24-044

Geochronology and Critical Mineral Potential of Selected Laramide Porphyry and Related Deposits in Southwest New Mexico

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ABSTRACT

Southwestern New Mexico is part of a large belt of Late Cretaceous to Eocene copper porphyry deposits found in Arizona, New Mexico, and Mexico. These deposits are the result of arc magmatism that occurred during the Laramide orogeny. Recently, attention has been brought to other commodities that can be extracted as by- and co-products, many of which are critical minerals. A new compilation of the geochronology of these deposits shows two main pulses of magmatism that produced mineralized deposits and, along with new dates by the author, shines new light on the geologic history of these deposits and the role it plays in critical mineral abundance.

INTRODUCTION

Copper porphyry deposits are some of the largest and most well-known copper deposits found in the world. They produce three-quarters of the world's copper supply, half of the molybdenum, and a large portion of the gold [1]. In addition to these primary commodities and co-products, many significant by-products are also produced from these deposits, which include Platinum Group Elements (PGEs), Te, In, Ga, Ge, Re, and others. Many of these elements are of increasing importance in the face of the coming green-energy transition, have important defense and national security uses, or are subject to supply chain issues due to the reliance on imports. As such, the United States Geological Survey has designated many of these commodities as critical minerals, while copper has been recently designated a critical energy material by the Department of Energy. Due to these reasons, copper porphyry systems have an increased importance in the future of mining, and increasing the domestic mining capability in the United States is critical.

Southwest New Mexico lies at the eastern end of the southwest Laramide porphyry belt stretching from Arizona into western New Mexico and northern Mexico (Figure 1). These deposits are responsible for a large portion of domestic copper production in the United States, and include world-class deposits. These deposits are largely Laramide in age, ranging from ~75–45 Ma [2][3]. While most of the larger deposits are well-known in age, some of the smaller deposits and prospects lack modern geochronology. This is especially important as there is overlap of Laramide and mid-Tertiary deposits in the same area, leading to some confusion as to the age and nature of some deposits. Mid-Tertiary deposits are the result of extensional tectonics, and as a result are more alkaline and have different geochemical characteristics, mineralogy, and commodities than Laramide deposits, which could have an effect on which critical minerals could be present. New and improved $^{40}Ar/^{39}Ar$ geochronology of various deposits in southwest New Mexico has settled the debate on whether some districts are Laramide or mid-Tertiary.

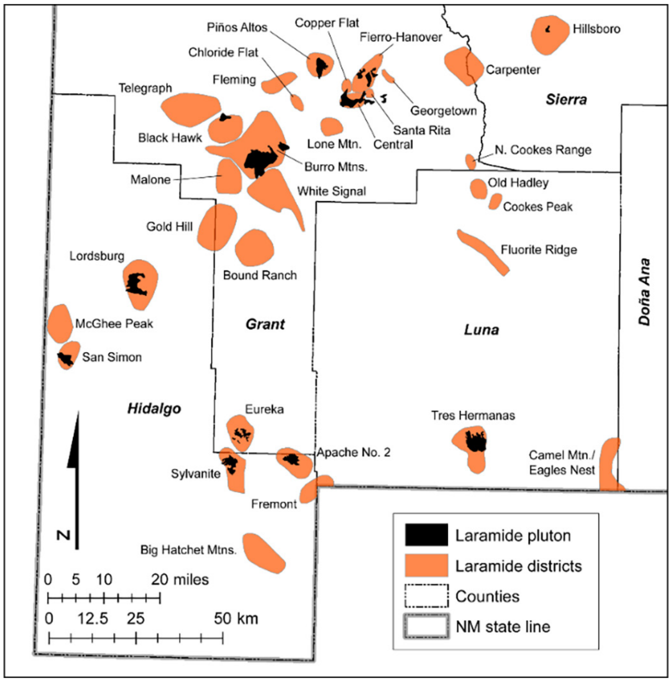

Figure 1. Map of suspected Laramide-age mining districts and plutons in SW NM. Districts are from McLemore (2017)

AGE OF MINING DISTRICTS AND ASSOCIATED PLUTONS

Previous geochronology data for Laramide or potentially Laramide plutons and associated mining districts in New Mexico suggests two to three pulses of magmatism (Table 1, Figure 2). The first initial pulse is from ~75 to 71 Ma, as seen by ages for Black Hawk, Hillsboro, Piños Altos, Little Hatchet Mountains, and Georgetown. The next pulse is from ~58–54 Ma, possibly extending into ~50 Ma, which includes ages for Lordsburg, Santa Rita, Fierro-Hanover, Copper Flat (Grant County), Burro Mountains, Lone Mountain, and potentially Tres Hermanas. Ages younger than ~45 Ma are likely mid-Tertiary and are a result of extensional magmatism, such as those for Cookes Peak and Old Hadley, Camel Mountain, Tres Hermanas, San Simon, McGhee Peak, Apache No. 2, and Fremont.

