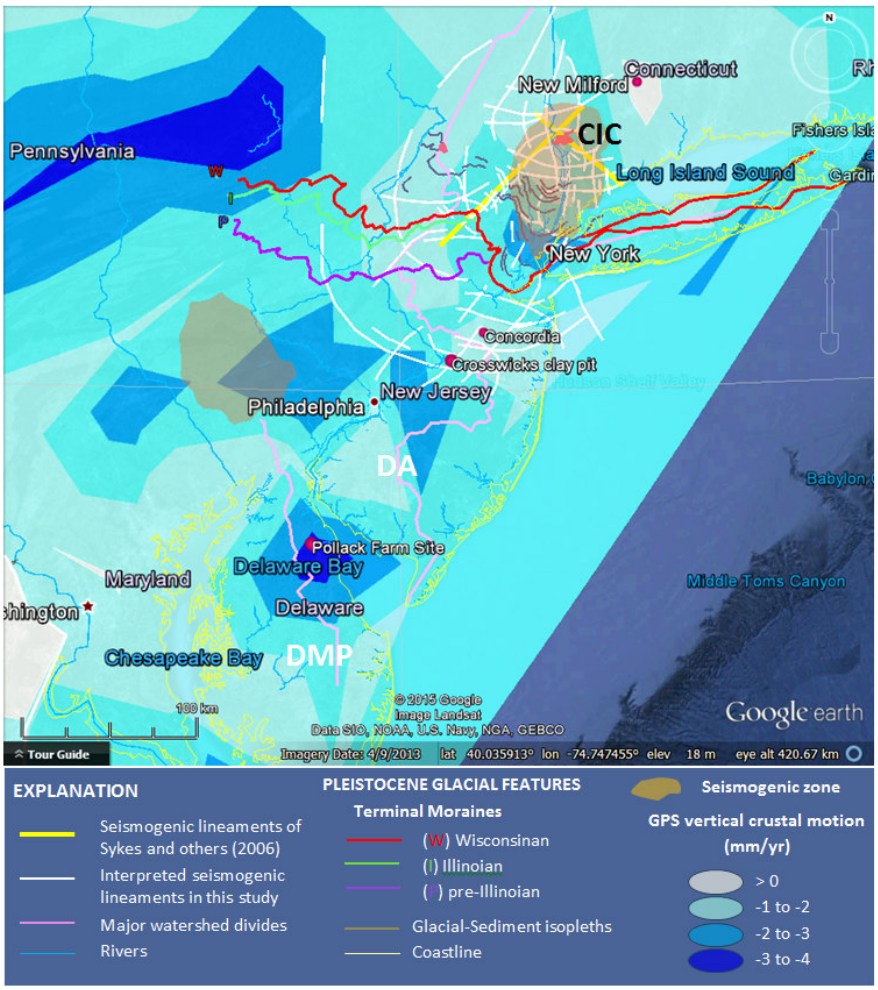
Neotectonics of the New York Recess

MEETING PROCEEDINGS AND FIELD GUIDE FOR THE 2015 CONFERENCE OF THE GEOLOGICAL ASSOCIATION OF NEW JERSEY

EDITED BY

Gregory Charles Herman and Suzanne Macaoay Ferguson

NEW JERSEY GEOLOGICAL & WATER SURVEY PENNJERSEY ENVIRONMENTAL CONSULTING



GEOLOGICAL ASSOCIATION OF NEW JERSEY

XXXII ANNUAL CONFERENCE AND FIELD TRIP

OCTOBER 16-17, 2015, LAFAYETTE COLLEGE, EASTON, PENNSYLVANIA

Neotectonics of the New York Recess

2015 CONFERENCE PROCEEDINGS FOR THE 32ND ANNUAL MEETING OF THE GEOLOGICAL ASSOCIATION OF NEW JERSEY

Edited by

GREGORY C. HERMAN

DEPARTMENT OF ENVIRONMENTAL PROTECTION

New Jersey Geological & Water Survey

and

SUZANNE MACAOAY FERGUSON

Pennjersey Environmental Consulting

Friday October 16th annual meeting hosted by Lafayette College

LAFAYETTE

Geology and Environmental Geosciences

Geological Association Of New Jersey
2014-2015 Executive Board

SCHEDULE

Friday, October 16th
Lafayette College Campus

11:30 to 1:30	Conference Registration
12:30 to 1:30	Teacher's Workshop: Teaching Earth Science with Google Earth
1:30 to 1:50	Dr. Gregory Herman - Welcoming comments, State of the GANJ organization, and business meeting.
1:55 to 2:25	Dr. Charles Merguerian, Duke Geological Laboratories - Review of New York City bedrock with a focus on brittle structures.
2:30 to 3:00	Dr. Ryan Mathur, Juniata College – Re-Os isotope evidence an Early Tertiary episode of crustal faulting and sulfide-mineralization in Pennsylvania with probable ties to the Chesapeake Bay bolide impact in Maryland, USA.
3:05 to 3:30	Dr. Frank Pazzaglia, Lehigh University - Geomorphic paleogeodesy and intraplate deformation associated with the Central Virginia Seismic Zone (CVSZ).
3:35 to 4:15	Dr. Dru Germanoski, Lafayette College - Geology museum and department tour, snacks and refreshments.
4:25 to 4:55	Dr. Gregory Herman - Neotectonics of the New York Recess.
5:00 to 5:40	KEYNOTE SPEAKER, Dr. Kenneth Miller, Rutgers University - The role of sea level and mantle dynamic topography on U.S. Atlantic passive-aggressive continental margin architecture.
6:30 to 8:30	Post-meeting dinner

Saturday, October 17th
Assemble at NJ Liberty Village Commuter Lot at 81 RJ-12W

