ABSTRACT

Illinois is experiencing an increase in demand for high-calcium limestone for flue-gas desulfurization in coal-fired power plants. High-calcium limestone is not widely present in Illinois and most limestone quarries we have examined consist of multiple layers or ledges whose quality with respect to CaCO₃ content varies significantly. In this study we compiled and updated geologic maps and conducted a layer-by-layer examination of a selected number of limestone quarries in order to identify and characterize the high-calcium limestone zones, especially those with CaCO₃ contents of 95 percent or more. These quarries were visited and limestone beds were described when possible. For safety reasons and because of inaccessibility to the desired zones in many quarries, we used rock cores donated by the quarry and private and commercial industries to delineate the information needed for this study. The results show that high-purity limestone (>95 percent CaCO₃) in Illinois is mostly confined to rocks older than Pennsylvanian System and are at or near the surface in the western and southern part of the state, especially near the Mississippi and Ohio Rivers. Very little high-purity limestone is found in the northern part of the state where the dolomite of the Ordovician and Silurian Systems predominates. In the Mississippian System, Ullin and Salem limestones are the primary source of high-calcium limestone. The Ste. Genevieve and Burlington limestones also contain high-purity beds in some locations. Other important sources of high purity limestone are the Ordovician Kimmswick Limestone, which occurs near the surface in several places in Illinois but currently only mined near the Illinois border in southeastern and northeastern Missouri. Examination of quarry exposures and more than 4000 feet of cores, and petrographic, chemical and mineralogical characterization of more than 600 samples have provided a valuable database on the location and characteristics of high-calcium limestone needed for flue-gas desulfurization. Layer-by-layer examination of the limestone quarries has provided important information regarding the thickness, depth, areal distribution and availability of the high-calcium limestone zones. The results will provide the utility and other industries that burn Illinois coal with a way to find the best quality limestone locally and at low cost.
Illinois is experiencing an increase in demand for high-calcium limestone. This is in response to environmental regulations set by state and federal governments which have made it necessary for coal-fired power plants to be equipped with limestone-based scrubber systems to reduce emissions of sulfur oxide and other pollutants. Stringent SO$_2$ control requirements have accelerated plans for installation of limestone-based flue-gas desulfurization (FGD) systems. Earlier studies supported by the ICCI (Lasemi et al., 2004, 2005) showed that limestone in most quarries investigated consisted of multiple layers or ledges whose quality with respect to CaCO$_3$ content varied considerably.

The first objective of this study was to identify and map high-calcium limestone resources of the state. To accomplish this task we visited a number of quarries that had the highest potential for containing high-calcium limestone resources and compiled various maps to show the distribution of those resources. The second objective of this study was to characterize the high-purity limestone zones in active quarries that were identified in Task 1 as having potential for high-calcium limestone mining. For this task, we examined a number of key quarries and outcrop exposures and made detailed description of the potential high-purity limestone zones. In most cases, detailed descriptions were made from available cores drilled at or near the quarry properties. Quarry and core samples were characterized chemically (X-Ray Fluorescence), mineralogically (X-Ray Diffraction) and petrographically (polarized light microscopy) to better constrain the high-purity limestone zones within those quarries.

**Task 1 – Identify and map high-calcium limestone resources:** Detailed descriptions of limestone units were made from a selected number of quarries. In some cases the descriptions were made from the quarry ledges but for safety reasons and inaccessibility of many ledges, available cores from the same quarries were described and various limestone zones were identified. The results show that, except for a few cases, most high-calcium limestone zones are interlayered with low-purity intervals. Therefore, selective mining is necessary to be able to extract the high-calcium limestone zones. A few quarries already do selective mining; others will be amenable to such practice if demand arises. A number of maps compiled for this study show the distribution of the rock formations with the highest potential for high-calcium limestone mining.

**Task 2 – Characterize high-calcium limestone resources:** The quality of the limestone layers identified and mapped in Task 1 was characterized chemically, mineralogically, and petrographically. More than 240 samples were analyzed chemically using XRF (X-Ray Fluorescence Spectroscopy); the same samples plus an additional 400 samples were analyzed with XRD (X-Ray Diffraction). In addition, chemical data from several quarries were also provided by power plant and quarry industries for this project. The results show that the high-purity limestone zones within the quarries examined can be clearly identified using these data. This information will give the electric power and quarry industries a means by which they can selectively extract the best sorbent for FGD systems from the existing quarries.
The results from this and previous studies show that high-purity limestone (>95 percent \( \text{CaCO}_3 \)) in Illinois is mostly confined to rocks older than Pennsylvanian System and are at or near the surface in the western and southern part of the state, especially near the Mississippi and Ohio Rivers. Very little high-purity limestone is found in the northern part of the state where the dolomite of the Ordovician and Silurian Systems predominates.

Rock units from which high-calcium limestone is currently produced or have potential for future production include: 1) the Ordovician Kimmswick limestone; 2) Lower and Middle Devonian Backbone, Grand Tower and Wapsipinicon limestones; and 3) the middle Mississippian Burlington, Ullin, Salem, and Ste. Genevieve limestones, and the upper Mississippian Glen Dean and Haney limestones.

