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Abstract

A pilot study has yielded the first infrared stimulated luminescence (IRSL) age from the upper part of the eolian Blackwater Draw Formation near its type locality in the Southern High Plains of Texas. The age on potassium feldspar is 294 ± 32 ka (50°C IRSL) and 347 ± 40 ka (290°C post-IR IRSL) and averaged 300 to 350 ka. Both ages are significantly earlier than previously reported thermoluminescence (TL) ages. A Middle Pleistocene age of the upper Blackwater Draw Formation is consistent with its mature argillic soil Bt horizon and the overprint of a well-developed calcic soil Bk horizon. The deposition of the Blackwater Draw Formation also pre-dates the Mescalero sand sheet of southeastern New Mexico, a late Pleistocene component of which has been miscorrelated with the Blackwater Draw. The tendency to regard all red eolian sands in the region as the Blackwater Draw Formation may be mistaken, overlooking younger red eolian sand bodies with less mature soil development.

Introduction

The Southern High Plains of Texas and eastern New Mexico formed on the resistant caprock calcrete of the Ogallala Formation. A prominent eolian sand deposit mantles the calcrete across the plains. It was noted by Frye and Leonard (1957), who documented it as a brick-red to dark-red silty sand 1.2 to 7.3 meters thick with caliche in the upper part. They called the deposit by the informal name "Cover sands" instead of naming it a formation. They referred to it as a complex of two or more sands of different ages, including the younger dune field topography of the Judkins Formation to the south and the older sheet sands to the north. Based on the stratigraphy and physiography of its occurrence, they concluded that the "Cover sands" began forming post-Kansan in the dry Yarmouthian and continued to form in the wetter Illinoian (Frye and Leonard, 1957, p. 28-29). Subsequently, the Cover sands were named the Blackwater Draw Formation by Reeves (1976), who recognized its variability. We sampled for luminescence dating the upper Blackwater Draw Formation near its type exposure in order to refine its geochronology and to critique the claim by others (Rich and Stokes, 2011) that the Blackwater Draw Formation extends into the Mescalero Plain of southeastern New Mexico.

Blackwater Draw Formation

The stratigraphy of the Blackwater Draw Formation is highly variable across the Southern High Plains. The formation directly overlies the caprock calcrete of the Ogallala Formation in most areas across the plains. Its thickness extends from zero to 27 meters (Reeves, 1976) and it is dominated by very fine to fine sand representing sheet sand and loess accumulation on a grassland savanna or prairie, the deposits derived by eolian processes (Gustavson, 1996). A modern-surface soil and four buried soils have been described at the type section (Reeves, 1976; Holliday, 1989).

The stratigraphy and age of the Blackwater Draw Formation are discussed and summarized by Gustavson (1996). The lower part of the formation contains the 1.61-Ma Guaje ash (Izett and Obradovich, 1994; Holliday, 1988). The modern-surface soil and argillic horizons of four buried paleosols at the 9.5-m-thick type section of the Blackwater Draw were analyzed for paleomagnetism. The modern-surface and first buried (b1) soils extend to about 4 meters depth and have normal polarity. The second buried soil (b2) has reversed polarity. The lower two buried soils (b3 and b4) have a mix of normal and reversed polarity (Holliday, 1989; Patterson and Larson, 1990). The change in magnetic polarity at about 4 meters depth is interpreted as the Matuyama-Brunhes boundary (Patterson and Larson, 1990) at 776 ka (Coe and others, 2004). Overall, given the presence of the volcanic ash and the paleomagnetic stratigraphy, the earliest age of the Blackwater Draw Formation is estimated as 1.6 to 1.8 Ma (Gustavson, 1996).

The age of the upper boundary of the Blackwater Draw Formation is less certain. At the type section, a thermoluminescence (TL) age from the first buried argillic paleosol (b1) at about 3.2 m depth is 118 ± 14 ka. A stratigraphically lower TL age from the second buried argillic paleosol (b2) at about 4.4 m depth is >270 ka (Holliday, 1989), although the reversed polarity of the b2 paleosol indicates an age greater than 776 ka (Patterson and Larson, 1990; Coe and others, 2004).

