A Geological Overview of Frac Sand in the United States

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U.S. Department of the Interior
U.S. Geological Survey

Outline

- Frac sand defined
- Properties of premium frac sand
- Ideal frac sand deposits
- Divisions of geologic time
- Geologic units that are main sources of frac sand in the U.S.
- Summary of geologic history that has resulted in premium frac sand deposits

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Frac sand defined

- Naturally occurring (raw) sand that is used as a proppant during hydraulic fracturing of unconventional oil and gas wells (grains prop open induced and natural fractures to increase and prolong hydrocarbon recovery)
  - Unconventional reservoirs are low-permeability (tight) reservoirs
    - Shale gas plays
    - Tight oil sand plays
    - Coal-bed methane plays

Properties of premium frac sand

- High silica content (~99% quartz) (mature, re-worked sand)
  - Quartz has a hardness of 7 on Mohs scale

Quartz

  - Low acid solubility, ≤3.0% weight loss after test (indicates absence of soluble cement or soluble mineral grains)

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Most sand is a mixture of several minerals or rock types

Rounded and fine-grained eolian sand sample from the Gobi Desert (near Dalanzadgad in Mongolia). The width of the view is 10 mm. By Siim Sepp (Own work) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons. http://en.wikipedia.org/wiki/Desert#mediaviewer/File:Sand_from_Gobi_Desert.jpg

Frac sand must be a high-silica (quartz-rich) sand: quartzose sandstone or quartz arenite

St. Peter Sandstone (from http://www.sandatlas.org/2010/02/quartz-sand/)

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Properties of premium frac sand – continued

- **Grain size range from 0.1 to >2 mm diameter (measured in standard ASTM sieve sizes)**

Proppant Size Designation

Sieve-opening sizes (µm)[a]										
	3,350/ 1,700	2,360/ 1,180	1,700/ 1,000	1,700/ 850	1,180/ 850	1,180/ 600	850/ 425	600/ 300	425/ 250	212/ 106
Typical proppant/gravel-pack size designations										
	6/12	8/16	12/18	12/20	16/20	16/30	20/40	30/50	40/70	70/140
Stack of ASTM sieves[b]										
First primary sieve in bold type	4	6	8	8	12	12	16	20	30	50
	6	**8**	**12**	**12**	**16**	**16**	**20**	**30**	**40**	**70**
	8	10	14	14	18	18	25	35	45	80
Second primary sieve in bold type	10	12	16	16	**20**	20	30	40	50	100
	12	14	**18**	18	25	25	35	45	60	120
	14	**16**	20	**20**	30	**30**	**40**	**50**	**70**	**140**
	16	20	30	30	40	40	50	70	100	200
	pan	pan	pan	pan	pan	pan	pan	pan	pan	pan

[a] Sieve series as defined in ASTM E11

[b] Sieves stacked in order from top to bottom

In the example of 20/40 frac sand, >90% of the sand passes through the 20 mesh (0.850 mm) sieve and is retained by the 40 mesh (0.425 mm) sieve.

(Modified from Getty, 2013)

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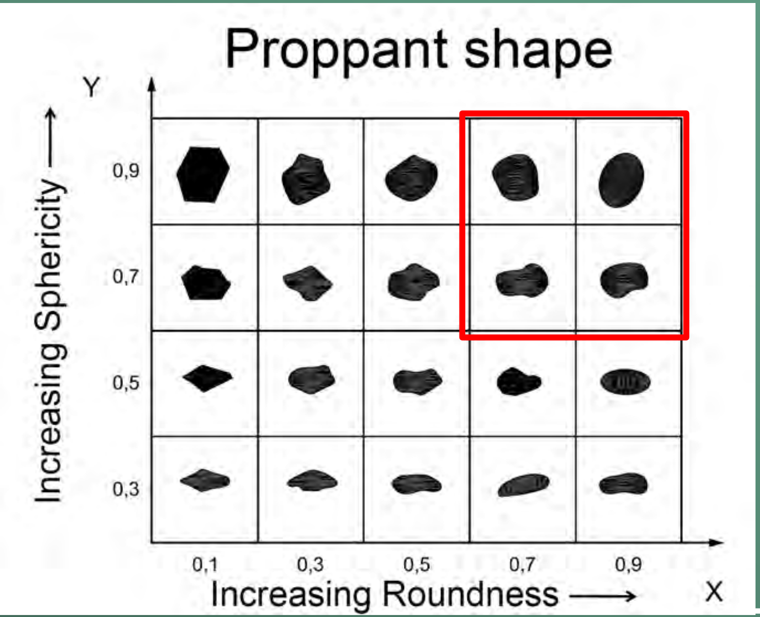
Properties of premium frac sand – continued

- A naturally occurring narrow grain size range is preferred (indicates a well-sorted deposit), but mechanical sorting can be done during processing to achieve sieve size designations for various products, such as 16/20, 16/30, 20/40, 30/50, 40/70, 70/140.
  - Uniformity of grain size enhances conductivity (flow) of hydrocarbons from fractures into the wellbore

Properties of premium frac sand – continued

- Grain shape that is well-rounded and spherical, ≥0.6
  - Creates space around grains to allow conductivity (flow) of hydrocarbons from fractures



(Krumbein and Sloss, 1963)

Properties of premium frac sand – continued

- Bulk density and specific gravity of sand are indicators of quartz purity when their values are similar to those of quartz.
  - Bulk density of silica sand is ~95 lbs/ft^3 (~1522 kg/m^3)
  - Specific gravity of quartz is 2.65