High-calcium limestone is being currently produced from Kimmswick in northeastern and southeastern Missouri. The potential for mining Kimmswick also exists in Illinois, especially in the western Illinois in Calhoun County and southernmost part of the state near Thebes. Chemical analysis indicates that the \( \text{CaCO}_3 \) content of the Kimmswick exceeds 95 percent, sometimes reaching as high as 98 percent.

In Jackson and Union Counties in extreme southern Illinois, the Lower Devonian Backbone is a pure limestone (95-98 percent \( \text{CaCO}_3 \)) up to 43 feet thick. The Backbone in these areas occur in the Shawnee National Forest and has little chance for mining at the present time because of thick overburden and environmental consideration involved with surface mining. The Middle Devonian Grand Tower Limestone crops out near Mountain Glen inside the Shawnee national Forest. It is a high purity limestone, up to 97.5 percent \( \text{CaCO}_3 \). Currently no quarry operation is extracting this limestone and because of its location within the Shawnee National Forest, it is not likely that this limestone be available in the near future. The Middle Devonian limestone is also mined in Rock Island County and a in a nearby underground mine across the Mississippi River near Buffalo, Scott County, Iowa. The high-calcium limestone is mined selectively from the Otis Member of the Wapsipinicon Limestone. Available data indicates that the calcium carbonate content of the Otis ranges between 94.5 and 97.0 percent.

Currently, the middle Mississippian Burlington, Ullin, Salem and Ste. Genevieve formations are the primary source of high-calcium limestone in Illinois. The Dolbee Creek Member at the base of the Burlington is a very high purity limestone (96-97 percent \( \text{CaCO}_3 \) content) in places in Adams County, Illinois. The limestone informally named “Quincy Lime” is currently being extracted from an underground mine in the Mississippi River Bluff in Quincy. The quality of Dolbee Creek is, however, variable and in some areas it becomes dolomitic and cherty. Dolbee Creek was also observed in several quarries in Adams, Hancock, Henderson, McDonough, Pike, and Warren counties. The rest of the Burlington is too cherty to be suitable for use in FGD scrubbers. The upper Ullin or Harrodsburg Member is a high-purity limestone with \( \text{CaCO}_3 \) content exceeding 95 percent. It is currently mined in Union County, few miles south of Jonesboro, Illinois. The Harrodsburg member of the Ullin has a unique property that makes it very desirable for desulfurization in FGD systems. It is soft and has high
absorption and low specific gravity. The porosity has been estimated at about 11 percent for the upper Ullin. The interparticle and intraparticle porosity in the Ullin contribute to increased surface area and thus higher reactivity with respect to sulfur capture from flue gas. Intraparticle porosity commonly occurs within the fossil remains of bryozoans, small colonial organisms that abundantly occur in the Ullin. The Harrodsburg Member or its equivalent (upper Warsaw) is also found in southwestern Illinois in the Prairie du Rocher area and as far north as the Dupo area in St. Clair County.

The Salem is a major source of high-calcium limestone in Randolph County, Illinois, and Ste. Genevieve County Missouri. The high-calcium limestone beds occur in multiple zones and the CaCO$_3$ content exceed 95 percent but can be as high as 98 percent in some zones. Similar cyclic, but thinner, high-purity intervals are also present in quarries in the St. Louis Metro East area in Monroe, St. Clair and Madison counties, Illinois.

Ste. Genevieve Limestone contains oolitic beds that are high-purity with CaCO$_3$ often exceeding 95 percent. Ste. Genevieve is not widely present in the St. Louis Metro East area. The high purity interval of the Ste. Genevieve is present around Alton, Illinois. Limited potential also exists in St. Clair County, Illinois. The best locations for high purity Ste. Genevieve limestone are in Union, Johnson and Hardin counties where this limestone is currently being mined in a number of quarries.

Results from this project will complement those from earlier ICCI-funded studies and provide detailed information needed to expand the database on scrubber stone resources developed for the state. Expanding the database to include the results of this focused study delineating high-calcium limestone resources will provide useful guidance for the electric power industry and others in selecting the best sulfur sorbent at an affordable cost.
OBJECTIVES

The overall objective of this project was to prepare maps that identifies and characterizes limestone resources with greater than 95 percent CaCO₃ within a 50-mile radius from existing or planned coal-fired power plants in Illinois. To accomplish these objectives we undertook a detailed study to delineate and characterize high-calcium limestone zones from a representative selection of quarries in the state, focusing on those within 50-miles of existing and potential coal-fired power plants. The project had two main tasks: 1) identify and map high-calcium limestone resources; and 2) characterize representative samples of the resources for their chemical, mineralogical, and physical properties. Results from this project complement those from earlier ICC-funded studies (Lasemi et al., 2004, 2005, 2008) and provides additional information for the comprehensive database identifying and characterizing high-calcium limestone in Illinois quarries within economic transportation distances from existing and planned coal-fired power plants.