In the vicinity of the type locality, at the Dune site, a TL age of 28.6 ± 4.0 ka was obtained from the top of red sands identified as the Blackwater Draw Formation. However, overlying eolian dune sands were dated earlier by both TL (42.72 ± 4.47 ka) and radiocarbon (33.75 ± 3.6 ka) (Holliday, 1985), although the two-sigma errors of the ages overlap. Based on published descriptions, the red sands at the Dune site lack the mature argillic soils that are typical of the upper Blackwater Draw Formation; we suggest that these red sands may represent a younger episode of eolian sand deposition that post-dates the Blackwater Draw Formation.

Study Area

The type section of the Blackwater Draw Formation was described and defined by Reeves (1976) at a deeply cut gully on the right bank of Blackwater Draw north of Lubbock, Texas. At present, the gully is partially filled in with construction debris and the outcrop is not easily accessible. Approximately 1.0 km east of Reeves' type exposure along the same east-west section line is a recent gully that exposes the upper four meters of the Blackwater Draw Formation (Figs. 1, 2). The base of the formation and its contact with the underlying Ogallala Formation is not exposed in the gully. About 35 to 45 cm of recent eolian-colluvial sediment rests on the eroded surface of the Blackwater Draw Formation. The young sandy sediment incorporates carbonate clasts derived from the underlying Blackwater Draw Formation and does not exhibit significant pedogenesis.

Downslope, toward the draw, the uppermost decimeters of the formation have been removed by slope erosion. The material that was luminescence-dated, however, was collected from 40 to 50 cm below the top of the exposed formation where local slope erosion appears to have been minimal. The upper argillic and calcic paleosol that we sampled for luminescence dating appears to be similar to the upper paleosol (b1) at the nearby type section (Holliday, 1989). Because of the hardness of the clayey sediment, the IRSL-dated material was chopped out of a fresh exposure in a block, then the material was wrapped in tinfoil in the field. Samples for chemistry and moisture analysis were also collected from the same spot. Samples for sediment analysis were collected at the same stratigraphic section. The dated exposure is located northwest of the community of New Deal at latitude 33° 45′ 58.7″ N, longitude 101° 51′ 42.9″ W (NAD 83), Lubbock County, Texas.

Methods

Luminescence dating

Sample preparation was carried out under amber-light conditions. The outermost layer of the sample was removed and the remainder wet sieved to extract the 90–150 μm fraction, and then treated with hydrochloric acid (HCl) to remove carbonates and with hydrogen peroxide to remove organics. Quartz and K-feldspar grains were extracted by flotation using a 2.7 g/cc sodium polytungstate solution. The portion used for quartz optically stimulated luminescence (OSL) was then treated for 75 minutes in 48% hydrofluoric acid (HF), followed by 30 minutes in 47% HCl. This portion was then re-sieved and the <90 μm fraction discarded to remove residual feldspar grains. The etched quartz grains were mounted on the innermost 5 mm of 1 cm aluminum disks using Silkospray. The portion used for potassium feldspar infrared stimulated luminescence (IRSL) consisted of grains separated by an additional flotation using a 2.58 g/cc sodium

