Report Text

Introduction

The original architecture and subsequent geologic processes that have affected the basement rocks in Pennsylvania are important to the interpretation of the environmental and economic geology of the Commonwealth. The geology of the basement rocks in large measure controls the occurrence and distribution of earthquakes and certain metal deposits as well as subtly affects the depositional patterns of some younger Paleozoic strata that host oil and gas deposits or coal beds. Unfortunately, except for the region southeast of the Great Valley, these basement rocks are covered by an extensive sequence of younger Paleozoic strata that thicken from west to east. Therefore, over most of Pennsylvania basement rocks occur only in the subsurface and our knowledge of them is based on geological and geophysical inference.

The principal objective of this project is to assemble a comprehensive geospatial database related to the basement structure and other basement features in Pennsylvania. The relevant data and information come from available geological, geophysical and remote sensing observations, earlier interpretations of them and from analyses carried out in this project. These individual datasets, ranging from point measurements to profiles to continuous maps or images along with associated metadata, are included as GIS data layers in the geospatial database that has been assembled. All are geo-referenced to a PA-Albers projection to facilitate comparisons, correlations and multi-layer overlays (products) for Pennsylvania.

The featured product is a composite structure contour map of the Precambrian-Cambrian unconformity (1:500000 scale: 500 m contour interval normalized to sea level) with basement faults, lithologies (where known) and point depths from seismic profiles and boreholes shown. The paucity and uneven distribution of hard depth data means that the structure contours are poorly constrained and thus are subject to many different configurations and interpretations. It is important to note that this Version 1.0 map should be regarded as a **dynamic representation** of the basement in Pennsylvania. As new observations become available or additional existing data and information are identified and incorporated into this geospatial database the Pennsylvania basement map will evolve. Also, other investigators may generate alternative interpretations from the present geospatial database. (The authors would greatly appreciate receiving feedback concerning alternative interpretations and additional data and information pertaining to the basement in Pennsylvania that can be added to the database for future use).

Users can view each of the data layers individually as well as construct other desired combinations of the data layers using standard geographical information systems (GIS) software (e.g. ArcGIS, ArcView), as described in "Software Requirements." Overlays of other combinations of the data layers (e.g. seismicity, basement faults, lineaments, gravity and magnetic fields) are shown as example products in the Preview.

More details concerning the project and the data sets included are given in the sections that follow.

Basement Definition and Geologic Features

In this study, basement rocks are dominantly ±1 Ga old Precambrian crystalline rocks of the Grenville terrane and as such are separated from the overlying Paleozoic strata by a 500 MY gap in the geologic record. In southern Ontario, where the Grenville is exposed it is a complex terrane. It has been subjected to multiple deformations and faulting and is composed of a variety of igneous and metamorphic rock types. These rocks extend south into New York State and Pennsylvania in the subsurface. Beneath the Appalachian Plateau and Ridge and Valley Province, which includes most of Pennsylvania, Grenville basement is deeply buried. Basement compositions in the subsurface are known from a few deep wells in northwestern Pennsylvania. These are summarized by Saylor (1999) in the volume *The Geology of Pennsylvania (1999)* as granitic gneisses and schists. The basement here has been little affected by subsequent Paleozoic deformations. It has principally subsided to accommodate a thick wedge of Paleozoic sedimentary rocks that accumulated upon the basement surface. Minor faulting, undoubtedly representing reactivation of larger Precambrian faults, and local uplift of the basement accompanied this regional subsidence; however, these basement features are important from an economic and environmental perspective.

Adjacent to the Great Valley, on the southeast, metamorphosed volcanic basement rocks are brought to the surface in South Mountain as allochthonous folds related to deep thrusts associated with Paleozoic orogenesis. These volcanic rocks, termed the Catoctin Formation, are of latest Precambrian age and represent the initiation of rifting at that time. The metavolcanic rocks exposed in South Mountain overlie deeper Grenvillian basement. The Catoctin is considered as local, younger basement that crops out adjacent to the southern Great Valley in Franklin, Adams, and York Counties but their subsurface extent is speculative, as these volcanic rocks are overridden by thrusts transporting older Grenville basement (Drake, 1999).