INTRODUCTION AND BACKGROUND

U.S. environmental regulations make it imperative that any new coal-fired power plant be equipped with scrubber systems to reduce sulfur oxide emissions. This is because the Clean Air Act not only limits emissions at the plant level but also caps the total national sulfur emissions for the unlimited future. Limestone-based desulfurization technologies in coal-fired power plants are a proven means of meeting the clean air standards. Illinois has abundant limestone and dolomite resources (e.g., Krey and Lamar, 1925; Goodwin and Baxter, 1981; Goodwin, 1983; Mikulic, 1990; Lasemi et al., 1999; Lasemi and Norby, 2001; Lasemi et al., 2004). However, high-calcium limestones are not readily available throughout the state. The suitability of limestones for either flue-gas desulfurization (FGD) or fluidized bed combustion (FBC) applications also differ, and the high-purity limestone resources (> 95% CaCO₃) now considered most suitable for FGD applications are not widely available (Lasemi and Norby, 2001; Lasemi et al., 2004, 2005).

The US Clean Air Interstate Rule (CAIR) requires significant SO₂ emission caps for all coal-fired power plants (USEPA 2005a). This will impact both large coal-fired power plants burning high-sulfur coal as well as smaller plants that burn low- to medium-sulfur coal, and most of these are in the states east of the Mississippi River. Stringent SO₂ control requirements have accelerated plans for installation of limestone-based FGD systems in such plants. It is, therefore, imperative that the issues associated with the availability and suitability of high-calcium limestone resources near Illinois power plants be addressed. Identification and characterization of in-state high-calcium limestone resources near coal-fired plants is an essential part of any strategies to promote increased utilization of Illinois coal.

The cost of transporting limestone by truck is so great that at 30 to 50 miles from the mine the delivered price of the FGD-suitable limestone nearly doubles (Bhagwat, 2000). For Illinois coal to sustain its current market position, it is necessary to ensure that the delivered cost of limestone is minimized. Geologic studies to find, analyze, and calculate...
the quantity of FGD- and FBC-suitable sorbents available near current and likely future utility sites are, therefore, integral to this strategy.

About one third of the nation’s coal-burning power plants that use desulfurization units to remove \( \text{SO}_2 \) emissions are located in the six-state region of Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia (Foose and Barsotti, 1999). In 1989, only 29 of the more than 160 coal-fired electric power plants within this region used FGD units. By 1994, the number of FGD units had increased to 40. This trend toward increasing numbers of FGD units is expected to continue far into the future, especially with the implementation of the US Clean Air Interstate Rule (CAIR). The result has been an increased demand for high-purity limestone for removing gaseous sulfur oxides.

Through grants from the Illinois Clean Coal Institute (ICCI), the Illinois State Geological Survey (ISGS) conducted statewide studies in 2004, 2005, and 2008 (Lasemi et al., 2004, 2005, 2008), mapping the location of existing quarries and characterizing limestone and dolomite resources mined from those quarries. The samples for these studies were primarily collected from the quarry stockpiles. Because of the large scope of those projects, bed-by-bed examination and delineation of zones containing the highest quality limestone (95% or better \( \text{CaCO}_3 \)) were not within the project timeframes or budgets. Nevertheless, the results of those studies were well received by the utilities and other industries using limestone. To date, the ISGS continues to receive many inquiries for acquisition of the databases and maps generated under those projects.

These studies showed that limestone in most quarries investigated consisted of multiple layers or ledges whose quality with respect to \( \text{CaCO}_3 \) content varied considerably. These results and inquiries from utilities and related industries have identified a need for additional studies to delineate high-calcium limestone zones within Illinois quarries near existing and potential coal-fired power plants. Those layers that have the highest quality limestone need to be identified and their thickness and depths determined to provide guidance to the quarry for selective mining when high-calcium limestone is needed for desulfurization purposes. Additionally, the mineralogical, chemical and physical properties of the high-calcium limestone zones need to be characterized and their reactivities with respect to sulfur capture need to be evaluated.
EXPERIMENTAL PROCEDURES

One of the objectives of this study was to identify and map high-calcium limestone resources of the state. To accomplish this task we compiled various maps showing the distribution of units having the most potential for high-calcium limestone mining. The maps, primarily from previous studies, were digitized and updated when possible. A number of 7.5-minutes bedrock geologic maps are also available from the ISGS that show the surficial distribution of bedrock. These maps are a valuable source of information for delineating the distribution of bedrock units containing high-purity limestone resources. These maps are available from the ISGS upon request.

For this study, a number of key quarries with potential for high-calcium limestone mining were measured and described in detail. Detailed descriptions were also made of available cores from selected quarries in the state. For safety reasons and because of inaccessibility to the desired zones in some quarries, the rock cores donated by the quarry companies or drilled by private and commercial industries provided the best resource to delineate the information needed for this study. Figure 1 and Table 1 show the location of the quarries examined or for which core and other data were available for this study. For all the cores and, when possible, quarry ledges, detailed descriptions were made and geologic column were prepared. Because of the large volume of the material produced most of these descriptions and columns are not included in this report but are available upon request.