8:00	Leave Flemington NJ Liberty Village Commuter Lot at 81 RJ-12W
8:30 to 10:30	STOP 1: *Eastern Concrete Materials plant,* 1 Railroad Ave, Glen Gardner NJ
11:15 to 1:15	STOP 2: *Mercer County Park,* 48 Valley Road, Lambertville, NJ,
1:20 to 2:00	STOP 3: *Trap Rock Industries Moore's Station Plant,* 1601 Daniel Bray Highway (Rt-29 S), Lambertville, NJ
1:20 to 2:00	STOP 4: *Delaware & Raritan Canal State Park Trail,* 43 Route 29 N, Stockton, NJ
4:50	Return to Flemington NJ Liberty Village Commuter Lot at 81 RJ-12W

Contents

Chapter 3. Re-Os isotope evidence of Early Tertiary crustal faulting and sulfide-mineralization in Pennsylvania with probable ties to the Chesapeake Bay bolide impact in Maryland, USA.

Ryan Mathur[1] David P. Gold[2], Chad J. Ellsworth[3], Arnold G. Doden[4], Marc Wilson[5], Joaquin Ruiz[6], Barry E. Scheetz[3], and Gregory C. Herman[7]

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Abstract

Re-Os isotope measurements of sulfide minerals from 11 occurrences that span a radial distance of over 200 Km serve to geochemically link epithermal mineralization in Pennsylvania and New Jersey to an Eocene event. The most likely geologic event that could have influenced the area during the Eocene is the Chesapeake Bay impact event. The significance of the discovery is twofold: no epithermal mineralization has been linked to the Chesapeake Bay impact to date nor has the process been clearly identified throughout the region.

Introduction

During the construction of a major interstate road (I-99) in Centre County, Pennsylvania (fig. 1) an epithermal pyrite deposit was unearthed. The study by Mathur (2008) examined the origin of the sulfide mineralization at this location. With Re-Os data measured in sulfide minerals and fluid inclusion data from co-genetic quartz, they interpreted a younger 33.8 ± 4MA, high temperature (>200^{o}C) mineralization event (represented by fault breccia pyrite) overprinted the Mississippi Valley type mineralization (termed MVT and represented by vein pyrite). The timing of the younger mineralization event coincides with two Cenozoic events in the Appalachian Basin: the Chesapeake Bay impact and Eocene volcanism in the southern portion of the Nittanny anticlinorium (Dennison, 1971).