Farther north along the Great Valley true Grenville crystalline basement is exposed in the complexly deformed Reading Prong region (Drake, 1999). Grenville granitic gneisses are exposed in the cores of nappes that are part of an immense thrust sheet complex that is surrounded by an envelope of Paleozoic sedimentary rocks. This sequence has been deformed

during the Paleozoic orogenesis that affected this area as well as by later Mesozoic rifting. In this project the entire nappe sequence, including metamorphosed sedimentary strata, is considered as basement.
The exposed Precambrian basement rocks of South Mountain and Reading prong are truncated on the southeast by a regional, east-dipping normal fault. This fault, which has displacement in excess of 3000 m in places, developed late in the evolution of the Mesozoic basins; it is underlain by basement rocks of the Grenville and Catoctin affinity, but their distribution is uncertain.

Emerging beneath the Mesozoic cover on the southeast are rocks of the Piedmont complex. They include multiply-deformed Cambro-Ordovician sedimentary rocks that comprise the Piedmont Lowland Section (Gray and Root, 1999). Farther southeast are highly deformed Precambrian and Lower Paleozoic crystalline and metamorphic rocks of the Piedmont Upland Section (Crawford et al., 1999). These are covered by a thin veneer of Cenozoic sedimentary rocks that are part of the Atlantic Coastal Plain Province. The rocks of the Piedmont represent undifferentiated basement and are highly faulted both by thin-skinned detachment faults as well as deeply-rooted faults.

Basement faults include both mapped faults and inferred faults. The mapped faults are those that are present where basement is exposed. Some of these are extended to basement beneath the mapped expression of faults in the Paleozoic cover rocks. Inferred faults are recognized in areas of covered basement by their signatures on various types of imagery, geophysical maps or as geologic features that likely represent faults extending into basement. In addition, some basement faults can be conclusively identified on available seismic reflection profiles.

Basement-Related Geophysical Observations

Potential fields (gravity and magnetic), seismic reflection profiles, remote sensing and earthquake activity provide important direct or indirect information on basement depth, structure, tectonics and composition. Data and information from each of these types of observations is included in the geospatial database and used in preparing the composite basement map generated in this project.
Bouguer gravity anomalies help to locate and constrain basement features including depth, major fault boundaries and rock densities. Because the overlying Paleozoic strata also contribute significantly to the observed anomalies, interpretations of basement features are best done in combination with other types of data (e.g. magnetic anomalies, seismic profiles, drilling logs).

Aeromagnetic total intensity anomalies are particularly useful in defining basement features, because the observed anomalies are caused almost exclusively by variations in the depth and lithology of the basement rocks. The sedimentary units above contribute negligibly to the observed magnetic field intensity (even though they are closer to the magnetometers making the measurements), because their magnetic susceptibilities are very small compared to those in the crystalline basement rocks that contain abundant magnetite and other magnetic minerals.

Seismic reflection profiles that have been collected for oil and gas exploration provide direct and unambiguous basement depths along the profiles. The seismic record sections represent cross-sections of the subsurface geologic formations expressed in terms of two-way reflection times from interfaces where seismic compressional-wave velocity and density change. From well logs from oil and gas boreholes the rock properties of each stratigraphic unit have been established, such that the reflection record sections can be interpreted to give layer thicknesses, hence depth below the ground surface. Prominent reflections from the basement surface below are typically clearly observed so the total depth to basement can then be determined. Seismic depths to basement determined in this manner by extending the interpretations in Scanlin and Engelder (2003) and Scanlin (2000), incorporating unpublished seismic depths from Lavin (pers. comm.) and interpreting other available profiles (Alexander--this project) are included as data layers. The accuracy of these seismic depths is judged to be within 0.25-0.5 km. Some of the seismic reflection profiles have clearly identifiable basement fault displacements; where found these basement faults and their sense of displacement are included in the database and plotted on the composite basement map.

In addition, wide-angle seismic reflections have been used by Hawman and Phinney (1992-1 and 1992-2)) to determine basement and Moho depths along extended profiles in eastern Pennsylvania. These depths have also been included in the database and plotted on the composite map. Their depth ranges agree well with other seismic depths (where available) and with estimates from other sources that indicate basement depths in excess of 12 km in some areas of eastern Pennsylvania.