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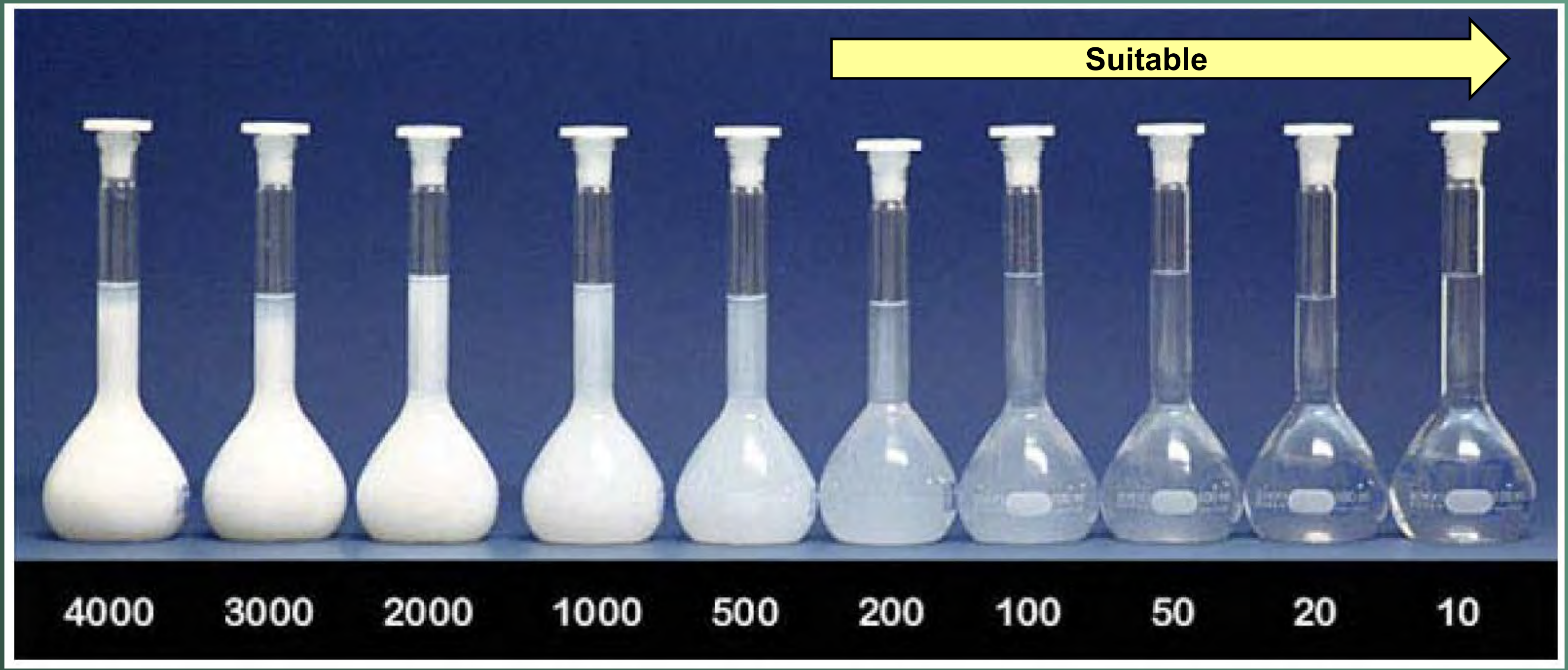
Properties of premium frac sand – continued

- **Low turbidity (few fines or impurities), ≤250 NTU (Nephelometric Turbidity Units)**

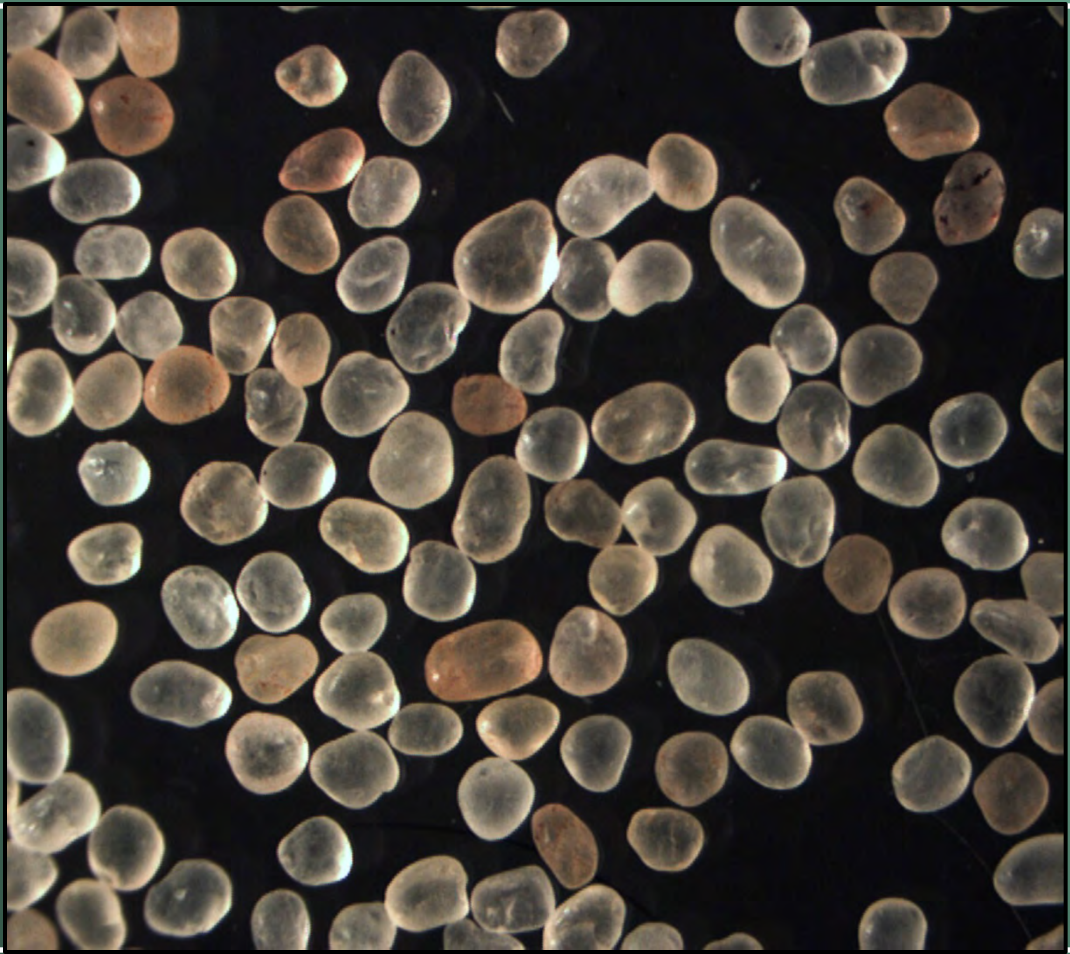


(Photo used with permission of optek-Danulat, 2014)