Mineralogical analyses of the project samples were performed at the Illinois State Geological Survey (ISGS) by x-ray diffraction (XRD) methods within the Industrial Minerals Section. For the XRD procedure, the samples were micronized in a McCrone® micronizing mill with deionized water for 10 minutes. Then they were transferred to a 50-mL centrifuge tube. The tubes were placed in a centrifuge for 20 minutes at 2000 rpm. The clear supernatant was poured off and the remaining material dried overnight in a low temperature oven. This remaining sample was mixed lightly with a mortar and pestle and then packed into an end-loading sample holder as a random powder bulk-pack. The random bulk-pack was analyzed with a Scintag® XDS2000 machine. Step-scanned data was collected from 2° to 34° 2θ with a fixed time of 5 seconds per 0.05°2θ for each sample. All resulting traces were analyzed using the semi-quantitative data reduction software from Materials Data Inc. (MDI) known as Jade+®. Figures 2-4 show example traces for several limestone samples of variable purity.

Chemical analysis for trace and major elements were determined by Activation Laboratories Ltd, Ontario, Canada (Actlab). X-ray Fluorescence spectroscopy (XRF), Actlab’s WRA-XRF Code 4c option, was used to determine the concentrations of elements in the samples. Elements determined (reported as oxides) include silicon (Si), aluminum (Al), iron (Fe), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), titanium (Ti), phosphorus (P), manganese (Mn), vanadium(V) and chromium (Cr). For more detailed information on methods used for these analyses refer to Activation Laboratory web site at www.actlabs.com. In addition, a significant amount of chemical data was also acquired from the quarry and electric power industries, which are not included in this report for proprietary reasons.
More than 4000 feet of cores were examined and sampled for this study. The total number of samples collected from these cores and quarries for analysis include 650 samples for mineralogical analysis (XRD) and 240 for chemical analysis (XRF). Thin sections were also prepared from representative outcrop and core samples for petrographic analyses under polarizing microscope. Thin section petrography provided valuable information for characterizing limestone quality and physical properties.

RESULTS AND DISCUSSION

Task 1. High-calcium limestone resources of Illinois: High-purity limestone resources (>95 percent CaCO\textsubscript{3}) in Illinois are mostly confined to rocks older than Pennsylvanian System (Fig. 5) and are at or near the surface in the western and southern part of the state, especially near the Mississippi and Ohio Rivers. Very little high-purity limestone is found in the northern part of the state where the dolomite of the Ordovician and Silurian Systems predominates.

The Ordovician Kimmswick is at or near the surface at Thebes, Illinois (Fig. 6); extensive study has been done by various companies prospecting for high-calcium limestone in the area, which is in close proximity to the Mississippi River. In Calhoun County, the Kimmswick Limestone is exposed along the Mississippi River bluffs in Sections 32 and 31, T. 11 S., R. 2 W. (Rubey, 1952). Proximity to the Mississippi River provides a relatively cheap mode of transportation. About 75 feet of Kimmswick is exposed here with the upper 55 feet being of the highest purity (Fig. 7). The Kimmswick was also mined underground near Valmeyer, Illinois before the mine closed in the early 1990s. The Kimmswick Limestone consists primarily of light gray, relatively coarse-grained, fossiliferous (crinoidal-bryozoan), high-calcium limestone. The upper part of the Kimmswick (Moredock Member) is exceptionally pure in western Illinois, northeastern Missouri, and southern Illinois near Thebes. Calcium carbonate content of the upper Kimmswick ranges between 94-98% (Baxter 1970; this study), making this formation an excellent source of high-calcium limestone for various applications. Because of its high-purity, the Kimmswick is an excellent source of limestone for flue-gas desulfurization in coal-burning power plants. The Kimmswick is currently being mined near Cape Girardeau and Clarksville, Missouri. The kimmswick at Huntington Quarry, northeastern Missouri, contains a 55-foot high-purity limestone interval in the upper part underlain by a 65-foot interval that is less pure with a high MgCO\textsubscript{3} content. The upper, high-purity interval currently supplies the scrubber stone for wet FGD system of a major coal-fired power plant in west central Illinois.

In Jackson and Union Counties in extreme southern Illinois (Fig. 8), the Lower Devonian Backbone is a pure limestone (95-98 wt% CaCO\textsubscript{3}) up to 43 feet thick (Lamar, 1959). The Backbone in these areas occur in the Shawnee National Forest and has little chance for mining at the present time because of thick overburden and environmental consideration involved with surface mining. The Middle Devonian Grand Tower Limestone crops out near Mountain Glen inside the Shawnee national Forest (Lamar, 1959). It is a high purity limestone, up to 97.5 wt% CaCO\textsubscript{3}. Currently no quarry operation is extracting this
limestone and because of its location within the Shawnee it is not likely that this limestone be available in the near future. The Middle Devonian limestone are mined in Rock Island County and in a nearby underground mine (Linwood Mine) across the Mississippi River east of Buffalo, Scott County, Iowa (Figs. 1, 7). The high-calcium limestone is mined selectively from the Otis Member of the Wapsipinicon Limestone (Grand Tower Equivalent). Available data indicates that the calcium carbonate content of the Otis generally exceeds 94.5 percent. The Middle Devonian Lingle Limestone is also mined in central Illinois near Tuscola in Douglas County, but its CaCO₃ content rarely exceed 95 percent.