Remote sensing imagery (especially Landsat Thematic Mapper) that has been collected repeatedly over Pennsylvania since the 1970s provides additional evidence for basement-related features even though they are only sampling the Earth’s surface. In particular, major lineaments were recognized in the early Landsat images for Pennsylvania (e.g.Gold et al., 1974) that have subsequently been shown to be the surface expression of basement discontinuities (faults); these include the parallel northwest-striking Mt. Union-Tyrone and Pittsburg-Washington lineaments that define a major fault-bounded crustal block developed in the Precambrian. Subsequent studies using gravity and magnetic anomaly patterns indicate that this block was displaced laterally approximately 60 km to the NW in the Precambrian (Chaffin, 1981; Davis, 1980; Lavin, Chaffin and Davis, 1982); the systematic lateral offset of this block had effectively ceased by Ordovician time and subsequent movements have been mostly vertical and not systematic, preserving the lineaments as fracture zones. A mosaic of Landsat images is included as a data layer along with a data layer with the mapped lineaments. A separate data set consisting of 7 channels of Landsat TM Multispectral Scanning (MSS) digital imagery (25 m resolution) covering Pennsylvania was also assembled. This data set is available but is not included with the geospatial data because of its very large size.

Earthquake activity in Pennsylvania is basement-related, either representing basement faulting or faulting at shallower depths induced by tectonic stresses in the basement and underlying crustal rocks. Compared to surrounding regions Pennsylvania is relatively aseismic, but there have been a number of earthquakes in recorded history, a few of which have caused moderate damage. The largest is a magnitude 5.2 earthquake that occurred in 1998 in northwestern Pennsylvania; it most likely is associated with an inferred NS basement fault included on the composite basement map. Each earthquake represents a contemporary fault movement, hence an active fault. Therefore, the epicenters of observed earthquakes identify the locations of active faults in Pennsylvania. It should be noted, however, that even the largest earthquakes in eastern North America have not broken the surface, which means they must occur at considerable depth with no observable associated fault displacement at the surface. Since the 1970s when instrumental recordings of regional earthquakes became available, typical epicenter determinations are within approximately 5 km of the true locations; aftershock monitoring with portable instruments has provided much better accuracy for a few of the larger events. Estimated depths in published seismic bulletins are generally unreliable because of tradeoffs in the hypocenter calculations between an event's origin time and depth and because regional velocity models used in the calculations are only approximate. In this project seismicity data were obtained from the USGS-NEIC database that includes historical (pre-instrument) events from the 1700s on, as well as instrumentally recorded events up to the present; these are in two separate data layers.

For a few of the larger Pennsylvania earthquakes there were sufficient recording stations to determine their focal mechanisms. These give the fault's strike, dip and slip directions as well as the principal stress orientations at the source. Consistent with many other contemporary tectonic stress measurements in eastern North America the maximum principal stress of the Pennsylvania earthquakes is compressive, approximately horizontal and oriented approximately N60E; this represents the current tectonic stress condition in the basement. These focal mechanisms are included in the geospatial database.

Other Basement-Related Data Layers

Well depths and other information for all the deeper boreholes in Pennsylvania are included as a data layer. Only three of these (all in NW Pennsylvania) reach to the basement. For the others extrapolations were made to obtain estimated depth to basement; however, in a number of cases where there are likely repeated sections in the deformed Paleozoic sedimentary sequence, these estimated depths are significantly less than those obtained from nearby seismic reflection data. Therefore, the estimated basement depths from well data should be regarded as minimum depths in many if not most instances.

Lead-zinc mineral deposits are thought to be the result of deep-seated fluid reactions that extend well into the basement. Therefore, the locations of lead-zinc mineral deposits should identify basement-related permeable zones (faults?). For this reason the distribution of these deposits in Pennsylvania by Rose (1999) is included as a data layer. The few known kimberlite locations are also included in the data base, because their sources were likely in the upper mantle.

The geologic map of Pennsylvania is included as a data layer allowing comparison of basement features or other data layers with surface features.

The topographic (DEM) map of Pennsylvania is included as a data layer allowing comparison of basement features or other data layers with surface topography.

Earlier Pennsylvania basement maps by Harris (1975) and by Saylor (1999) are included as separate data layers for comparison with this project's composite map.

Examples of Combinations of Data Layers

With standard GIS software users can generate various combinations of data layers as overlays to produce other maps of interest. Included in the Preview are several examples of such combinations as additional products relevant to basement features in Pennsylvania. Layers of the basement map can be accessed using ArcGIS software (see Software Requirements).

Users are encouraged to generate their own combinations of the data and information contained in this geospatial database for Pennsylvania for applications of interest to them.

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