Properties of premium frac sand – continued

- Crush resistance of grains is rated as the highest loading pressure that yields no more than 10 wt. % fines; frac sand is typically tested up to 9,000 psi. Factors in addition to high silica content that increase crush resistance:
  - ≤1.0% clusters (grain aggregates)
  - Absence of crystal overgrowths
  - Absence of stress fractures or weak planes within grains
  - Absence of deep surface pitting of grains

Premium Frac Sand: “Northern White” or “Ottawa” sand



(“Northern White” frac sand - Photo Courtesy of Fairmount Santrol, 2014)

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API Standards for Frac Sand (Proppants)

API RP 19C / ISO 13503-2, *Recommended Practice for Measurement of Properties of Proppants Used in Hydraulic Fracturing and Gravel-packing Operations*

Typical Properties			ISO 13503-2	40/70 Ottawa
Turbidity (NTU)			≤250	26
Krumbein Shape Factors				
Roundness			≥0.6	0.7
Sphericity			≥0.6	0.7
Clusters (%)			≤1.0	0
Bulk Density (g/cm^3)				1.46
Bulk Density (lb/ft^3)				91
Specific Gravity				2.65
Mean Particle Diameter, mm				0.298
Median Particle Diameter (MPD), mm				0.29
Solubility in 12/3 HCl/HF for 0.5 Hr @ 150°F (Weight Loss %)			≤3.0	1.4
Particle Size Distribution	**mm**	**US Sieve No.**	**wt. % retained**	**wt. % retained**
	0.600	30	≤0.1	0
	0.425	40		1.3
	0.355	45		13.7
	0.300	50		32.3
	0.250	60		26.3
	0.212	70		23.4
	0.150	100		2.9
	<0.150	Pan	≤1.0	0
	Total			100
	% in Size		≥90	95.7
Crush Resistance			**wt. % fines generated**	**wt. % fines generated**
@ 8,000 psi			≤10	9.6
@ 9,000 psi			≤10	13.3
K-Value				8k

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(Modified from U.S. Silica, 2014)

Ideal frac sand deposits

- Near-surface access to deposit
  - Minimal over-burden
- Friability of deposit (loose sand, poorly cemented, poorly consolidated)

(Image from Kbh3rd at Wikipedia, Public Domain, from Wikimedia Commons at http://en.wikipedia.org/wiki/File:St_Peters_Sandstone_Pacific_MO_5-med.jpg)

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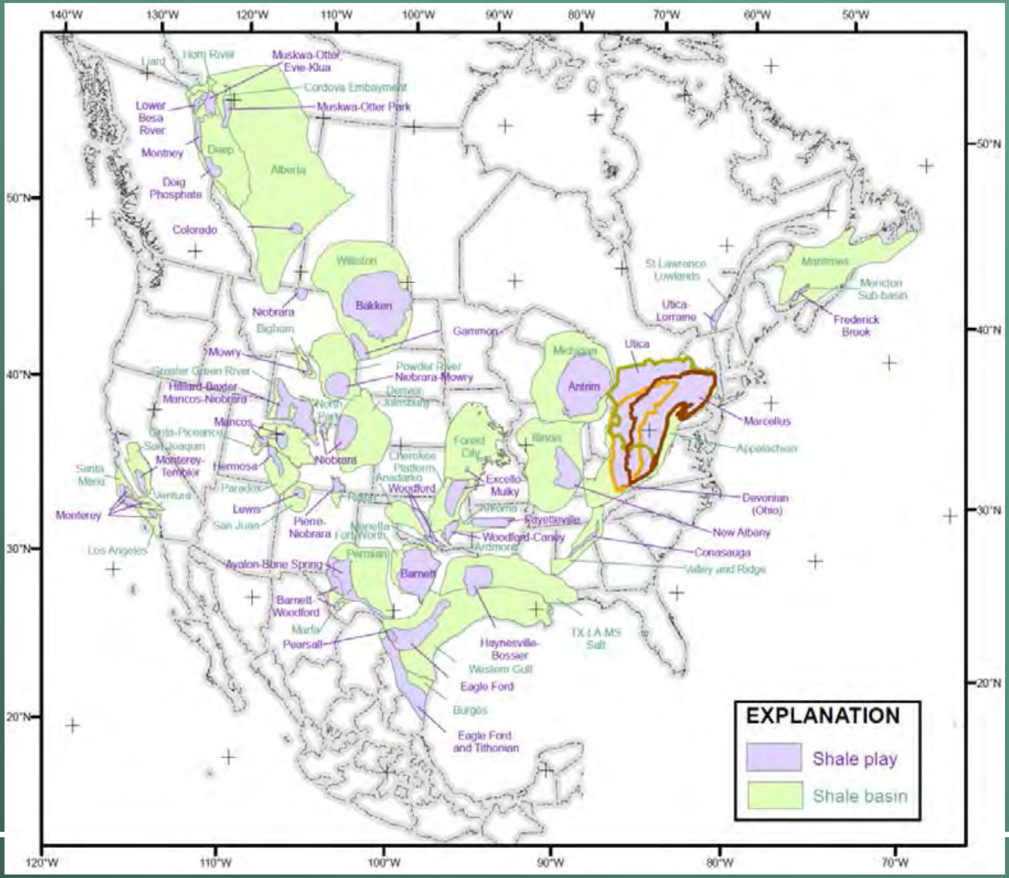
Ideal frac sand deposits – continued

- **Close proximity to the petroleum plays that use frac sand**

North American
Shale Plays in
Shale Basins



(Modified from U.S. Energy Information Administration, 2011; and Kuuskraa and others, 2011)