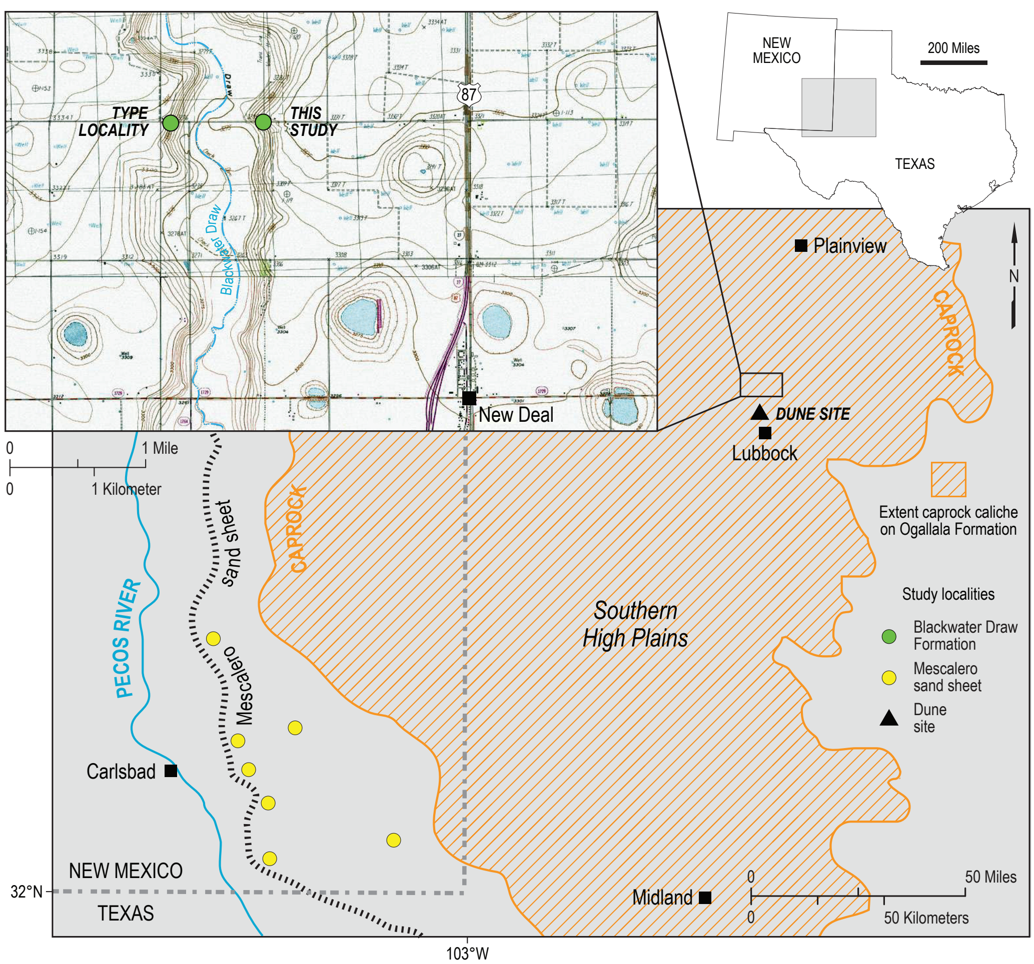

Figure 1. Location map of Blackwater Draw Formation (BDF) type section and this study site; the Dunes site mentioned in the text occurs about 8 miles south of our study locality (Holliday, 1985); yellow circles are occurrences of the Berino paleosol and Lower eolian sand unit (OSL age 90 to 50 ka) in the Mescalero sand sheet from Hall and Goble (2016).