Ages of plutons that produced mineralized deposits are correlated with episodes of arc magmatism in southwest New Mexico. Both McMillan (2004) [4] and Amato et al. (2017) [5] report three episodes of arc magmatism in southwest New Mexico. A lack of mineralized deposits exists between 70–60 Ma in New Mexico, but exists elsewhere such as in Arizona [2]. The lack of magmatism and mineralized deposits in New Mexico could be due to a lack of outcropping plutons as compared to Arizona or a quiescence of magmatism in the specific area.

Table 1. Mining districts with current estimated age and dating method. "?" indicates age may be incorrect

District	Age (Ma)	Method	Reference
Hillsboro	75	$^{40}Ar/^{39}Ar$	McLemore et al. (1999)
Black Hawk	75.7, 72.5	U-Pb, K-Ar	Amato et al. (2017), Hedlund (1980)
Piños Altos	74.4	K-Ar	McDowell (1971)
Eureka and Sylvanite (Little Hatchet Mtns)	71.4	$^{40}Ar/^{39}Ar$	Lawton et al. (1993)
Georgetown	71	$^{40}Ar/^{39}Ar$	McLemore (1998)
Lordsburg	58.5	$^{40}Ar/^{39}Ar$	McLemore et al. (2000)
Santa Rita (Chino mine)	58.3	$^{40}Ar/^{39}Ar$	Heizler et al. unpublished
Fierro-Hanover	57.55	$^{40}Ar/^{39}Ar$	McLemore et al. (1995)
Copper Flat (Grant County)	55.4	K-Ar	NMBGMR unpublished data
Burro Mountains (Tyrone mine)	54.5	$^{40}Ar/^{39}Ar$	Heizler et al. unpublished
Lone Mountain	51.5	K-Ar	P.B. Hubbard and P.G. Dunn Unpublished
Cooks Peak and Old Hadley	38.95	$^{40}Ar/^{39}Ar$	Schwenk unpublished
Camel Mountain – Eagle's Nest	36.8, 86.3?	$^{40}Ar/^{39}Ar$	McLemore et al. (2001), NMBGMR unpublished data
Tres Hermanas	34.65, 50.3?	$^{40}Ar/^{39}Ar$, K-Ar	McLemore et al. (2001), Leonard (1982)
San Simon	33.2	$^{40}Ar/^{39}Ar$	McLemore et al. (1995)
McGhee Peak	32.5	K-Ar	Hoggat et al. (1977)
Apache No. 2 and Fremont	30.66	K-Ar	Deal et al. (1978)

SAMPLING AND METHODS

New ages for some districts were obtained using modern, high-precision $^{40}Ar/^{39}Ar$ geochronology performed at the New Mexico Geochronology Research Laboratory (NMGRL). Samples were collected at the Camel Mountain – Eagle's Nest, Hillsboro, Tres Hermanas, Black Hawk, Eureka, Sylvanite, McGhee Peak, Lordsburg, and Piños Altos districts. Samples of fresh, least altered intrusive rocks were collected for geochronology, as well as for whole rock and trace element geochemistry and thin section