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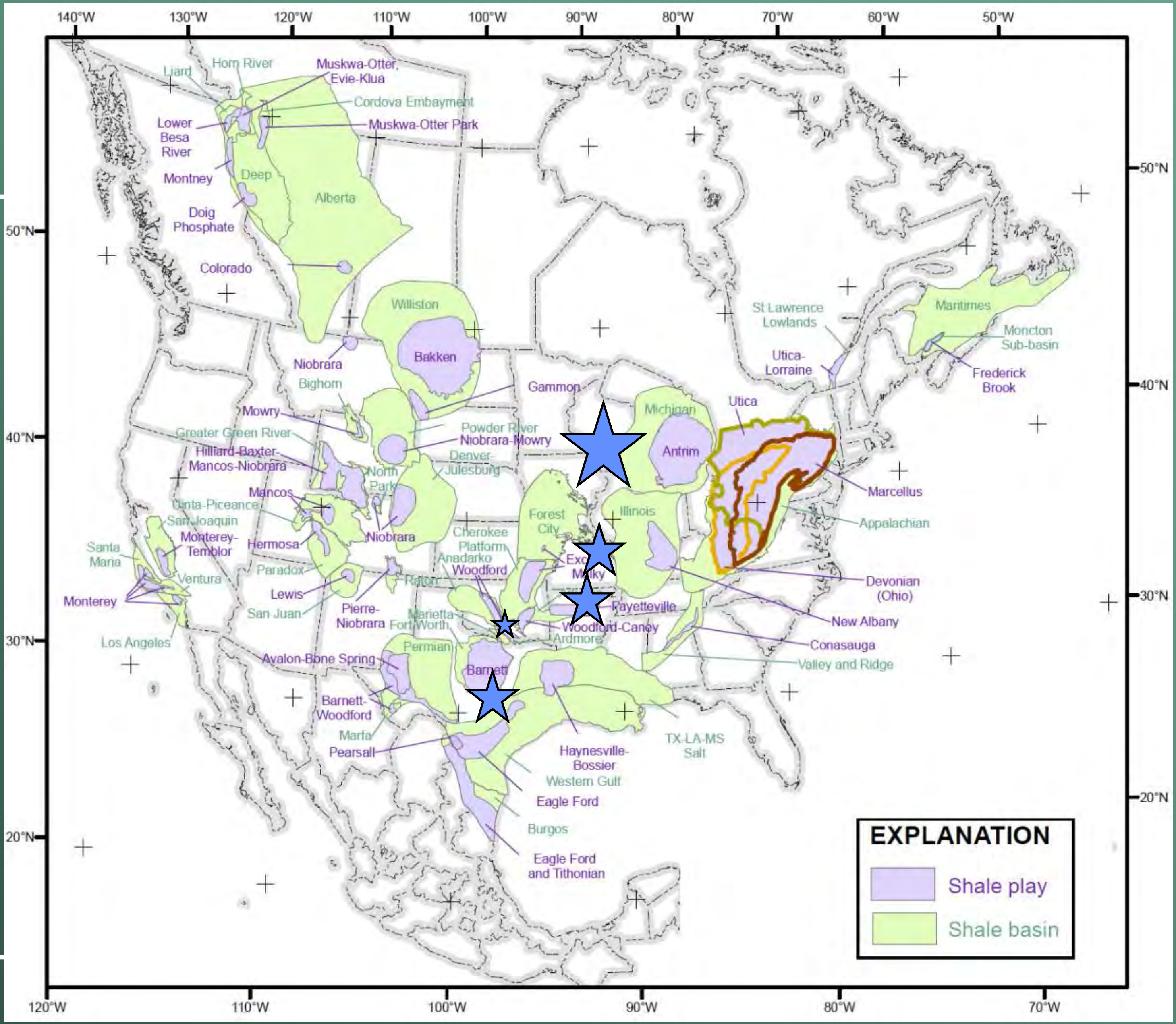
North American Shale Plays in Shale Basins