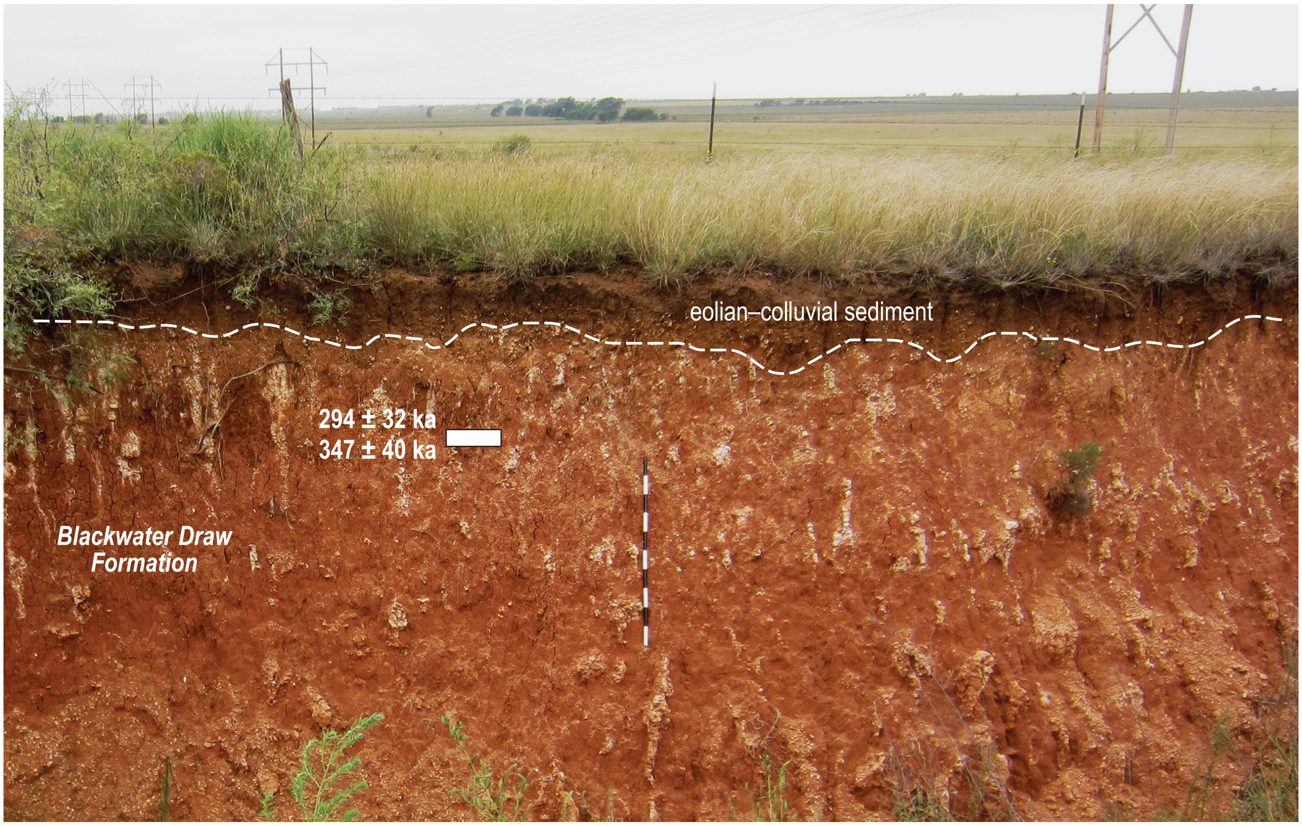

Figure 2. Upper part of the Blackwater Draw Formation in the Southern High Plains, Lubbock County, Texas, sampled for luminescence dating at 40–50 cm below the top of the formation. Eolian sediment of the formation is fine to very fine sand. High iron and clay content is a consequence of pedogenesis. Secondary carbonate is preferentially aligned in vertical fractures, perhaps accumulating during the Sangamon. Overlying, younger eolian-colluvial sediment may be late Holocene in age; photograph taken before sample collection; 1-m scale.

polytungstate solution, then treated for 40 minutes in 10% HF to etch and remove the outer alpha-irradiated layer from the rims, followed by 30 minutes in 47% HCl.

Chemical analyses were carried out using a high-resolution gamma spectrometer. The feldspar dose-rate was calculated using an assumed K_2O content of 16.9% (pure potassium feldspar). Dose-rates were calculated using the method of Aitken (1998) and Adamiec and Aitken (1998) and the updated dose rate conversion factors of Guerin et al. (2011). The cosmic contribution to the dose-rate was determined using the techniques of Prescott and Hutton (1994).

Luminescence measurements

Luminescence analyses were carried out on Risø Automated OSL Dating System Models TL/OSL-DA-15B/C and TL/OSL-DA-20, equipped with blue and infrared diodes, using the Single Aliquot Regenerative Dose (SAR) technique for quartz (Murray and Wintle, 2000). Early background subtraction (Ballarini et al., 2007; Cunningham and Wallinga, 2010) was used. Preheat and cutheat temperatures of 240°C/10s and 220°C/10s were used for the quartz OSL measurements. Growth curves showed that the sample was above saturation (D/Do >2; Wintle and Murray, 2006), above which uncertainty in signal estimation results in larger, and asymmetrical uncertainty in equivalent dose estimation (Murray and Funder, 2003; Murray et al., 2002). Typical growth curves observed from single aliquots of the sample during blue OSL, 50°C IRSL, and 290°C post-IR IRSL are shown in Figure 3. Signal data have been arbitrarily scaled to 100% maximum. Note that the blue OSL curve saturates on a plateau at a much lower applied dose that do the two superimposed IRSL curves. Blue OSL signal data from an aliquot of quartz plot at approximately 320 Gy (98% of full saturation) on the upper curve, whereas IRSL and post-IR IRSL data plot at approximately 600 Gy and 770 Gy, respectively, on the lower curve, well below saturation. Although the feldspar signal saturates at a much higher level than does the quartz signal, anomalous fading, a decrease in signal level with time, is an inherent problem for which correction must be made. Recent attempts to minimize the effect has led to several newer measurement techniques which utilize an initial IRSL measurement at 50°C, followed by a subsequent measurement at 225°C or 290°C (post-IR IRSL) (Thiel et al., 2011; Buylaert et al., 2009); 290°C post-IR IRSL was used for the Blackwater Draw sample.