An area rich in high-calcium limestone resources includes the St. Louis Metro East region in southwestern Illinois. The St. Louis Metro East region as defined in this study extends from Alton in Madison County, Illinois, to Prairie du Rocher (Randolph County, Illinois) and Ste. Genevieve, in Ste. Genevieve County, Missouri (Fig. 9). A regional cross section of the Mississippian units, containing high-calcium limestone intervals in the St. Louis Metro East region is shown in Figure 10. The cross section prepared from detailed description of quarry exposures, cores, and well cuttings in the area serves as a useful guide for identifying potential sources of high-calcium limestone resources in the area and helps delineate lateral and vertical variations in the thickness and quality of those resources.

Mississippian limestones are the most widely exposed bedrock formations in the St. Louis Metro East region (Fig. 9), and the high-calcium Kimmswick Limestone described earlier occurs near the surface to the north of the area in Calhoun County. In general, bedrock in the region dips toward the Illinois Basin to the east-southeast from the north (i.e., Alton area) and to the east-northeast from the south (i.e., Prairie du Rocher area). As a result, thick Mississippian limestone units (Valmeyeran and lower Chesterian strata) are progressively more deeply buried beneath the dominantly siliciclastic rocks of the upper Mississippian and Pennsylvanian System. Substantial erosion during the Pennsylvanian Period resulted in thinning or complete removal of Chesterian strata (Weller and Weller, 1939), exposing the thick Mississippian limestone intervals in many areas, especially in the bluffs of the Mississippi River. Overburden, which includes the Quaternary deposits and upper Mississippian (Chesterian) and Pennsylvanian siliciclastics thickens to the east away from the bluffs to more than 200 feet within 3-10 miles. In areas of thick overburden, underground mining is economically more feasible than an open pit quarry operation, which would require the removal of a substantial amount of overburden material.

Several major and a few small geologic structures have been identified in the St. Louis Metro East area (Weller and Weller, 1939; Baxter, 1960; Nelson, 1995). The major structures include the Lincoln Fold situated northwest of the Metro East area and the Waterloo-Dupo and Valmeyer Anticlines in the southern part of the study area (Fig. 9). Erosion on these structures has modified the thickness and distribution of the Mississippian rocks. The overlying Pennsylvanian and younger Mississippian strata have been eroded in many places along these structures, bringing the thick Mississippian limestone intervals close to the surface. On parts of the Valmeyer Anticline, erosion has
resulted in the total removal of Devonian, Mississippian, and Pennsylvanian rocks, exposing the Middle and Upper Ordovician limestones and shale. The Ordovician Dunleith Limestone (Kimmswick Limestone of Missouri), a high-calcium limestone, was mined underground from near the crest of the Valmeyer Anticline in Monroe County (Fig. 9) for chemical and refractory purposes and other applications (Baxter, 1960). Several other smaller upfolds are also present locally within the study area (Baxter, 1960) on which erosion has removed parts of the lower Chesterian and upper Valmeyeran limestone units.

The Mississippian formations with high-calcium limestone potential in the area include, in ascending stratigraphic order, the Valmeyeran (Osagean-Meramecian) Burlington-Keokuk, Warsaw, Salem and St. Louis Formations, and the lower Chesterian Ste. Genevieve Limestone (Figs. 5, 9).

**Burlington Limestone**

The Burlington Limestone consists of light gray to brown, coarse-grained, crinoidal limestone, commonly containing considerable amounts of nodular and bedded chert (Goodwin and Harvey, 1980). The Keokuk Limestone (up to 80 feet thick), which overlies the Burlington, is also a cherty, gray, crinoidal limestone that is so similar to the Burlington that it is difficult to differentiate the two formations in this area and they are commonly mapped as one unit. The Keokuk is generally more cherty than the Burlington, especially in its lower part. The combined thickness of the Burlington and Keokuk varies from 100-225 feet in the area. Although they are extensively quarried in western Illinois, the abundance of deleterious cherts in the Burlington-Keokuk Limestones makes it difficult to produce high-calcium limestone suited for use in FGD systems.