Principal U.S. Frac Sand Sources ★



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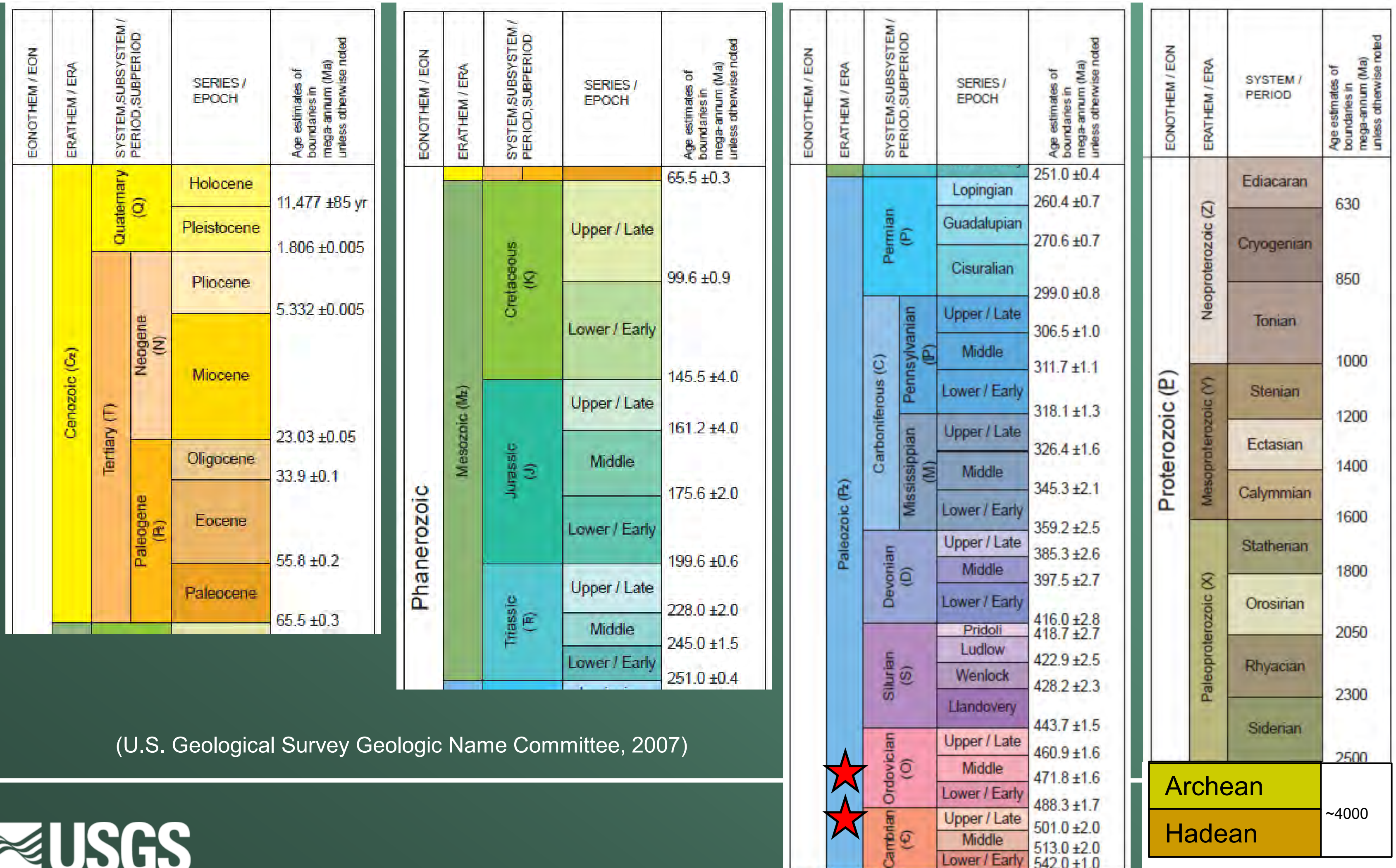
(Modified from U.S. Energy Information Administration, 2011; and Kuuskraa and others, 2011) youngest

Divisions of geologic time



(U.S. Geological Survey Geologic Name Committee, 2007)

oldest

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Divisions of geologic time

Most of the U.S. frac sand supply comes from rock units that are older than 450 million years of age: Cambrian and Ordovician.

EONOTHEM / EON	ERATHEM / ERA	SYSTEM, SUBSYSTEM / PERIOD, SUBPERIOD		SERIES / EPOCH	Age estimates of boundaries in mega-annum (Ma) unless otherwise noted
					251.0 ±0.4
	Paleozoic (Pz)	Permian (P)		Lopingian	260.4 ±0.7
				Guadalupian	270.6 ±0.7
				Cisuralian	299.0 ±0.8
		Carboniferous (C)	Pennsylvanian (P)	Upper / Late	306.5 ±1.0
				Middle	311.7 ±1.1
				Lower / Early	318.1 ±1.3
			Mississippian (M)	Upper / Late	326.4 ±1.6
				Middle	345.3 ±2.1
				Lower / Early	359.2 ±2.5
		Devonian (D)		Upper / Late	385.3 ±2.6
				Middle	397.5 ±2.7
				Lower / Early	416.0 ±2.8
		Silurian (S)		Pridoli	418.7 ±2.7
				Ludlow	422.9 ±2.5
				Wenlock	428.2 ±2.3
				Llandovery	443.7 ±1.5
		Ordovician (O)		Upper / Late	460.9 ±1.6
				Middle	471.8 ±1.6
				Lower / Early	488.3 ±1.7
		Cambrian (Ꞓ)		Upper / Late	501.0 ±2.0
				Middle	513.0 ±2.0
				Lower / Early	542.0 ±1.0

(U.S. Geological Survey Geologic Name Committee, 2007)