Measurements for 50°C IRSL and 290°C post-IR IRSL were carried out on feldspars using the dating protocol outlined by Thiel and others (2011). Data for skew, kurtosis, and overdispersion shown in Table 1 indicate that the central age model (Galbraith et al., 1999) is appropriate for equivalent dose calculations (Bailey and Arnold, 2006; Galbraith, 2005). Equivalent doses were corrected for residual dose of 7.59 ± 0.55 Gy (50°C IRSL) and 31.61 ± 1.40 Gy (290°C post-IR IRSL). Fading corrections were determined over a 5 month

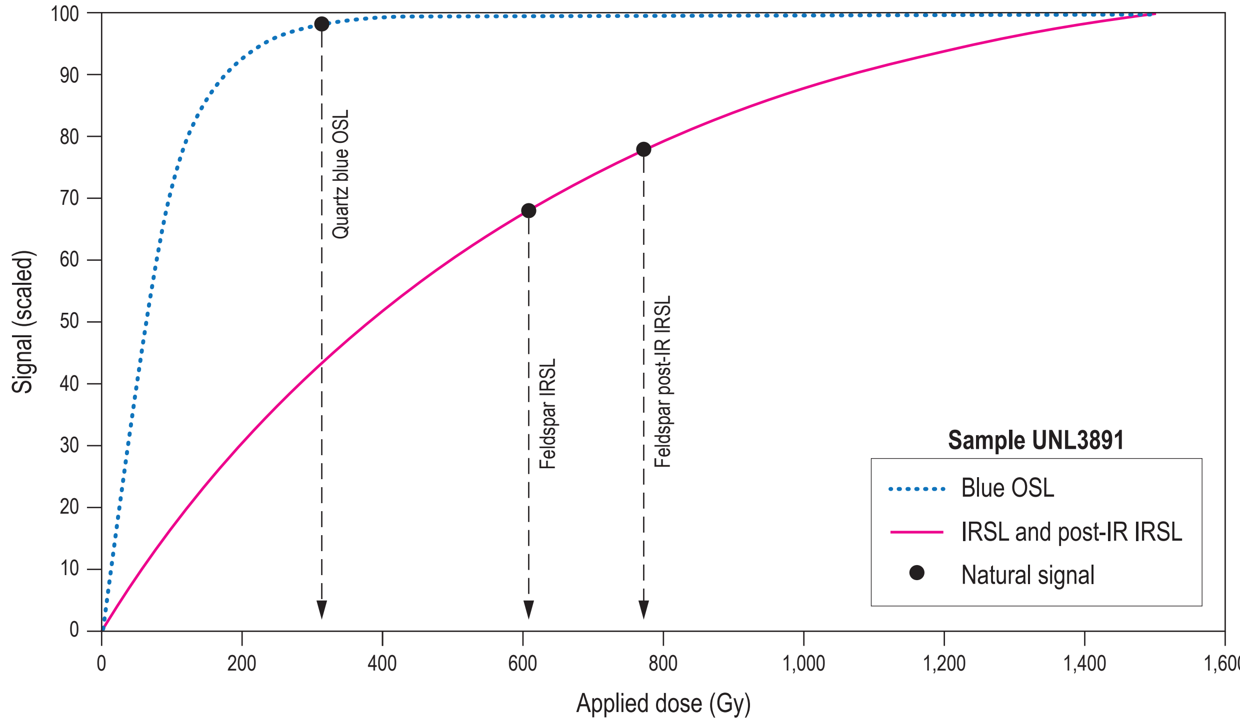

Figure 3. Growth curve for single aliquots of UNL3891 calculated from data recorded during blue OSL, 50°C IRSL and 290°C post-IR IRSL. The latter two curves are superimposed. The signals have been scaled to 100% maximum. Natural signal levels observed for quartz blue OSL and potassium feldspar IRSL and post-IR IRSL are indicated.

period and applied using the methods outlined by Huntley and Lamothe (2001) and Auclair and others (2003). Fading corrected ages are 294 ± 32 ka (50°C IRSL) and 347 ± 40 ka (290°C post-IR IRSL). Laboratory data are presented in Table 1.