The Burlington has been divided into three members in Iowa (Harris and Parker, 1964). These members are also recognizable in the northern part of the study area (Baxter, 1970). The upper part (Cedar Fork Member) is a glauconitic, slightly cherty limestone about 5 to 25 feet thick. The middle part (Haight Creek Member) is a cherty, partly dolomitic limestone about 50 to 80 feet thick. Chert content ranges from 5-25 percent. The basal Dolbee Creek Member (Quincy Bed) is generally a pure limestone that ranges from 0 to 20 feet in thickness and, in most places, contains less than 1 percent chert. Chemical analysis of the Dolbee Creek shows a calcium carbonate content of 94 to 98 percent, magnesium carbonate, 3 to 4.5 percent, and silica, 1.5 to 2 percent (Baxter, 1970; Goodwin and Harvey 1980, Cloos and Baxter 1981). Underground mines in the Quincy area (Adams County) produce high-calcium limestone from the Dolbee Creek Member for various chemical and industrial applications. The Dolbee Creek was observed in this study to be present in some of the quarries in Adams, Hancock, Henderson, McDonough, Pike and Warren counties (Fig. 11). Figure 12 from Cloos and Baxter (1981) shows the thickness and depth to top of the Dolbee Creek in western Illinois away from the bluffs of the Mississippi River. The characteristic Dolbee Creek lithology appears to be absent in the St. Louis Metro East region.
Warsaw Formation
The Warsaw Formation occurs widely in western and southwestern Illinois (Figs. 7-10) and adjacent parts of southeastern Iowa and eastern Missouri. The Warsaw is generally divided into an upper and a lower interval (Lasemi et al., 1999). The lower part of the Warsaw (up to 100 feet thick) is primarily a shale, whereas the upper part consists mostly of limestone and, in some areas, dolomite. The Warsaw as previously mapped in the study area primarily included the shale with some interlayered limestone and dolomite that belong to the lower Warsaw Formation (Lasemi et al., 1999). The upper carbonate-dominated interval of the Warsaw previously was assigned to or mapped with the Salem. Petrographically, the upper Warsaw carbonates consist largely of poorly sorted, crinoidal- and bryozoan-rich limestone beds that are locally dolomitized in western Illinois and adjacent parts of Iowa and Missouri. The upper Warsaw is lithologically similar and, at least in part, equivalent to the upper Ullin Limestone (the Harrodsburg Member) in southern Illinois (see Ullin below). The limestone of the upper Warsaw (up to 100 feet thick) is relatively soft in many places. In southwestern Illinois, the upper Warsaw includes high-purity intervals that could be potential sources of high-calcium limestone.

Ullin Limestone
Ullin is divided into an upper interval of light gray, coarse-grained, high-purity limestone (Harrodsburg Member) and a lower, cherty and partly argillaceous lower purity interval (Ramp Creek Member). Shakespeare Aggregates produces high-purity limestone from their Jonesboro plant, few miles south of Jonesboro, Union County, Illinois (Fig. 8). About 200 feet of coarse-grained, crinoidal-bryozoan limestone characterizes the Harrodsburg Member in this quarry. Additional reserves are present in the area. Another quarry north of Ullin (Ullin Quarry operated by Shakespeare Aggregates) (Fig. 14) contains some high-purity beds in the upper part but the CaCO$_3$ content for the upper 80 feet or so averages only about 89 percent, in contrast to the Harrodsburg Member in Jonesboro, which has CaCO$_3$ exceeding 96 percent. In southwestern Illinois and in Ste. Genevieve, Missouri, the upper Warsaw is a high-purity limestone equivalent and comparable in CaCO$_3$ to the Harrodsburg Member of the Ullin Limestone. From Prairie du Rocher northward, the upper Warsaw becomes thinner but still maintains its high-purity character for the most part. From Alton area northward, the upper Warsaw is often more dolomitic and of lesser purity to be a source of high-calcium limestone.

The Harrodsburg Member has distinctive qualities that make it valuable for the two main uses of scrubber stone and agricultural limestone (to neutralize the acidity and improve the texture of soils). At the Jonesboro quarry (operated by the Shakespeare Aggregates), the limestone generally tests greater than 96% CaCO$_3$, approximately 3% to 4.5% water absorption, and almost 2.4 g/cc bulk density (Harvey, 1994). These data indicate an average porosity of about 11%. Such qualities of purity and implied softness make this stone exceptionally valuable as an agricultural limestone and an excellent sorbent for desulfurization in wet FGD systems. Currently Jonesboro quarry provides limestone for desulfurization purposes in scrubbers at two major power plants in Illinois. In one case, the stone is trucked about 150 miles to a power plant located in west-central Illinois.
Salem Limestone
The Salem is about 60 to 70 feet thick in the Alton area, but thickens to more than 200 feet in the Prairie du Rocher-St. Genevieve area (Figs. 9, 10). It consists of thick-beded, fine- to coarse-grained, bioclastic limestone. It is in part oolitic to pseudo-oolitic, especially in the southern part of the study area in parts of Monroe and Randolph Counties in Illinois and Ste. Genevieve County in Missouri. Our examination of quarry exposures and cores in the southwestern Illinois outcrop belt indicates that the Salem in this area contains four major cyclically deposited limestone beds. Each cycle consists of a high-calcium, bioclastic and/or oolitic to pseudo-oolitic limestone capped by a poor-quality, argillaceous, cherty microcrystalline limestone and dolomite. The high-purity cycles of the Salem are excellent sources of both high-calcium limestone and construction aggregate. All grainstone cycle of the Salem have significant thickness of high-calcium limestone with carbonate content of at least 96 percent. The uppermost cycle of the Salem, the Rocher Member (Baxter, 1960) contains more than 75 feet of high-calcium limestone in Monroe and Randolph Counties in Illinois and near Ste. Genevieve (Ste. Genevieve County), Missouri. As shown in Figure 13, the thickness of the high-calcium Rocher Member decreases northward, but in extreme southern Monroe County and northernmost Randolph County, near Prairie du Rocher, these thick high-calcium limestones are within reach of shallow shaft mines. Two underground mines operated by Martin Marietta Aggregates near Prairie du Rocher currently extract high-calcium limestone from the Rocher Member of the Salem. These operations and the Mississippi Lime Company’s underground mine and the Lhoist Lime Company/Tower Rock Quarry near Ste. Genevieve, which also mine the same member in addition to other high-calcium limestone zones, are conveniently located near the Mississippi River for barge transport. Elsewhere in Monroe, St. Clair, and Madison Counties, the Salem is primarily mined for construction aggregate, but the high-purity cycles could be selectively extracted for desulfurization and other purposes. The chemical and mineralogical data from this study (Appendices A, B and C) can be used as a guide for selective mining of the high-calcium limestone zones.