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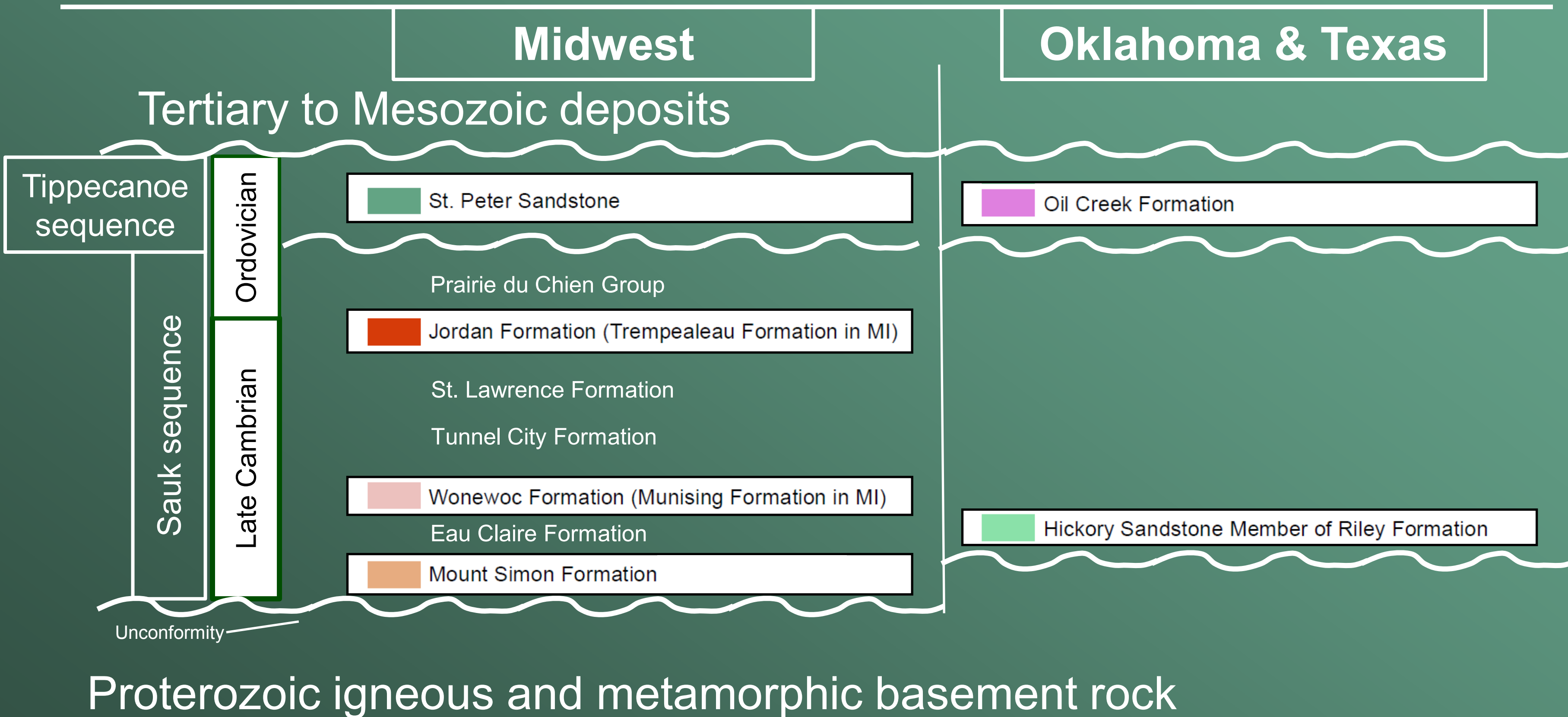
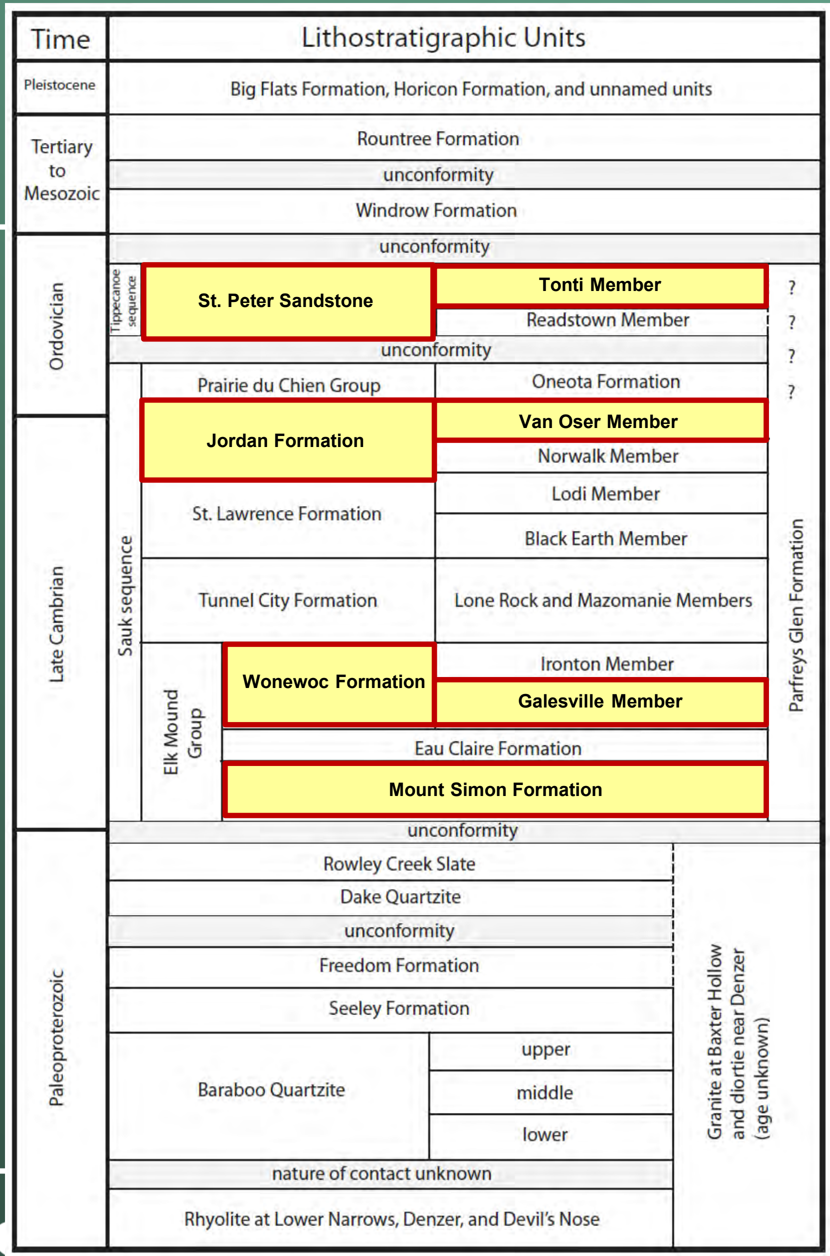
Geologic units that are main sources of frac sand in the U.S.



Geologic units that are main sources of frac sand in the U.S. – continued

- Major frac sand source units
  - Premium “Northern White” or “Ottawa” sand in Midwest states: Wisconsin, Minnesota, Iowa, Illinois, Missouri, Arkansas
    - St. Peter Sandstone (Ordovician)
    - Jordan Formation (Ordovician & Cambrian)
    - Wonewoc (Cambrian)
    - Mount Simon (Cambrian)

Stratigraphic Column for Upper Midwest frac sand source units



St. Peter Sandstone (Middle Ordovician)

Jordan Formation (Upper Cambrian & Lower Ordovician)

Wonewoc Formation (Upper Cambrian)

Mount Simon Formation (Upper Cambrian)

Proterozoic igneous and metamorphic basement rock

(Modified from Clayton and Attig, 1990)