IRSL age

In our study, the IRSL age on potassium feldspar from 40 to 50 cm below the top of the Blackwater Draw Formation is 294 ± 32 ka and 347 ± 40 ka (1σ); the rounded age is 300 to 350 ka. It is the first IRSL age from the Blackwater Draw Formation and is significantly earlier than previously reported TL ages (Holliday, 1989). The 300–350 ka geochronology is consistent with the Brunhes normal paleomagnetic polarity at the nearby type section (Patterson and Larson, 1990) and the degree of argillic pedogenesis and secondary soil carbonate accumulation in the upper part of the formation.

Sediment Characterization

Three sediment samples associated with the dated material from the upper Blackwater Draw Formation were analyzed for particle size and chemistry. Particle-size analysis by hydrometer yielded percentages of sand (2.0–0.0625 mm), silt (62.5–2.0 µm), and clay (<2.0 µm). Sand was further analyzed at 1-Φ Wentworth scale categories using dry brass sieves: very coarse (2.0–1.0 mm), coarse (1.0–0.5 mm), medium (0.5–0.25 mm), fine (0.25–0.125 mm), and very fine (0.125–0.0625 mm). The amount of iron (Fe) content in mg/kg was determined by the ICP/ICPMS method (Table 2).

The upper formation at our study site is dominated by fine quartz sand with similar amounts of medium and very fine sand. Silt content ranges from 8 to 18 percent. Clay content ranges from 21 to 44 %, and iron content is 1.22 to 2.24 %, with higher amounts in the upper sample. The high clay and iron content indicate mature argillic pedogenesis. The red Munsell color (2.5YR 4/6-8) of the upper Blackwater Draw Formation is from the high iron content. The clay and iron contents of the formation are dramatically greater than found in the well-documented late Pleistocene argillic Berino paleosol in the Mescalero sand sheet (Hall and Goble, 2012) (Fig. 4).

Discussion

One of the issues of surficial geology in the region concerns the identity of the Blackwater Draw Formation. We suspect that the great variability in thickness, lithology, argillic and calcic paleosols, and ages that are purported to represent the Blackwater Draw Formation indicate that more than one "formation" is present, as was originally observed by Frye and Leonard (1957). The comparatively young TL ages of late Pleistocene red sands associated with Paleoindian archaeological sites may represent post-Blackwater Draw Formation deposits (Holliday, 1985, 1997, 2001).

The IRSL age, 300–350 ka, that we obtained near the type locality of the Blackwater Draw Formation and the presence of the mature argillic paleosol with a strong calcic horizon overprint in the upper Blackwater Draw Formation suggest to us that the terminal age of the Blackwater Draw Formation is Middle Pleistocene, at least in the area of the type locality.

Table 1. Laboratory and age data, Blackwater Draw Formation, Texas.

Field No.	Burial depth (cm)	Water (moisture) content (*in situ* H_2O) (%)	K_2O (%)	U (ppm)	Th (ppm)	Cosmic[a] (Gy)	Dose rate (Gy/ka)		D_e (Gy) *	Aliquots (count)	Residual dose (Gy)	Net dose (Gy)	Uncor-rected age (ka, 1σ)	Fading rate **	Fading corrected age[b] (ka, 1σ)	Skew/2σ$_c$ [c]	Kurt/2σ$_k$ [c]	c/c$_{crit}$ [c]	k/k$_{crit}$ [c]	Overdisp[d] (%)
Sample UNL3891																				
BD-1	75	4.7	1.84 ± 0.05	1.33 ± 0.12	8.00 ± 0.39	0.23	3.19 ± 0.11 (feldspar)	**Feldspar IRSL**	604.4 ± 15.8	25	7.59 ± 0.55	596.8 ± 15.8	187 ± 8	4.56 ± 0.44	294 ± 32, initial at 50°C	-0.44	-0.35	-0.06	-0.34	12
								Feldspar post-IR IRSL	771.0 ± 17.3	25	31.61 ± 1.40	739.4 ± 17.4	232 ± 10	4.10 ± 0.52	347 ± 40, subsequent at 290°C	0.13	-0.54	0.02	-0.53	8

* Error on D_e is 1 standard error (σ), shown as 2σ on Figure 5.
** Fading rate in [G_{2days}, (%)/decade].