The significance of the overprinted Eocene age becomes apparent by examination of previous models that described sulfide deposit genesis related to older mineralization events. Two timeframes for mineralization have been suggested for MVT deposits in the Appalachians:

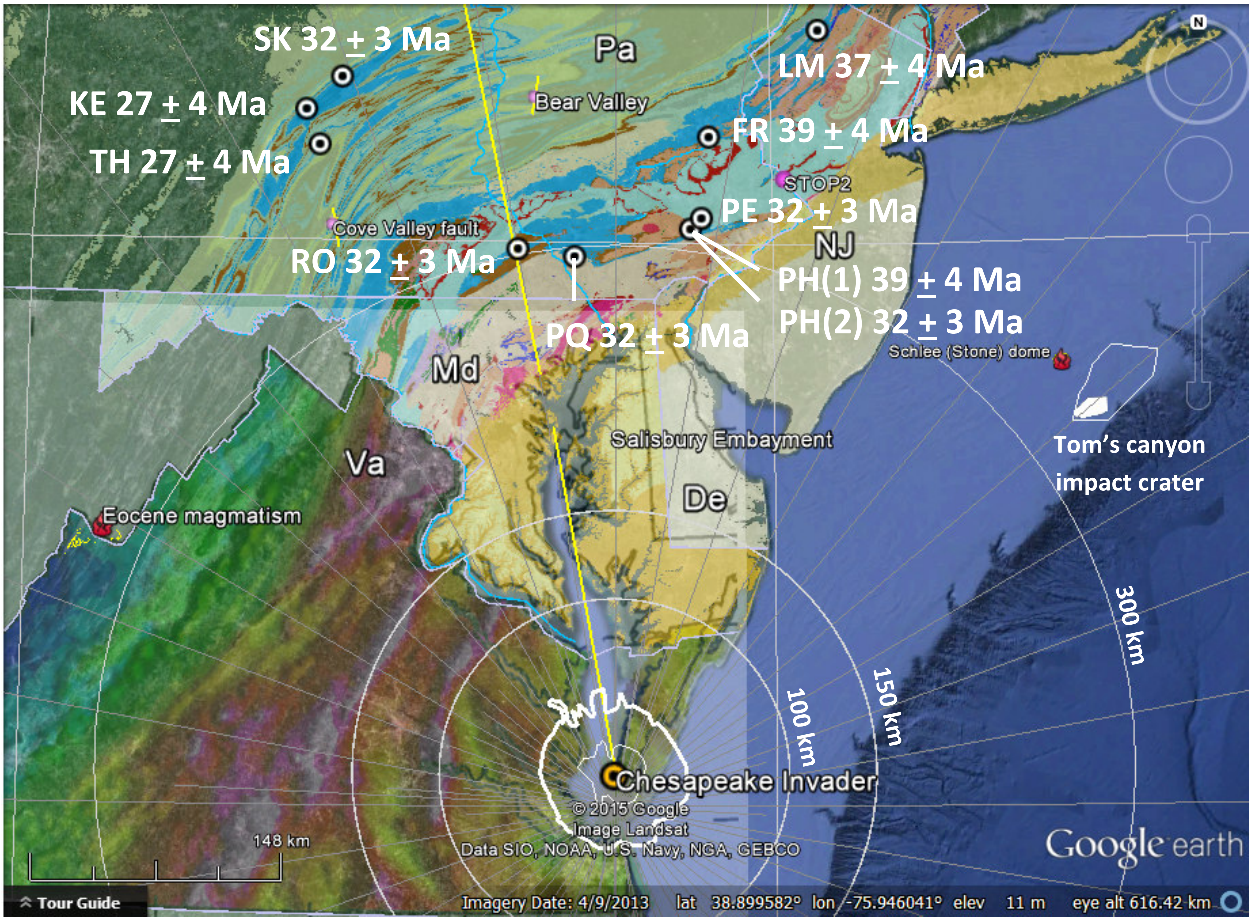

Figure 1. Location map of nine of eleven (11) epithermal sulfide deposits in Pennsylvania and New Jersey analyzed in this report for Re-Os radioisotope ages. Also shown are the locations of late Eocene igneous rocks in West Virginia and Virginia (Southworth and others, 1993; Tso and others, 2004), and the Tom's Canyon impact structure (Poag and Pope, 1988). The two base themes include an integrated, generalized, geological theme covering Maryland through New Jersey adapted from the USGS (see Chapter 4 for explanation and unit key), and a Bouger Gravity anomaly map of Virginia (http://pubs.usgs.gov/of/2005/1052/html/va_grav_large.htm) showing rings of 100- and 150-km radii surrounding the Chesapeake impact crater. The presumed direction of bolide flight is from the SSE to NNW along the bright yellow line extending from the crater up the spine of Chesapeake Bay, following a primary direction of crustal compression resulting from a directed, oblique, hypervelocity strike of the crust. The light gray lines project from the crater outward into the surrounding, like wheel spokes, one which symmetrical bisects the Tom's Canyon impact structure.

1) Radiometric dates from alteration silicates indicate that mineralization occurred in the late Permian age (Hearn, 1987), and

2) Structural geology (Kesler, 1990) indicates a Devonian age.

Traditional models of sulfide deposition in the area have favored two different models (similar to the genesis of base metal occurrences in the mid-continent): as related to an extension of a larger MVT system (Heyl, 1982) or as related to diagenesis (Kutz, 1989). For instance, fluid inclusion studies of quartz in the gossans and sulfur isotope studies of sulfides from Pb-Zn occurrences by Howe (1981) indicated that MVT processes occurred in the area. The second model relates mineralization could have formed during diagenesis. Rose (2005) used trace and major element geochemical signatures from the veined sulfides and host rocks to argue that the sulfides formed during diagenesis as a result of sulfidation of the host rock.