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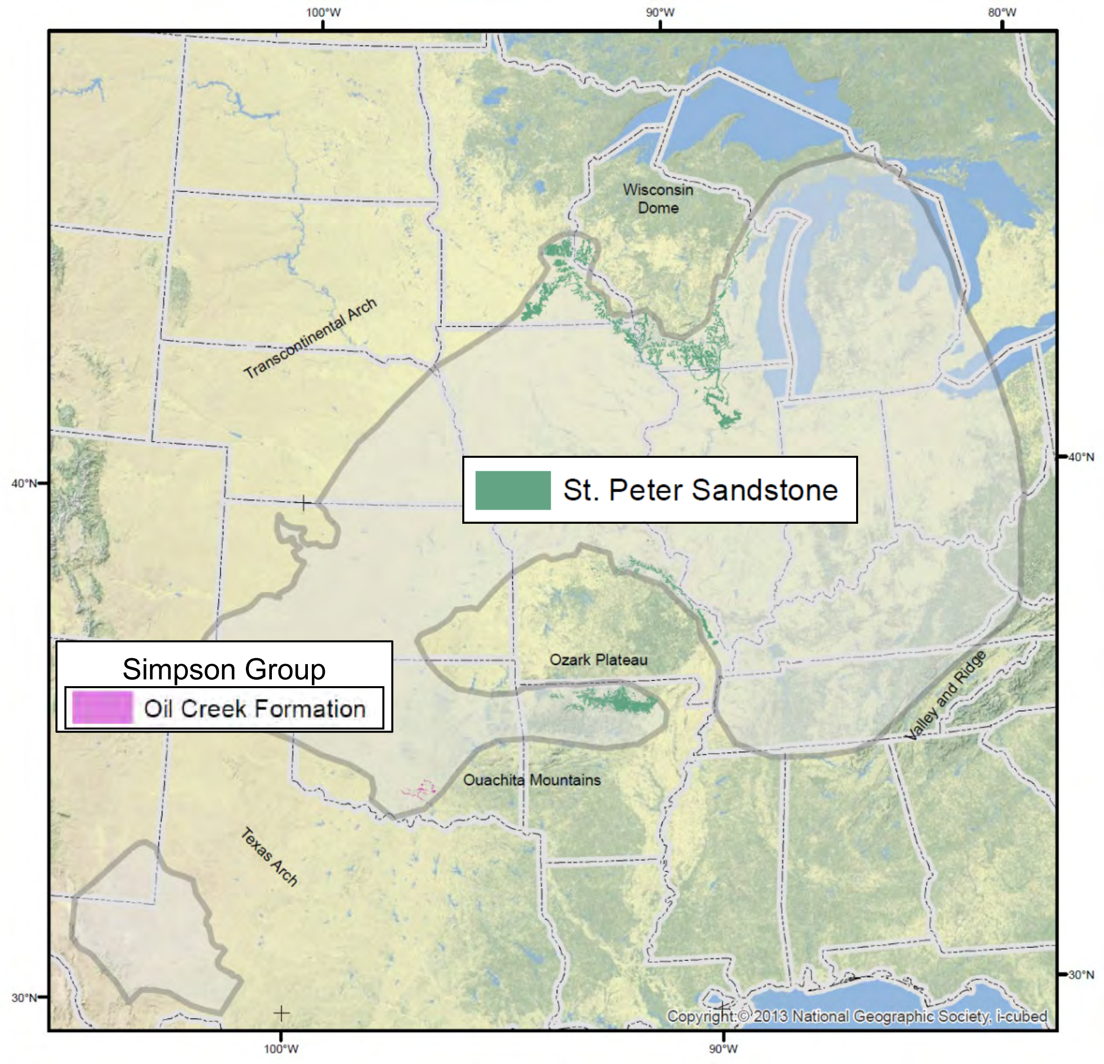
St. Peter Sandstone and partial equivalent Simpson Group

Surface and subsurface extent of the St. Peter Sandstone of the Midwest combined with the Simpson Group of the southern mid-continent that is partially equivalent in age and depositional environment to the St. Peter Sandstone.

The Oil Creek Formation of the Simpson Group contains sand that has similar properties to those of the St. Peter Sandstone.



(Modified from Dake, 1921; Dapples, 1955; Cole, 1975; Jones, 2009; and Davis, 2011)

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Geologic units that are main sources of frac sand in the U.S. – continued

- Marginal “Northern White” type sand in Oklahoma and west Texas
  - St. Peter-equivalent sands of the Simpson Group
    - Oil Creek Formation (Ordovician)
      - Basal sand of the Oil Creek (also known as the Connell Sandstone Member)

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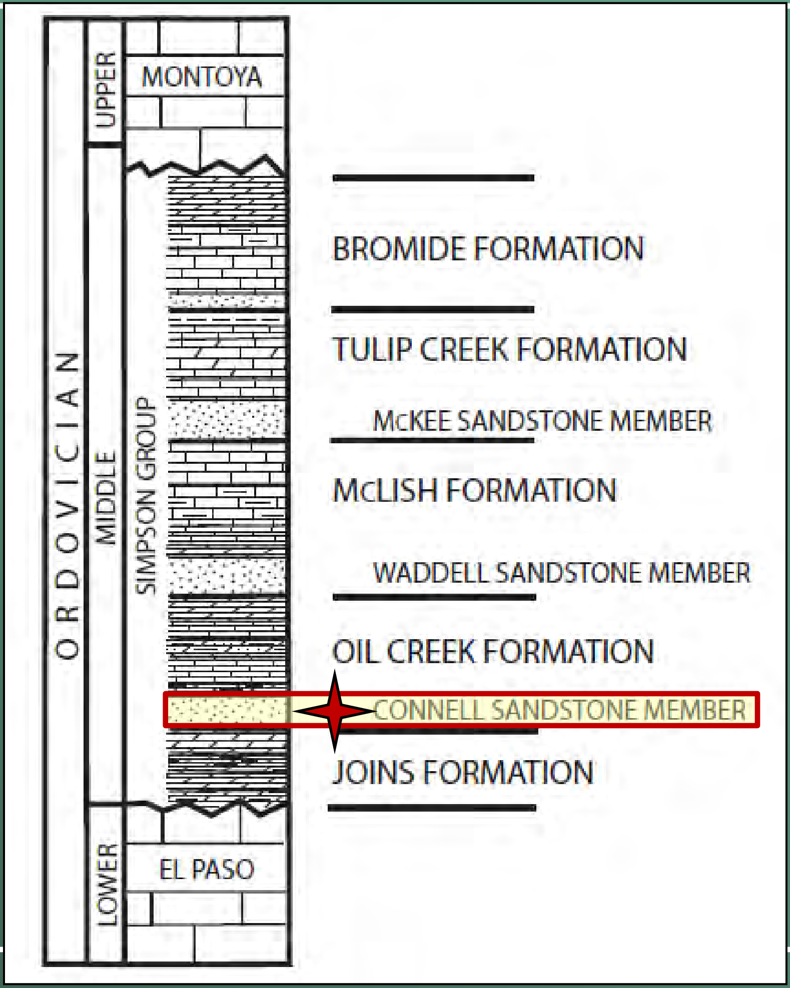
Oil Creek Formation of the Simpson Group in Oklahoma and west Texas