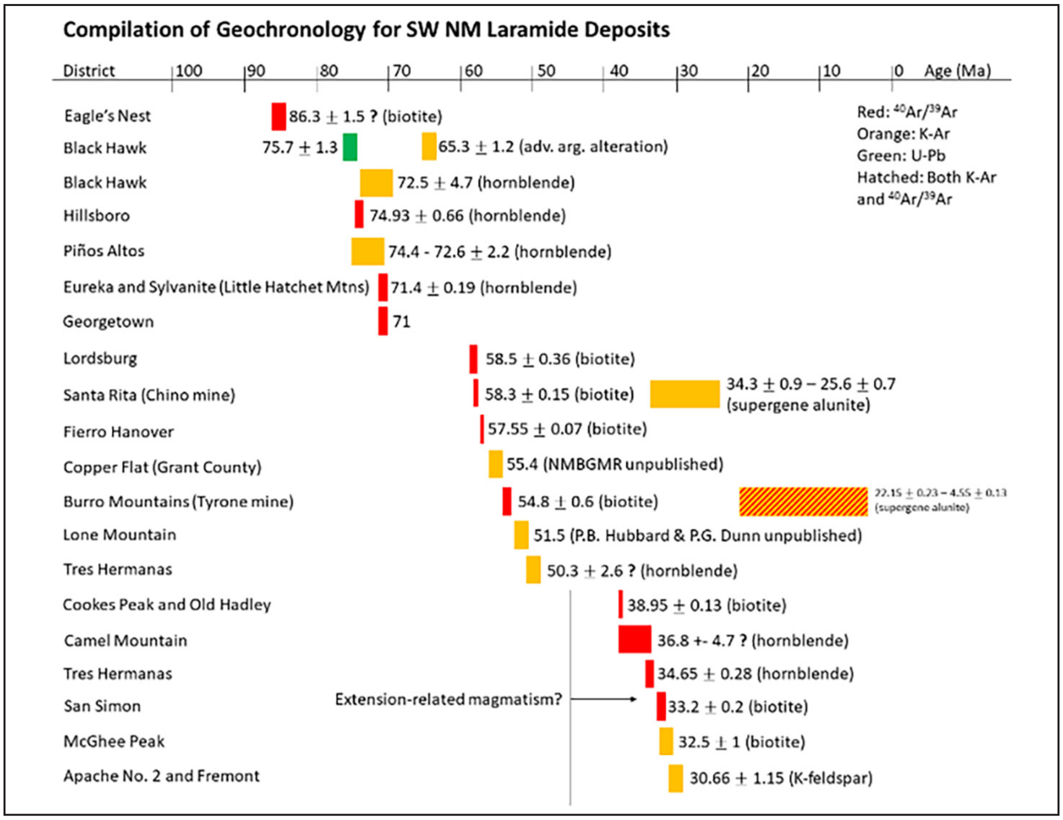

Figure 2. Legacy geochronology data for Laramide porphyry and related deposits in SW NM. Districts younger than ~45 Ma are likely related to mid-Tertiary extensional magmatism. Supergene dates are from Gerwe (1986), Cook (1994), and Leveille and Stegen (2012). "?" indicates age may be incorrect

preparation. Additional samples of mineralized material were collected where applicable.

Samples for $^{40}Ar/^{39}Ar$ geochronology were crushed and sieved to several size fractions to determine the best mineral separates for each sample. Samples were washed with hydrochloric acid in an ultrasonic bath, with heavy liquid density separation or magnetic separation being performed as necessary. Mineral separates were picked using a binocular microscope, with biotite, hornblende, groundmass concentrate, and plagioclase being used for the emplacement or eruptive ages, and K-feldspar being used for the alteration ages.

Samples were sent to the USGS TRIGA reactor in Denver, Colorado for irradiation. After irradiation, samples were loaded in trays for analysis. Samples were step-heated using a Photon Machines 810 nm diode, and the extracted gas was cleaned using a cold trap at -198 °C and a D50 getter. Gas was analyzed using a Thermo-Fisher Helix MC mass spectrometer. Gas from the sample, atmospheric air samples with an $^{40}Ar/^{36}Ar$ ratio of 295.5, and a gas "cocktail" with an $^{40}Ar/^{39}Ar$ ratio of 6.71 were run to monitor detector drift and intercalibration, with blanks run for the air, cocktail, and unknowns.

DATA

New dates (Table 2) from the Hillsboro and Camel Mountain – Eagle's Nest districts show that the intrusion at Granite Hill is 40.19 ± 0.041 Ma, and the Eagle's Nest andesite is 39.31 ± 0.5 Ma. A pegmatite dike at Prospect Hills at the south of the district was dated at 35.96 ± 0.84 Ma for the hornblende and 31.26 ± 0.56 Ma for K-feldspar. The intrusion at Prospect Hills was dated at 35.2 ± 3.4 Ma, although the mineral dated contained very little potassium and the date is very poor. A coarse-grained biotite from Hillsboro was dated at 83.65 ± 2.2 Ma using inverse isochron, and also yielded a very complex and discordant age spectrum.