St. Louis Limestone
The St. Louis is variable in lithology; it is not a microcrystalline (micritic) limestone throughout the formation as generally perceived. Upper 30-35 feet of the St. Louis consists of light gray, very fine-grained limestone with thin bands of bryozoan fossil remains. The unit contains some chert that is reddish and fossiliferous. Most of this unit is pure and composed mainly of very fine-grained high-calcium limestone exceeding 95 percent CaCO₃. Chemical and mineralogical data show that the St. Louis may have additional zones of high-purity limestone in the area. In Madison County near Alton (Fig. 9), Illinois, Fred Weber Inc. operates an underground mine in the St. Louis Limestone. Kimaterials, Inc. operates a small quarry near Godfrey, north of Alton in the St. Louis along with the Salem and upper Warsaw. Other companies have surface-mining operations in the St. Louis Limestone in St. Clair County near Dupo and in Monroe County near Waterloo (Fig. 9). The St. Louis is also mined in Union County at Anna, Illinois (Fig. 8). The St. Louis has generally not been considered a major source of high-calcium limestone, although data from this study suggest that the St. Louis do contain some high-purity limestone intervals. However, the very dense nature of this rock makes
the rock less reactive with respect to sulfur capture. The CaCO$_3$ content of the St. Louis also decreases in the southern part of the state where the limestone is more cherty and siliceous.

**Ste. Genevieve Limestone**
The Ste. Genevieve Limestone (Figs. 9, 10) is only present sporadically in southwestern Illinois due to truncation prior to deposition of the Pennsylvanian sediments. It is 20–45 feet thick in the Alton area and up to 55 feet thick in the Cahokia area. Some oolitic beds of the Ste. Genevieve are high-purity intervals that are potential sources of high-calcium limestone. Our data indicates that the CaCO$_3$ content of the Ste. Genevieve oolitic limestone in the Alton area ranges between 94 and 96.5 percent. The Alby Quarry in Alton, Illinois, still has some reserve of high-purity limestone in the Ste. Genevieve. In southern Illinois, the Ste. Genevieve oolitic limestone is much better developed (Figs. 8, 15, 16). It is currently being extracted in several quarries in Union County (e.g., Anna Illinois), Johnson County (3 miles south of Cypress) and Cave-in-Rock area (operated by Hastie Mining and trucking Company, Lafarge, and Martin Marietta Aggregates)(Figs. 6, 8, 15). Hastie also includes a fine limestone grind operation which uses the Ste. Genevieve oolitic limestone as a source.

**Upper Mississippian limestone Resources**: In Randolph County near Menard, 60 feet of Glen Dean contains more than 95 percent CaCO$_3$. Glen Dean was mined underground near Chester Illinois (Fig. 9). At Roots, in the Mississippi River bluff and at Marigold, a few miles to the east, a pure oolitic facies of the Haney Limestone, known informally as “Marigold Oolite” was quarried in the past (Bradbury, 1963). Currently, there is no high-calcium limestone production from the upper Mississippian carbonates (Chesterian) the southwestern or southern Illinois.

**Pennsylvanian limestone resources**: A number of quarries extract limestone from the Pennsylvanian System in central Illinois (Fig. 1). The Pennsylvanian rock formations that are mined in central Illinois are Millersville, Lonsdale, and Omega limestones with the Millersville being of the highest purity and the Omega of lowest purity with respect to calcium carbonate content. These limestones are generally thin (15-25 feet thick). Although the CaCO$_3$ content is generally less than 95 percent (mostly 90-93.5 percent), their efficiency with respect to sulfur capture could be still high. The test of one of these limestones (Millersville) at a FGD scrubber at a power plant in central Illinois showed that these limestones were comparable in their efficiency in sulfur capture to some of the very high-purity limestones tested. Because of the lack of nearby source of high-purity limestone resources in central Illinois, these limestones provide a comparable sorbent for desulfurization in these areas.