[a] Refer to Thiel et al. (2001) and Buylaert et al. (2009).
[b] Prescott and Hutton (1994)
[c] Bailey and Arnold (2006)
[d] Galbraith (2005)

Table 2. Sedimentary data, Blackwater Draw Formation, Texas.

	Grain-size distribution								Composition		
Depths (cm)	Very-coarse sand 2.0–1.0 mm (%)	Coarse sand 1.0–0.5 mm (%)	Medium sand 0.5–0.25 mm (%)	Fine sand 0.25–0.125 mm (%)	Very-fine sand 0.125–0.0625 mm (%)	Sand 2.0–0.0625 mm (%)	Silt 62.5–2.0 µm (%)	Clay <2.0 µm (%)	Carbonate (%)	Iron (mg/kg) (%)	Dry Munsell Color
20–30	0.1	0.6	22.1	56.5	20.6	38	18	44	2.7	2.24	2.5YR 4/6
60–70	<0.1	<0.1	18.4	63.1	18.5	53	11	36	0.8	1.64	2.5YR 4/6
100–110	<0.1	<0.1	18.0	63.3	18.8	71	8	21	1.8	1.22	2.5YR 4/8

* Percent carbonate by weight determined by HCl titration, Energy Laboratories, Billings, Montana.

Beyond the Southern High Plains, the Mescalero sand sheet occurs immediately west of the caprock and east of the Pecos River in southeastern New Mexico (Hall and Goble, 2006, 2011) (Fig. 1). Isolated exposures of red sand in the sand sheet yielded OSL ages ranging from 87.4 to 47 ka, and the deposits have been correlated with the Blackwater Draw Formation (Rich and Stokes, 2011). These OSL ages are similar to those of 90 to 50 ka that we reported from the reddish Lower eolian sand unit elsewhere on the Mescalero sand sheet (Hall and Goble, 2016). Rich and Stokes (2011) also report earlier and later OSL ages for red eolian sands on the southern High Plains and in the Monahans, Texas area, ranging from 204 to 34 ka. They correlate all of their dated red sands with the Blackwater Draw Formation. A reassessment of each of these localities has not been conducted and is beyond the scope of this pilot study.

The Lower eolian sand unit of the Mescalero sand sheet, however, has nothing in common with the Blackwater Draw Formation. The Lower sheet sand is less than 3 meters thick, commonly less than 1 meter, and is the earliest unit of the sand sheet, resting directly on caliche of the Mescalero paleosol. The Lower unit is capped by the non-calcic, argillic Berino paleosol (Hall and Goble, 2012). While the Berino gives the sand unit its red color, it is much less mature than the upper argillic paleosol that occurs at the top of the Blackwater Draw Formation, containing less pedogenic clay and iron (Fe) than the Blackwater Draw Formation (Fig. 4). In addition, the Lower unit sand contains only one argillic paleosol, not the three or four paleosols commonly present in the Blackwater Draw Formation. Furthermore, the Berino paleosol lacks carbonate, whereas calcic horizons in the Blackwater Draw Formation exhibit stage II and III morphologies. Thus, based on multiple considerations, the Lower eolian sand unit and Berino paleosol of the Mescalero sand sheet are significantly younger, lacking the great antiquity exhibited by the Blackwater Draw Formation.

Conclusion

In conclusion, the IRSL age of the upper Blackwater Draw Formation is 300–350 ka, indicating that its deposition in the type area ended in the Middle Pleistocene. The Blackwater Draw Formation does not occur in the Mescalero sand sheet in southeastern New Mexico, and correlation of the reddish Lower eolian sand unit in that area with the Blackwater Draw Formation is in error (Fig. 5). The observation by Frye and Leonard (1957) that two or more different "formations" are included in their "Cover sands" complex on the Southern High Plains is likely correct, as supported by these new results.