Table 2. Geochronology results for Hillsboro and the Camel Mountain – Eagle's Nest districts. GMC: groundmass concentrate, Plag: plagioclase, Hbld: Hornblende

Sample	Area	Material	Mineral	Age (Ma)	Age Method
Hill 2000	Copper Flat Pit	Coarse grained phlogopite	Biotite	83.65 ± 2.2	Inverse Isochron
EAG 101	Eagle's Nest	Granitoid	Biotite	40.19 ± 0.041	Inverse Isochron
EAG 103	Eagle's Nest	Andesite	Plag	39.31 ± 0.5	Inverse Isochron
EAG 103	Eagle's Nest	Andesite	GMC	39.35 ± 0.23	Inverse Isochron
PROS 100	Prospect Hills	Granitoid	Hbld	35.2 ± 3.4	Age spectrum
PROS 100-1	Prospect Hills	Pegmatite dike	Hbld	35.96 ± 0.84	Age Spectrum
PROS 1004	Prospect Hills	Pegmatite dike	K-spar	31.26 ± 0.56	Age Spectrum

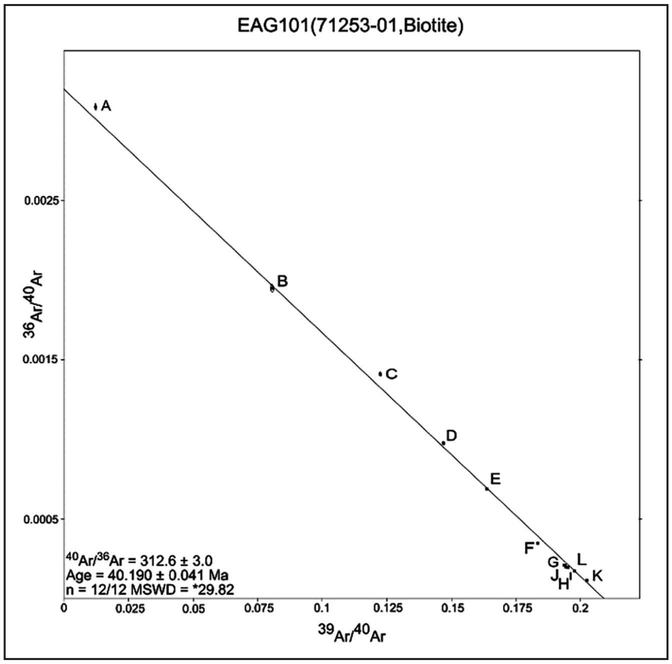

Figure 3. Inverse isochron diagram for EAG 101

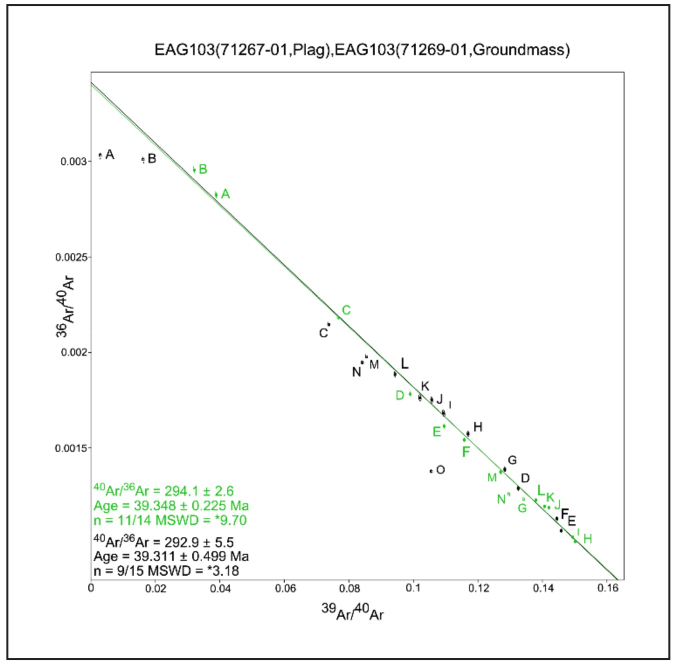

Figure 4. Inverse isochron diagram for EAG 103, showing isochrons for both plagioclase (black) and groundmass (green)

DISCUSSION

Age spectra and inverse isochrons can be used to interpret $^{40}Ar/^{39}Ar$ geochronology data beyond just the age of the intrusion. Age spectra are obtained by step heating a sample, with each step correlating to an apparent age. An inverse isochron is obtained by plotting the $^{36}Ar/^{40}Ar$ ratio over the $^{39}Ar/^{40}Ar$ ratio, which can help identify potential outlying steps.

