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Derivative Mapping of Potential Industrial Mineral Resources in Ohio

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ABSTRACT
The Ohio Department of Natural Resources (ODNR), Division of Geological Survey, has an ongoing program to create a new surficial geology map for a 30 × 60-minute (1:100,000-scale) quadrangle each year. Through 2010, the ODNR–Division of Geological Survey has mapped 19 of the 34 complete or partial 30 × 60-minute quadrangles that cover Ohio. The geologic maps contain polygons of three-dimensional “stacks” that summarize the gross lithologic material followed by its thickness (divided by 10) for the entire stack of materials overlying the bedrock lithology. A mapped polygon may contain a labeled stack such as T5|SG3|T2|Ls, which would indicate this sequence contains approximately 50 ft (15.2 m) of till, overlying 30 ft (9.1 m) of sand and gravel, which overlies 20 ft (6.1 m) of till, above limestone bedrock. The (stack) geologic maps are then imported into a geographic information system (GIS) geodatabase, which may be integrated with mineral industry databases containing historical production data, geologic units mined, geochemistry, physical properties, and transportation networks to produce derivative maps. These derivative maps can then be used as a reconnaissance tool to help evaluate the availability and suitability of industrial mineral resource locations throughout Ohio. Industrial minerals mined in Ohio in 2010 had an estimated value of more than US$864 million. The combined value of all industrial minerals (limestone and dolomite, sand and gravel, sandstone and conglomerate, clay and shale, salt, and peat) sold in Ohio in 2010 was more than US$864 million, which represents an increase in value of 97% since 1990 (Weisgarber 1991; Wolfe 2011). Industrial mineral production increased steadily from 1990 until 2008, but the recession led to large declines in the production of most commodities; the lone exception is the continually increasing production of salt since 1990 (+42%). Limestone and dolomite production has declined by 15.7% compared with 1990, and the production of other industrial minerals has decreased more significantly: sand and gravel by 36%, sandstone and conglomerate by 34.5%, and clay and shale by 70%. Peat is produced in minor amounts, and gypsum has not been produced in Ohio since 2002. Ohio is a national leader in industrial mineral production. In 2010, Ohio ranked fourth in the United States, producing 5.1 million metric tons (Mt) of salt and ranking fifth in the production of lime (1.1 Mt), sixth in the production of crushed stone (49.2 Mt) and aggregates (74.6 Mt), and seventh in the production of clay and shale (0.8 Mt).

The Ohio Department of Natural Resources, Division of Geological Survey, also known as the Ohio Geological Survey, has researched the geology of industrial mineral deposits, including aggregates, for more than 170 years. Smith (1949) studied sand and gravel deposits on a regional basis in northern Ohio. County-scale sand and gravel resource studies were completed for nine counties in the 1980s (Hull 1980, 1984; Risser 1981, 1985, 1986; Struble 1986, 1987a,b,c). In the 1990s, Stith (1995a,b, 1996a,b) completed mapping for potential crushed-stone and sand-and-gravel resources in the Bellefontaine and Piqua 30 × 60-minute quadrangles.

The expanding production of industrial minerals in Ohio is competing with many other land uses in a state with more than 11.5 million residents. Planning for sequential land use that includes development of industrial mineral resources in these growing areas is vital to the sustainability of urban and suburban centers. Three-dimensional surficial materials mapping is an indispensable tool for informed land-use planning. The Ohio Geological Survey has mapped 19 of the 34 complete or partial 30 × 60-minute quadrangles that cover Ohio, including a large portion of glaciated Ohio (Figure 1). These mapped polygons may contain three-dimensional, 30 × 60-minute surficial geology maps that can be used not only for regional land use but also for preliminary evaluation of industrial mineral availability in Ohio (Wolfe 2001) and to create derivative maps that delineate areal areas with the potential for additional crushed-stone or sand-and-gravel resources (Wolfe and Stith 2007; Wolfe et al. 2008; Pavey et al. 2011; Venteris et al. 2011; Figure 1).