Stratigraphic Column of Simpson Group

Ordovician Simpson Group is a partial equivalent to the St. Peter Sandstone.

Principal frac sand in the Simpson Group is from the basal sandstone (Connell Sandstone Member) of the Oil Creek Formation.



(Modified from Suhm and Ethington, 1975)

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Geologic units that are major sources of frac sand in the U.S. – continued

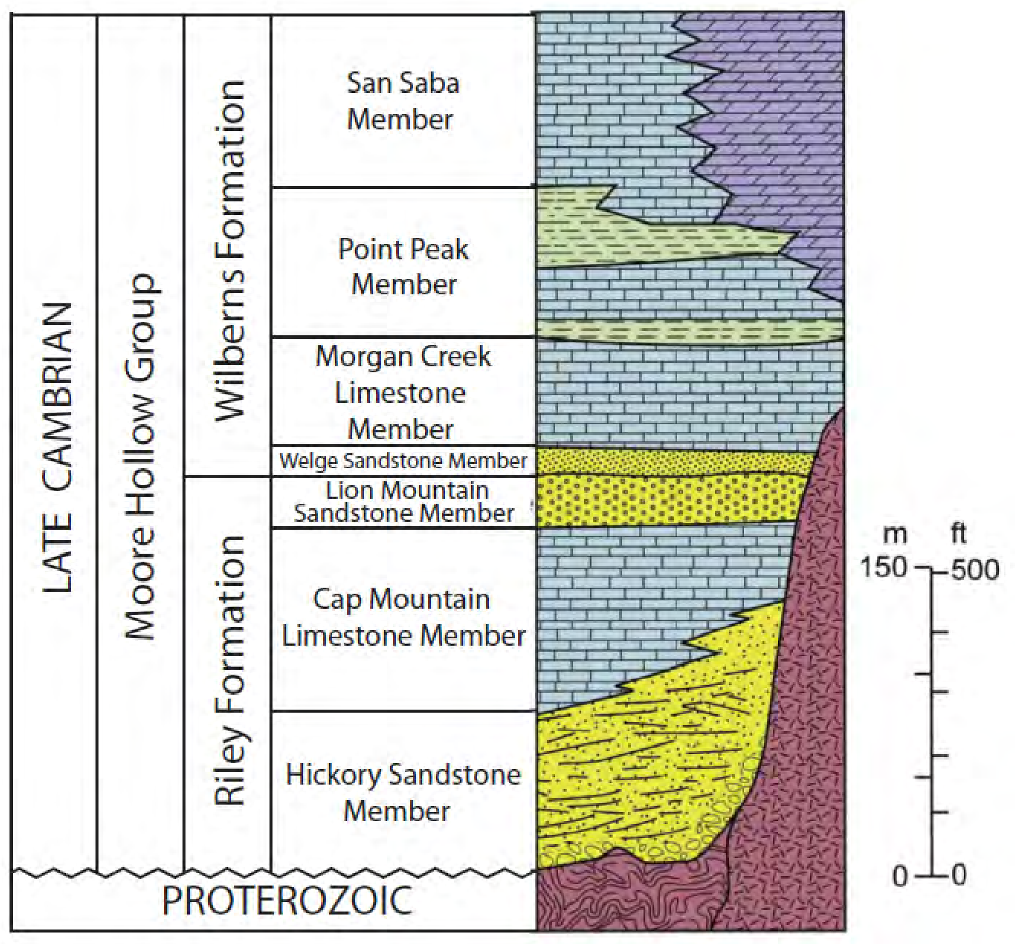
- "Brady" or "Brown" sand of central Texas
  - Hickory Sandstone Member of Riley Formation (Cambrian)

Hickory Sandstone Member of the Riley Formation in central Texas

Stratigraphic Column of Riley Formation in Texas

Principal frac sand in the Cambrian Riley Formation is from the basal sandstone (Hickory Sandstone Member).

Hickory Sandstone Member: deposited on the unconformable surface of Proterozoic igneous and metamorphic basement rock



(Modified from Kyle and McBride, 2014; modified after Barnes and Bell, 1977)

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Summary of geologic history that has resulted in premium frac sand deposits

- High-silica sandstone = quartz arenites (Sloss, 1988)
- Early Paleozoic or older in age (Runkel and Steenberg, 2012)
- Often overlying a deeply eroded surface (unconformity) (Sloss, 1988; Barnes and others, 1996)
- Deposited in a broad transgressive shallow sea (Barnes and others, 1996) formed in a slowly subsiding basin (Sloss, 1988; Runkel and others, 2007)
- Has a long history of reworking by marine and aeolian (wind) processes (Dott and others, 1986)
- Preserved in the interior of a craton, away from tectonically active continental plate margins (Zdunczyk, 2007)

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Disclaimer

1. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

2. Note that the source units identified in this presentation are provided as reported in published literature or websites as major or potential sources of frac sand, despite whether or not they meet any or all of the API specifications for frac sand. None of these units has been independently assessed, analyzed, or evaluated by the U.S. Geological Survey, and neither the U.S. Geological Survey nor the presenters make any claim as to the suitability of these units as frac sand.

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