Sample EAG 101 is likely affected by excess argon, which can show an anomalously old age. This is shown by the $^{40}Ar/^{36}Ar$ ratio being 312.6 (Figure 3), whereas the normal $^{40}Ar/^{36}Ar$ ratio corrected for atmosphere is 295.5.

Sample EAG 103 shows two closely agreeing isochrons (Figure 4) for the plagioclase and groundmass concentrate, when outlying steps are eliminated. The groundmass shows a more precise age, while the plagioclase shows a lower MSWD.

Sample PROS 100 shows a highly imprecise spectrum, with a high initial step followed by a rising age spectrum (Figure 5). The K/Ca values and imprecise age infer that the mineral dated contained little potassium, and could possibly be a pyroxene or hornblende altered to actinolite. The weighted mean could possibly be interpreted as the youngest possible age for the intrusion.

Samples PROS 100-1 and 1004, a hornblende and K-spar from a pegmatite dike, show plateaus in the age spectra. PROS 1004 (K-spar) shows low steps at the beginning, followed by high steps before a plateau (Figure 6). This is likely a result of argon loss for the low steps and excess argon for the higher steps [6]. Due to the difference in closure temperature between hornblende (~550 °C) and K-spar (lower, around ~250 °C) [7], the age of

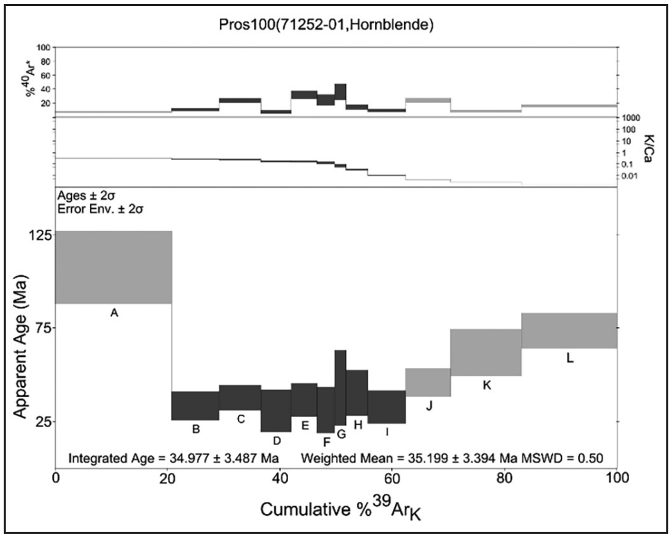

Figure 5. Age spectrum for PROS 100

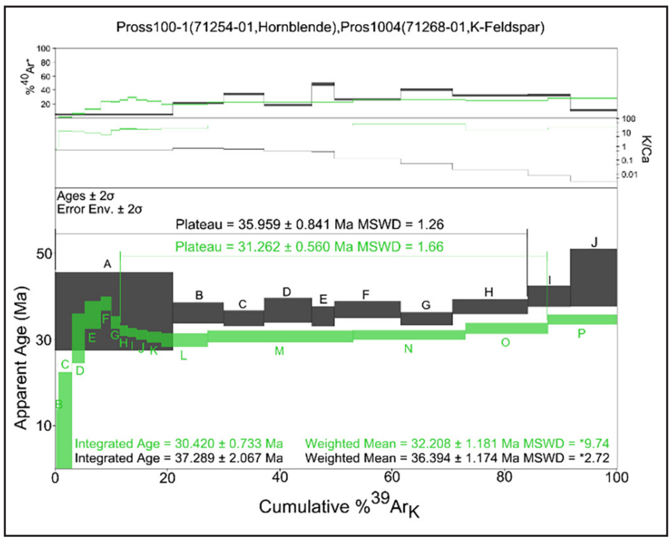

Figure 6. Age spectrum for PROS 100-1 (hornblende, black) and PROS 1004 (K-spar, green)

the hornblende can be interpreted as the intrusion age of the dike, and the age of the K-spar can be interpreted as an alteration episode.