Mineralization throughout central and eastern Pennsylvania has been geochemically linked to MVT-like processes. Kesler and van der Pluijm (1990) (the study identified similarity of Pb isotopic composition of ore from the Keystone mine and Friedensville to other Appalachian MVT deposits), Kesler et al., 1995 (the study identified similarities of fluid inclusion evidence from the Schad and Keystone to other Appalachian MVT deposits), and Appold (1995) (the study correlated sulfur isotope data for the Appalachian MVT and the data collected by Howe (1981) to indicate a common source of sulfur for these deposits) link Pb + Zn mineralization in Pennsylvania to Appalachian MVT deposits. The results were interpreted to indicate that mineralizing fluids formed by a combination of connate and formation water brines most likely mobilized by Alleghanian orogenesis (between 280-310 Mya), with ore deposition analogous to Mississippi Valley-type Pb-Zn deposits (further described in Oliver, 1986).

This contribution explores the extent and overall impact of the previously unknown Eocene event. Previous studies identified and described Pb-Zn sulfide occurrences in Paleozoic strata in this area of the Valley and Ridge Province and several other locations in eastern Pennsylvania (Howe, 1981; Rose, 1999; Smith, 1977). Thus, to further understand the origin of epithermal sulfide deposits in the area and the extent of the younger mineralization, we measured the Re-Os contents of sulfides from 10 different mineral locations (fig. 1) spread throughout eastern to western Pennsylvania and New Jersey. The selection of the suite of deposits provides the following comparative analysis:

1. We chose both minor occurrences (Thompson mine, Keystone mine, and Roosevelt mine) along with the historically largest Pb-Zn mines in Pennsylvania (Pequa mine, Friedensville mine and Phoenixville mine).

2. The selected deposits span a large geographic region. The inclusion of eastern Pennsylvania and New Jersey sulfide occurrences allows for improved interpretation for the causes associated with the Eocene mineralization event.

Methods

Samples for the Pennsylvania sulfides were obtained from the collections at the Carnegie Museum of Natural History, Hillman Hall of Minerals; samples for the New Jersey sulfides were obtained from drill cores and hand specimens. No fresh sulfides from the historic mine sites were collected due to the chemical weathering of sulfides in a humid climate. The samples were hand-picked and powdered for analyses.