INTRODUCTION

The combined value of all industrial minerals (limestone and dolomite, sand and gravel, sandstone and conglomerate, clay and shale, salt, and peat) sold in Ohio in 2010 was more than US$864 million, which represents an increase in value of 97% since 1990 (Weisgarber 1991; Wolfe 2011). Industrial mineral production increased steadily from 1990 until 2008, but the recession led to large declines in the production of most commodities; the lone exception is the continually increasing production of salt since 1990 (+42%). Limestone and dolomite production has declined by 15.7% compared with 1990, and the production of other industrial minerals has decreased more significantly: sand and gravel by 36%, sandstone and conglomerate by 34.5%, and clay and shale by 70%. Peat is produced in minor amounts, and gypsum has not been produced in Ohio since 2002. Ohio is a national leader in industrial mineral production. In 2010, Ohio ranked fourth in the United States, producing 5.1 million metric tons (Mt) of salt and ranking fifth in the production of lime (1.1 Mt), sixth in the production of crushed stone (49.2 Mt) and aggregates (74.6 Mt), and seventh in the production of clay and shale (0.8 Mt).

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Glacial Geology

The glacial deposits of Ohio are represented by numerous glacial episodes. Early pre-Illinoian erratics have been found in isolated areas of the state. In
Figure 1 Map highlighting the 30 x 60-minute quadrangles in Ohio in which three-dimensional surficial mapping has been completed or was in progress on September 26, 2011. Quadrangles in which potential sand-and-gravel or mineable-bedrock resources derivative maps have been produced are also depicted.
Several other glacial features are commonly found in the glaciated portions of Ohio. Kettle holes, depressions left when remnant ice masses melted, can range in size from an acre to several square miles. Kettle holes are normally the sites of bogs, swamps, and lakes and may contain peat. Lacustrine or glacial lake deposits are found throughout Ohio and range from coarse sand to fine silts and clays. Silt of windblown origin (loess) and up to 3.3 ft (1 m) thick is present in many places in northeastern Ohio. Three major and five minor strandlines or beach ridges are present in the northern portion of the state. These ridges represent ancient beaches that formed when lake levels were as much as 197 ft (60 m) higher than current levels because of damming to the north by the retreating Wisconsinan glacier (Forsyth 1959; Pavey et al. 1999).

**Bedrock Geology**

The bedrock geology of eastern Ohio consists of alternating series of rock consisting of shale, siltstone, and sandstone with interbedded limestone, clay, and coal. The bedrock of western Ohio is predominantly dolomitic limestones with thin interbeds of silty shales. A thick organic shale and siltstone sequence overlain by siltstones and sandstones is transitional between the cyclical deposit of eastern Ohio and the carbonate-dominated deposits of western Ohio. A structural feature, the Cincinnati Arch, trends generally north–south in western Ohio and had a major influence on deposition in the Paleozoic. The bedrock stratigraphic interval in the areas covered by the aggregate resource derivative maps includes the following (from youngest to oldest): Pennsylvanian-age Allegheny and Pottsville Groups; Mississippian-age Logan and Cuyahoga Formations; Mississippian-age Sunbury and Bedford Shales; Devonian-age Berea Sandstone; Devonian-age Ohio, Olentangy, Silica, and Antrim Shales; Devonian-age Delaware and Columbus Limestones; Devonian-age Detroit River Group and Dundee Limestone; Silurian-age Salina Group; and Silurian-age Tymochtee, Greenfield, and Lockport Dolomites (Shrake et al. 1998; Slucher et al. 2006).

**DERIVATIVE THREE-DIMENSIONAL SURFICIAL GEOLOGY MAPS**

Four primary aspects are depicted on a surficial geology map: (1) major lithologies; (2) thicknesses (in feet); (3) lateral extents; and (4) vertical sequences, shown by stack symbols. Each stack represents a generalized cross-section for that polygon. Thicknesses are reported in feet as a factor of 10 and are gross averages that can vary up to 50%, except (1) those followed by a minus sign (−), which represents the maximum thickness of a thinning trough- or wedge-shaped sediment body, or (2) units in parentheses, which indicate discontinuous distribution of those units. As an example, a mapped polygon may contain a labeled stack such as T5[S]G3[T2]Ls, which would indicate this sequence contains approximately 50 ft (15.2 m) of till overlying 30 ft (9.1 m) of sand and gravel that overlies 20 ft (6.1 m) of till above limestone bedrock (Figure 2). The maps are color-coded using the uppermost surficial material.

Data were obtained from county soil maps that were modified by interpretation of local geomorphic settings and from other sources, such as Ohio Department of Natural Resources, Division of Water water-well logs, Ohio Department of Transportation test-boring logs, theses, and published or unpublished geologic reports and maps. Total thicknesses were calculated from Ohio Geological Survey 7.5-minute, open-file bedrock topography maps. Bedrock units were determined from Ohio Geological Survey open-file bedrock geology maps.