The age spectrum for Hill 2000 is highly discordant, with the best estimate using an inverse isochron at ~83 Ma, 8 million years older than the previous estimates of the intrusion at around ~75 Ma [8]. The high apparent age for steps F and G suggests excess argon (Figure 7), possibly from fluid inclusions or xenocrystic material. It is possible that the material dated may be from nearby Proterozoic material.

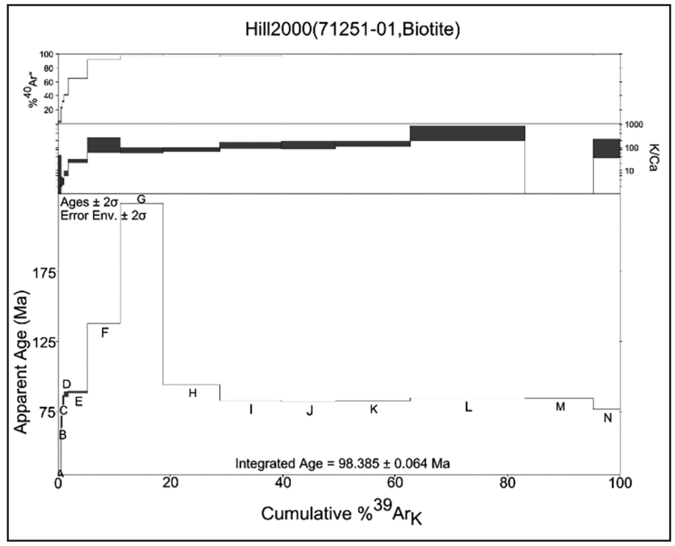

Figure 7. Age spectrum for Hill 2000

This new geochronological work for the Camel Mountain – Eagle's Nest district shows that the intrusions of the area are more likely mid-Tertiary and extensional related rather than Laramide arc-subduction related.

FUTURE WORK

Further geochronology of more mining districts in New Mexico is currently underway to improve the geological understanding of these mineral deposits, as well as additional characterization with whole rock and trace element geochemistry, petrography, and electron microprobe analysis (EMPA). It is expected that in addition to differences in age, mid-Tertiary systems could also have different geochemical characteristics, and the potential critical mineral byproducts from production could be different.

PRELIMINARY CONCLUSIONS

New geochronology for the Camel Mountain – Eagle's Nest district shows that intrusions and mineralization in the district is mid-Tertiary in age, not Laramide. More geochronology work in other systems will enhance our geological understanding of these systems, along with further characterization with geochemistry, petrography, and electron microprobe analysis.

ACKNOWLEDGMENTS

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24-045

Geology Says Otherwise

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Here's what I've been wondering.

If fire hides in wood
what hides in a stone?

(from Alyson Hallett, 2013, *Conversation with a Pebble*)

INTRODUCTION

I spent 41 years as a geologist with the US Geological Survey (USGS) conducting geologic studies and preparing peer reviewed maps and reports describing the results of those studies. Since retiring from the USGS in 2011, I have been a consultant specializing in aggregates and other industrial minerals. Consequently, I have had the opportunity and pleasure to apply the information contained in those kinds of geologic maps and reports to real-life situations.

About half of my consulting is performing due diligence for mineral resource evaluations of one type or another where resource information has been provided by the property owner. Many of those jobs necessitate that I conduct desktop studies followed by field work. I then use my information to review and comment on the written reports of others; reports variably referred to as geologic reports, resource studies, reserve analyses, and so forth. While there are many well written reports addressing geologic resource issues, I was surprised to see that there are also a significant number of so-called geologic reports that only pay cursory attention to geology. Unfortunately, that lack of rigorous geologic investigation commonly leads to erroneous conclusions.

This paper addresses three such reports covering concrete sand, metallurgical gravel, and proppants (frac sand). Although all three examples are located in the Gulf Coastal Plain Province, I do not reveal the exact location of any of the properties for purposes of confidentiality. Furthermore, I have generalized the site descriptions and illustrations. However, all the descriptions faithfully define the geologic situation.

The three case examples are arranged from the least to the most complicated.

"SUCH QUANTITIES OF SAND"

The Walrus and the Carpenter
Were walking close at hand;
They wept like anything to see
Such quantities of sand.

(From Lewis Carroll, 1871,
The Walrus and the Carpenter)