatic research.’ Und noch einmal einen 2. Preis erhielt ich für den Vortrag: Episodes of sand mobilization and stabilization in the Rolling Plains of Texas bei der ‘Geological Society of America south - central’ Tagung, in Austin, Texas, 1996.

Seit November 1997 arbiete ich bei der Lower Colorado River Authority (LCRA) in Austin Texas als ‘Computer system analyst’ in der “Surveying and Mapping” Abteilung. Mein Hauptaufgabenbereich liegt in der Anwendung von GIS. Im Jahre 1999 bin ich zum Senoir GIS Analyst in der WaterCo Abteilung befördert worden und arbeite nun in den Themengebieten der DFIRM Production und Floodplain Mangement. Seit ich in WaterCo bin habe ich an folgenden Fortbildungen teilgenommen:

Designing the Geodatabase, ESRI, December 2000 (5 Tage)
What’s New in ArcInfo 8, ESRI, June 2000 (4 Tage)
Cooperative Technical Community Workshop (CTP), FEMA, June 2000 (5 Tage)
Project Delivery Systems, CH2MHILL, February 2000 (2 Tage)
Managerial Grid, LCRA, October 2000 (5 Tage)
Programming with Avenue, ESRI, December 1999 (3 Tage)
ARC/FM conference seminar, ESRI, June 2000 (1 Tag)
Introduction to Maximo Work Order Management System (4 Tage)

Seit der Beförderung habe ich mehrere Konferenzen in der U.S.A. besucht und die foldgenden Themen präsentiert:

Association of Civil Engineers Conference, Texas Section, April 2001, San Antonio, Texas
Title: Dr. Bluem, M., Dr. McLeod J., 2001: Map modernization using GIS: Lessons learned from the digital conversion process of FIRM maps.
(Invited and published paper)

Association of State Floodplain Managers Meeting, June 2000, Austin, Texas,
Title: Dr. Bluem, M., Dr. McLeod J., Kevin Donnelly, 2000: Map modernization using GIS: a DFIRM Pilot Project for Lago Vista Texas
(Published paper)

Association of State Floodplain Managers Meeting, June 2001,Charlotte, North Carolina,

Title: Dr. Bluem, M., Riley, C., Dr. McLeod, J., and Jack Quarles: A DFIRM for Meadowlakes, Texas – The next challenge in GIS map modernization
(Published Paper)

National Hydrography Data (NHD) conference, Austin, Texas, December 2000
(Attended)

ESRI GIS user conference, June 2000, San Diego, California
(Attended)

Seit eingen Wochen bin ich in die Water Resources Abteilung versetzt worden um an einem neuen Project (SAWS, San Antonio Water Systems) mit der Stadt San Antonio zu arbeiten. Seit dem letzten Jahr habe ich mehrer Auszeichnungen von der Lower Colorado River Authority erhalten.

Certificate of Appreciation for the dedication and support of the Texas Colorado River Floodplain Coalition, June 2001.

Community Service Award honoring volunteer commitments during the year 2000 presented by Joseph J. Beal, P.E., LCRA General Manager.

Making A Difference Award presented by LCRA WaterCo for efforts made and extra hours worked during the flood events in October/November 2000.

Making A Differnce Award presented by LCRA WaterCo for skills associated with contractor negotiations on the Floodplain Mapping Project.

Ich wurde 1995 als Mitglied in die Ehrengesellschaft ‘Pi lambda theta’ aufgenommen. Dies ist eine internationale Ehrengesellschaft in den Erziehungswissenschaften. Meine Sprachkenntnisse sind Englisch (fließend in Wort und Schrift), Portugiesisch (Grundkenntnisse), Französisch (ausbaufähig) und Latein.

Die Referenzen sind auf Anfrage erhältlich.