Map units of primary interest for industrial mineral evaluation include the following: SG, Wisconsinan-age interbedded sand and gravel commonly containing thin, discontinuous layers of silt and clay; IC, Wisconsinan-age ice-contact deposits composed of highly variable, poorly sorted sand and gravel deposited from stagnant ice as kame or esker landforms and commonly containing inclu-
**Figure 2** Cross section illustrating thickness and mapping conventions for a hypothetical stack-unit map in the Ohio Department of Natural Resources, Division of Geological Survey’s SG-2 map series. Solid-line boundaries separate map-unit areas having different lithologic units at the surface; underlying lithologic units may or may not differ. Dashed-line boundaries separate map-unit areas having the same surface lithologic unit but different thicknesses or different underlying lithologic units. Thickness values are in tens of feet and are gross averages that can vary up to 50%, except (1) those followed by a minus sign (−), which represents the maximum thickness of a thinning trough- or wedge-shaped sediment body, or (2) units in parentheses, which indicate discontinuous distribution of those units. Precise surface topography can be determined from topographic maps available from the division’s Geologic Records Center.
majority of the sand-and-gravel production in the Cleveland South, Mansfield, and Canton 30 × 60-minute quadrangles is from these units (Figure 2).

Bedrock map units of interest for the evaluation of industrial mineral potential, principally in areas of thin till delineated on the Shaded Drift-Thickness Map of Ohio (Powers and Swinford 2004), are primarily economic-quality carbonate rock. The Marion and Findlay 30 × 60-minute quadrangles contain Silurian-age and Devonian-age limestone and dolomite units that supply aggregates or have other industrial uses. These rock units are, in ascending order, Lockport Dolomite; Greenfield Dolomite; Tymochtee Dolomite; Salina Group undifferentiated; and the Detroit River Group, Dundee Limestone, and Columbus Limestone.

A geographic information system (GIS) was used to query the database for areas of thin till over bedrock for potential crushed stone resources (Marion and Findlay Quadrangles) or areas with less than 40 ft (12.2 m) of overburden overlying thick sand and gravel deposits (Mansfield and Canton Quadrangles). The final derivative maps include bedrock geology and drift-thickness inset maps that show historic and active mining locations. The inset maps can be used in conjunction with the derivative map to delineate areas for more detailed resource evaluation. After initially identifying areas of interest, the three-dimensional derivative maps can be used to determine potential mineable resources (Figure 3). Cross sections showing general deposits can be constructed and first-pass resource tonnages can be calculated. Land-use and zoning restrictions can be overlain on the derivative maps and analyzed. General transportation networks, mined areas, and possible markets are included on each derivative map and are factors in determining whether a more detailed evaluation is justified.

**Sand and Gravel Resources**

Kames and kame terraces are the most important sources of commercial sand and gravel deposits in the Cleveland South and Canton 30 × 60-minute quadrangles (Wolfe 2001; Pavely et al. 2011). The largest kame complex in Ohio extends from northern Summit County through west-central Portage County into southern Geauga and central Stark Counties (White 1982; Pavely et al. 1999). This large kame complex is thought to have formed either when vast amounts of meltwater flowed in the interlobate area between the Killbuck sublobe and the Grand River sublobe or as an endmoraine gravel phase, created solely by the action of the Grand River sublobe (Hull 1980).

Valley train and outwash plain deposits and associated terraces are important sources of sand and gravel in the Mansfield 30 × 60-minute quadrangle and are secondary sources of aggregate in the Canton and Cleveland South 30 × 60-minute quadrangles (Pavely et al. 2000, 2002, 2011; Venteris et al. 2008b). Alluvial terraces adjacent to these outwash deposits often contain commercial quantities of sand and gravel. Approximately 30 sand and gravel operations were active in 2010, and related deposits in the quadrangles cited above during 2010, providing several million tons of aggregate for local construction and highway projects. Kame deposits or areas of outwash in buried valleys are potential future resources as existing reserves are exhausted or mining technology advances sufficiently to make these subsurface deposits economically attractive.

The northern portion of the large kame complex associated with the Kent Moraine extends into southern Geauga County. This complex has up to 66 ft (20 m) of sand and gravel with 0 to 197 ft (0 to 60 m) of till overburden across large areas. Near Ohio Route 87, an area of sand and gravel 30 ft (9 m) thick may have potential as a sand and gravel resource. Also nearby are thick sand and gravel deposits (greater than 148 ft [45 m]) under thick till or lake deposits (20 to 263 ft [6 to 80 m]). These would require significant exploration expenditures to accurately define the economic potential, but because of expanding suburban populations, they may be economically feasible in the future.