To characterize the mineralogy and chemistry of the samples, powdered X-ray diffraction (XRD) were performed on the sulfides. XRD analysis was conducted using a Scintag X-ray powder diffractometer. XRD scans were completed in slow, step-scan mode for precision analysis. For Re-Os analysis, 0.7 to 2.1g sulfide mineral powders were completely dissolved by the carius tube method (Shirey, 1995). Os and Re were separated by distillation and ion exchange chromatography, respectively (Mathur, 2000c). Samples were loaded into a thermal ionization mass spectrometer as salts (Creaser et al., 1991) and concentrations of Re and Os were determined by isotope dilution. Blank measurements for Re and Os ranged from 24-41 picograms and 0.4-1.2 picograms respectively, and the measured 187Os/188Os of the blank was 0.20 ± 0.02 throughout this study. All measurement errors have 2σ<0.5%; however, the greatest source of error in the measurement is the Os blank. Therefore, errors reported in Table 1 were calculated by varying the concentration of the Os blank between 1 and 2 picograms (further discussion in Mathur, 2000).

Results

The XRD mineral identifications as well as the Re-Os concentration and isotope ratios are reported in table 1. The concentration of Re and Os range from 0.2- 2.3 part per billion (ppb) and 3-50 parts per trillion (ppt), respectively. A comparison of average concentration with 1 sigma errors of Re and Os in sphalerite (0.92 ± 0.80 ppb and 10 ± 9.2 ppt), pyrite (0.95 ± 0.9 ppb and 9 ± 6 ppt) and galena (1.1 ± 0.4 ppb and 33 ± 14 ppt) does not reveal any mineral phases containing higher concentrations of either element. The overall average concentrations of Re and Os are similar to those measured in porphyry copper deposits and other types of epithermal mineralization (Mathur, 2000a, b, 2002, 2005; Mathur et al., 2003).

Isochron plots of the data reveal three linear trends (fig. 2). The calculated ages of the trends were determined using a conventional isochron plot with the ratios of daughter ($^{187}Os/^{188}Os$) versus parent ($^{187}Re/^{188}Os$) plots: $^{187}Os_m = ^{187}Os / ^{187}Os_i + ^{187}Re_m(e^{\lambda t}-1)$; where: m= measured, λ= decay constant, t= time, i= initial (Ludwig, 2001). The decay constant we used for Re is 1.66 x 10^{-11} yr^{-1} (Selby et al., 2007). Four samples from Phoenixville and Freidensville lie on a trend that yields a Model 1 age of 39 ± 4 Ma, $^{187}Os/^{188}Os_i$= 0.27± 0.03, MSWD= 1.3. Three samples from Keystone and Thompson lie on a trend that yields an age of 27 ± 4 Ma,

$^{187}Os/^{188}Os_i$ = 0.05 ± 0.04; because three points does not possess statistical significance no MSWD is reported. Sixteen samples from Skytop, Pequa, Perkiomen, and Roosevelt lie on a trend that yields a Model 3 age of 32 ± 3 Ma, $^{187}Os/^{188}Os_i$ = 0.23 ± 0.03, MSWD= 5.3. The ages overlap within reported errors, with the exception of the samples from the Keystone and Thompson mines, which lie slightly younger than the other trends on the isochron plot. The initial Os ratio is relatively consistent for all isochrons and possesses a significant non-radiogenic source for Os.

Table 1. Re-Os analytic analyses from Ten Mines in Pennsylvania having late Eocene hydrothermal event with sulfide minerals