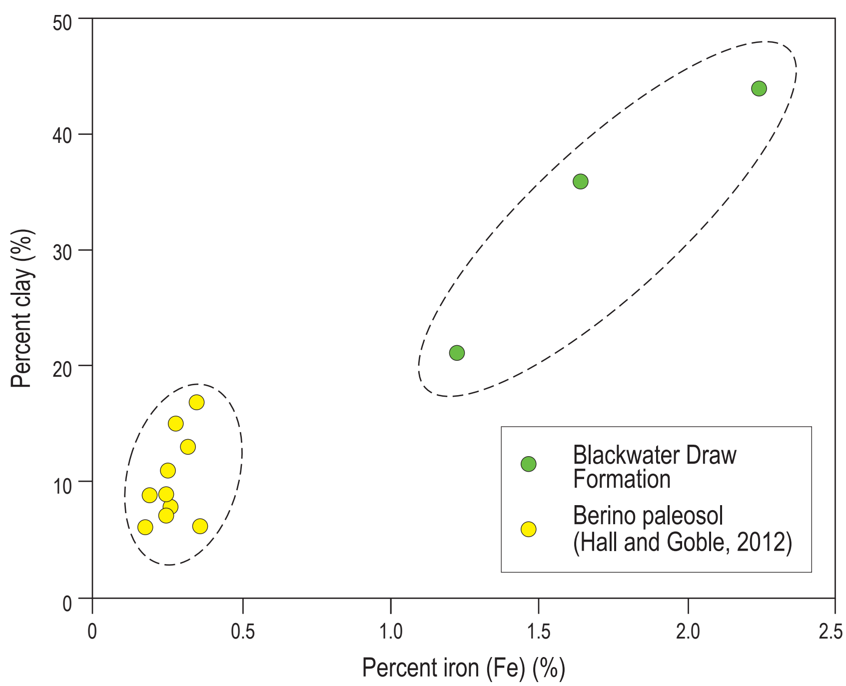

Figure 4. Percentages of iron (Fe) and clay in samples from the upper Blackwater Draw Formation (Table 2, this study) and the Berino paleosol (Hall and Goble, 2012). Higher Fe and clay contents in the Blackwater Draw Formation indicate a higher level (maturity) of argillic pedogenesis relative to the late Pleistocene Berino paleosol in the Mescalero sand sheet (plotted by SigmaPlot 12).

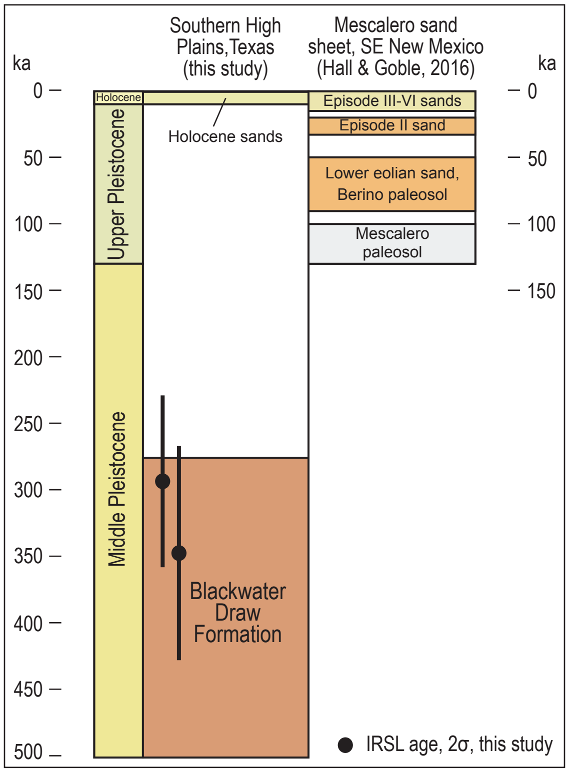

Figure 5. Geochronology of the upper part of the Blackwater Draw Formation, Southern High Plains, Texas, and the Mescalero sand sheet, southeastern New Mexico (Hall and Goble, 2016). Age of Holocene sand deposits on the Southern High Plains from Holliday (2001). IRSL ages are shown with 2σ errors as opposed to 1σ in Table 1.

Acknowledgments

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