A major portion of the largest kame complex in Ohio extends from southwestern to north-central Portage County and contains more than 70% of the estimated resources of sand and gravel in the county. The ice-contact deposits (eskers and kames) of Portage County are estimated to contain a minimum of 4.1 billion metric tons (bt) of sand and gravel (Hull 1980). Outwash valley trains, outwash plain, and associated alluvial deposits are also important, with an estimated 1.5 bt of sand and gravel. Northwestern Portage County and northeastern Summit County have experienced steady growth since 1990, adding thousands of new residents and generating increased demand for aggregates.

More than 15 Mt of sand and gravel was produced in the Mansfield Quadrangle from 1997 to 2010. Fifteen sand and gravel operations were active in 2010, including four new operations since 2002. Potentially thick sand and gravel accumulations are associated with glacial outwash along major drainages or in highly variable ice-contact deposits that generally trend northwest-southeast in the northern portions of the map area (Totten 1973). Preliminary results indicate that more than 3.5 bt of potential sand and gravel resources are located in the Mansfield Quadrangle (Wolfe et al. 2008). Organic deposits associated with sand and gravel were included in the resource estimate because of the possibility of recovering peat and aggregates in a single operation.

**Bedrock Resources**

Areas of thin drift [less than 40 ft (12.2 m)] of till or other glacial deposits in the Findlay and Marion 30 × 60-minute quadrangles have the greatest potential for the development of industrial minerals, primarily aggregates (Wolfe and Stith 2007; Venteris et al. 2008a, 2011). The northwest portion of the Findlay Quadrangle contains areas of thin drift overlying the Devonian-age Detroit River Group, Silica Formation, and Dundee Limestone. Dolomite units in the Detroit River Group can be up to 100 ft (30.5 m) thick and are used as aggregates. The Dundee Limestone is generally a high-calcium limestone and is used to produce cement in Paulding County. The Silica Formation shale layers are also used in the cement
Figure 3  Examples of portions of derivative 30 x 60-minute quadrangle surficial maps in Ohio that show areas with (A) sand-and-gravel resources and (B) potential mineable bedrock. Modified from Wolfe et al. (2008) and Wolfe and Stith (2007).
industry. The remainder of the Findlay Quadrangle and the entire Marion Quadrangle contain thin-drift areas underlain by Silurian and Devonian carbonates, Lockport Dolomite, Tymochtee Dolomite, Greenfield Dolomite, Salina Group, and the Columbus and Delaware Limestones. The Delaware is normally mined in conjunction with the Columbus, with a combined thickness of 120 ft (36.6 m), but thins northward. The underlying Salina Group can be up to 300 ft (91.4 m) thick but contains intervals of shale and evaporites. The Tymochtee, Greenfield, and Lockport Dolomites may have a combined thickness of more than 200 ft (61 m) and are generally very good aggregates.

The 2010 production of limestone and dolomite from quarries located in the Findlay and Marion Quadrangles exceeded 16 Mt, representing nearly 35% of the carbonates produced in the state. The majority of the limestone and dolomite produced was used as aggregate; minor amounts were used as fluxstone, extenders and fillers, and agricultural limestone. Shale units were not mined in the Findlay and Marion Quadrangles in 2010 but may have potential in the cement, ceramic, or sanitary landfill industries. Additional detailed mapping may determine detrimental conditions, such as karst development; shale, chert, or evaporite interbeds; reefal structures; faulting; or their combination, that would affect the economic viability of the bedrock resource.

DISCUSSION

The industrial mineral derivative maps created by the Ohio Geological Survey can be used as a quick-look reconnaissance tool to help evaluate the availability of potentially mineable industrial mineral resources. Aggregates represent 90% of the volume of asphalt, concrete, and road base needed for highway and building construction. Areas within the Marion, Findlay, Mansfield, and Canton 30 × 60-minute quadrangles were delineated to show potential future aggregate resources; in addition, areas with little to no potential for aggregate resources were delineated. Generalized cross sections can be constructed and rough estimates of original resources can be calculated. The derivative maps are digital GIS products that can easily be revised when additional information is added to the database. These maps are a general guide for exploration or zoning of potential crushed-stone and sand-and-gravel resources in the mapped quadrangles. A more detailed geologic and engineering investigation should be completed before decisions are made regarding the mining suitability of a specific site.

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