Mine-sample #	County	Mineral	Re (ppb)	Os (ppt)	$^{187}Re/^{188}Os$	error	$^{187}Os/^{188}Os$	error
Thompson	Mifflin	pyrite	2.30	19	1142	103	0.53	0.03
Roosevelt	Mifflin	sphalerite	0.33	17	90	8	0.29	0.02
Keystone-Gn-1	Juniata	galena	1.15	19	377	34	0.21	0.01
Keystone-Sph-1	Juniata	sphalerite	3.03	18	833	75	0.43	0.03
Perkiomen	Montgomery	pyrite	0.65	11	365	33	0.41	0.02
Perkiomen	Montgomery	sphalerite	1.10	5	574	52	0.47	0.03
Perkiomen-657	Montgomery	sphalerite	0.41	5	371	33	0.41	0.02
Perkiomen	Montgomery	pyrite	1.08	3	1906	172	0.23	0.01
Perkiomen- 700	Montgomery	pyrite	0.20	5	224	20	0.32	0.02
Perkiomen- 25692	Montgomery	sphalerite	1.24	30	203	18	0.29	0.02
Friedensville- 702	Lehigh	sphalerite	0.54	4	699	63	0.71	0.04
Friedensville- 703	Lehigh	sphalerite	0.31	15	118	11	0.36	0.02
Phoenixville- 1-689	Chester	sphalerite	0.76	5	849	76	0.88	0.05
Phoenixville- 1-690	Chester	sphalerite	0.82	2	894	107	0.90	0.07
Phoenixville- 1-6920	Chester	galena	1.48	30	250	23	0.32	0.02
Phoenixville 2-1	Chester	sphalerite	0.65	3	1049	126	0.66	0.06
Phoenixville 2-2	Chester	galena	0.43	21	106	10	0.29	0.02
Phoenixville 2-3	Chester	pyrite	0.50	7	2312	208	0.91	0.05
Pequa Gal	York	galena	1.29	50	119	11	0.29	0.02
Pequa Gal	York	galena	1.20	46	110	10	0.27	0.02
Little Juniata	Centre	pyrite	0.495	19.000	1309	118	0.850	0.051
Little Juniata	Centre	pyrite	0.543	24.000	1319	119	0.870	0.052
Lafayette	New Jersey	sphalerite	3.32	5	9004	540	6.4	0.38

Discussion

The Re-Os results from the sulfides serves to geochemically link the epithermal deposits to an Eocene age and relatively non-radiogenic sources of Os. Two aspects of the results tie the 10 analyzed occurrences (spanning over 200 Km radial distances to one another) to a similar event. First, multiple deposits that exist in western and eastern Pennsylvania (Pequa, Skytop, Roosevelt, and Perkiomen) fall along similar trends on the isochron diagram indicating a similar source fluid precipitated mineralization. Secondly, the calculated age and initial Os ratios for Layfayette, Pequa, Skytop, Roosevelt, Perkiomen, Phoenixville and Friedensville overlap. This overlap indicates that mineralization age and source could be the same. The Thompson and

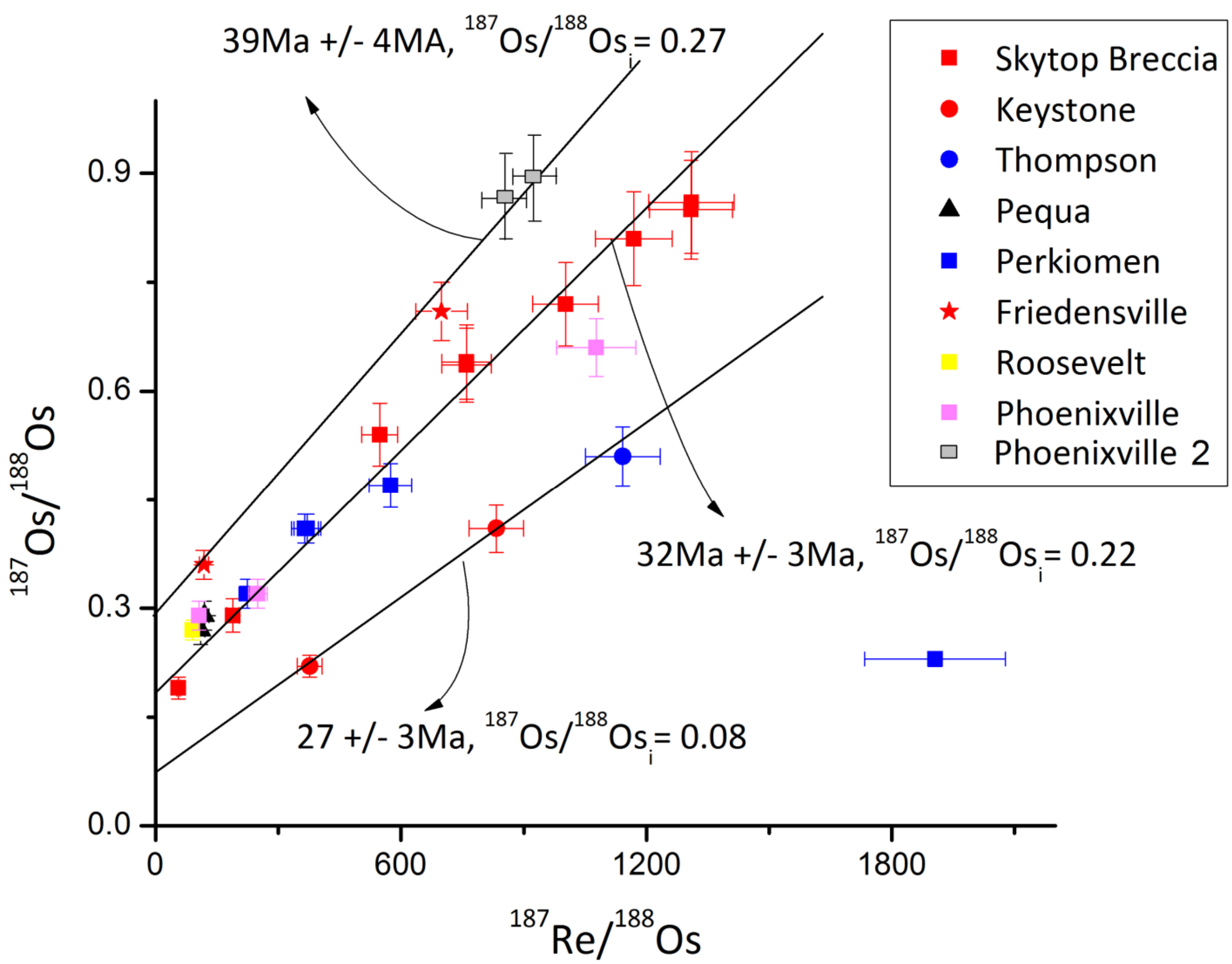

Figure 2. Re-Os isochron plots of sulfide minerals analyzed for eight (8) locations in Pennsylvania (fig. 1). Results from Lafayette Meadows (LM) are not plotted because the Re/Os ratios are significantly larger and the trends become difficult to view.

Keystone results do not overlap with the Eocene age and have an Os initial ratio that barely overlaps with chondritic mantle. Although inconsistent with the other 8 occurrences, the young age and non-radiogenic Os initial ratio clearly point to a process not related to MVT-style mineralization.

Mathur and others (2008) hypothesized the young mineralization event related to two possible causes, the Chesapeake Bay impact or Eocene volcanism present in southerly portions in the same geologic structure (the Eocene volcanics are labeled in fig. 1). However, because the deposits analyzed span a larger geographic region, the Eocene volcanism present in the West Virginian portions of the Appalachians (Southworth and others, 1993; Tso and others, 2004) could not be a cause for the mineralization in eastern Pennsylvania. No geologic relationships tie the Lafayette, Phoenixville, Friedensville, Perkiomen or Pequa with the alkalic volcanism present in West Virginia. Also kimberlites occur in this that could have caused mineralization area (Bikerman and others, 1997), however the ages of known kimberlite activity do not coincide with the Re-Os ages determined here. Therefore, the young event that might have impacted mineralization in eastern Pennsylvania is the Chesapeake Bay impact. Tom's Canyon impact identified in the Atlantic Ocean tens of kilometers east of New Jersey could also be important as it occurred at roughly the same time (Poag, 1998b).

Constraining the cause to the Chesapeake Bay impact is the most significant interpretation of the dataset. The impact crater sits at the mouth of Chesapeake Bay (fig. 1) and is currently the fifth largest recognized meteoric impact crater on Earth. As first identified by Wiley Poag in 1997, it represents a major tectonic event for the eastern continental margin of the North American Plate (Koeberl and others, 1996; Poag, 1996; Poag and others, 2009). Dating of the impact places it at 35±0.5 million years ago. Manifestations of this event include tsunami deposits on the Atlantic shelf to the north, and a tektite ejecta field in the Atlantic Ocean, and as the source for the locally distributed jasper-pebble deposits in northeastern Virginia. One of the authors, as part of an FHWA SHRP program in 1985, identified echelon quartz twinning in petrographic thin sections of the Townson gravel, a quartz aggregate use locally for concrete formulations. But just how the impact lead to the genesis of the epithermal sulfide veining event throughout Pennsylvania remains unclear. Links between ore deposits and impacts is not a new discovery. Many studies have demonstrated impacts such as Sudbury, Canada and the Vredefort dome in South Africa caused mineralization (Grieve, 1994; Grieve, 2005; Reimold and others, 2005). In fact, Grieve defined three general types of mineralization associated with meteor impacts: progenetic (ores existing before impact), syngenetic (formed during) and epigenetic (post impact). The isotopic and field evidence indicate that the mineralization analyzed here is epigenetic.

The exact processes that lead to mineralization could be related to two general mechanisms: hydrothermal convection cells driven by the heat of the impact or release of mantle fluids analogous to antipodal volcanism associated with impacts. With respect for the hydrothermal-convection mecahanism, breccias and ores associated with the Sudbury and Vredefort large impacts are thought to be associated with hydrothermal flow of meteoric fluids associated with convective flow spanning up to 8 km (Pirajno, 2005). But the distribution of breccia and mineralization seen in this region would require meteoric-driven mineral sources driven by heat to occur over hundreds of square kilometers, making it highly unlikely. However, two factors associated with the Chesapeake Bay impact may have allowed for the existence of a larger hydrothermal system. The Chesapeake impact occurred near or within seawater and the surrounding crust contains several overlapping joints and faults that would serve as ideal conduits for fluid flow. The preexisting fracture network is not clearly defined; however the Roosevelt, Thompson and Keystone sites are associated with the well documented and studied Tyrone/Mt. Union lineament (Gold, 1999), where mineralization has been recognized for nearly 200 years. Gold (1999) also reports an alignment of sulfide mineralization along a short lineament in Montgomery County which included the Perkiomen mine. The Skytop deposit represents a juncture of a minor lineament and a recognized fault. Many other lineaments exist throughout the eastern and western Pennsylvania that could have served as conduits due to an orogenic history that has at least four mountain building events (Grenville, Taconic, Acadian, Alleghanian) impacting the area over the past billion years.

The second mechanism that could lead to mineralization is for the ground shock of impact to drive a fluid release from mantle depths, as evidenced by fluid inclusion temperatures of 400^{o}C (Howe, 1981; Mathur and others, 2008). The fluids would have risen to the surface through a plumbing system comprised of either preexisting fractures, impact-generated fractures, or a combination of both. The nearly 0 ‰ per mil sulfur isotope data for Friedensville presented by Kesler and van der Plujm (1990) could be interpreted as a magmatic sulfur isotope signature. Continued analyses of other sulfide occurrences throughout the radial impact area should illuminate which pathways served as channels for the epithermal mineralization.

Aside from understanding processes associated with impacts of meteors, this identification of large-scale mineralization in Pennsylvania associated with the Chesapeake Bay impact has long-range implications for future exploitation of economic resources, as well as a direct impact on the civil transportation infrastructure. The Interstate 99 example resulted in $80 million dollar expenditure by the Commonwealth of Pennsylvania to remediate the effects of acid rock drainage that was a direct consequence of the exposure and weathering of pyrite in this deposit. The extent of the mineralization proposed in this hypothesis has not yet been fully delineated. There is no reason to believe that the observed regional mineralization is limited just to Pennsylvania and New Jersey. Applying a systematic radius about the impact crater for a radial distance to Lafayette Meadows, NJ or Skytop, PA suggests that areas as far south as South Carolina and as far north as Connecticut including West Virginia, Virginia, Maryland, New York, and Delaware may contain similar structures and mineralization. As seen in figure 1, Eocene magmatism occurs at radial distances of over 300 km from the crater.

Acknowledgements

We would like to thank MAUTC, ACS and the Pennsylvania DCNR for their kind support of the project. The project was greatly aided by the assistance of D. Nicholas and G. Huston.

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