**Task 2. Chemical, mineralogical and petrographic characterization of limestones**
The second objective of this project was to characterize limestone units from selected quarries chemically, mineralogically and petrographically in order to identify potential high-calcium limestone zones for future extraction. The results of the chemical and mineralogical analysis are provided in Appendices A, B and C. All data and charts in the Appendices are proprietary data and can not be released without permission from the ISGS and/or the company. The results clearly show that limestones in quarries examined are not uniform and that high-purity intervals are interlayered with low-purity interval.
These data can be used as a guide for selecting the most suitable limestone for scrubber systems. It also provides the quarry operators a means for selectively extracting the high-purity limestone when needed. Two charts showing the distribution of XRD (mineralogy) and XRF (chemistry) data are shown in Figures 17 and 18 as examples. The data clearly allows for identification of zones that have the highest potential as a source of high-calcium limestone.

Mineralogical data such as percent calcite (CaCO$_3$) obtained by XRD is a few percent less than that calculated from XRF data. This needs to be taken into consideration when XRD data is used. The zones that show high XRD calcite values then should be verified by chemical analysis such as x-ray fluorescence spectroscopy or other methods to obtain a more accurate picture of the limestone purity.

Because of the propriety of the data more details about these results are avoided in this section. The tables and charts included in the Appendices are self-explanatory, and those interested in the results should contact the PI to determine if the data could be released.

**Petrographic analysis**

Petrography refers to the describing of a limestone’s constituents and texture by viewing a translucent thin section of the rock through a petrographic microscope. High-calcium limestones are quite variable with regard to grain composition and texture. While some limestones are composed of a mixture of fossil fragments of various size and shapes, others may consist of microcrystalline calcite with few or no visible fossil remains. Some limestones are made up of rounded grains called ooids that may show radial or tangential microstructure. Yet, others may contain grains of variable roundness and shape that consist of very finely crystalline calcite. Some high-calcium limestones are soft, absorbent and porous, while others are dense with very little porosity. The wide variability in composition and physical properties can also influence their reactivity with respect to sulfur capture regardless of their purity.

Thin section petrography is an important tool for characterizing limestone quality. This method provides valuable information regarding the suitability of various limestones for desulfurization and other industrial applications. In selecting limestone for these uses, the major emphasis is often placed on the purity (95 percent CaCO$_3$ or better) of the rock, and petrographic characteristics are generally ignored. Detailed thin section petrography shows that high-calcium limestones can vary significantly in their petrographic characteristics and texture. These differences can affect calcination behavior during lime production and could influence the limestone’s effectiveness in capturing sulfur dioxide in flue gas scrubber systems in coal-burning power plants and its suitability for other industrial applications. Harvey et al. (1974) showed that the efficiency of high-calcium limestones as a control of SO$_2$ in flue gas depends not only on purity, but also on intercrystalline and intracrystalline porosity and permeability, which increase the effective surface area. High-calcium limestone was found to be quite variable in effective surface area. For example samples from Dolbee Creek were found to be about midway through the range, indicating an intermediate effectiveness for SO$_2$ removal. Petrographic data reactivity tests have shown that the Harrodsburg Member of the Ullin Limestone for
example is uniquely suited for certain desulfurization processes, mainly those classified as wet-limestone "scrubbing" (Harvey et al. 1974) and, to a lesser extent, fluidized-bed combustion (Rostam-Abadi et al. 1989). In the study by Rostam-Abadi et al. (1989), thermal gravimetric analyses of the 300 to 425 µm particles from this quarry absorbed more S0₂ than all other limestones tested. The Harrodsburg, as quarried at Jonesboro, provided the highest S0₂ reactivity of the 11 rather typical carbonate rocks that were laboratory tested. Microscopic analyses suggest that the high reactivity of this stone is due to the high porosity that exists between the 5 to 20 µm calcite crystallites that constitute the abundant bryozoan fragments. Another contributing factor may be traces of highly reactive soluble salts (mainly NaCl) that occur as fluid inclusions within the large crystals that constitute the crinoid fragments.

CONCLUSIONS AND RECOMMENDATIONS

The Kimmswick Limestone, the lower member of the Burlington, the Harrodsburg Member of the Ullin, upper Warsaw, Salem, and Ste. Genevieve are for the most part medium- to coarse-grained bioclastic or oolitic limestone. In some cases these coarser limestones are somewhat porous and soft. These factors make these limestones less suitable for some construction purposes. However, these coarser-grained limestones are generally pure with more than 95 percent or more CaCO₃ content, making them an excellent raw material for the manufacture of lime, the capturing of SO₂ in coal-burning power plants, and the production of chemical grade calcium carbonates.

The results of this project provide a database consisting of mineralogical and chemical properties pertinent to the high-calcium limestone layers that have the best quality for desulfurization. Such a more focused study will enable the utility industry and quarry operators to select the high-purity limestone sorbent quickly and at relatively low cost when needed. The coal-fired electric power industry installing new FGD systems is required by manufacturers to use a high-purity limestone (at least 95 percent CaCO₃). High-calcium limestone is also the preferred sorbent to ensure that a high-purity gypsum byproduct comes from the FGD scrubber. The strict limitation on limestone quality prohibits utilization of limestone from most quarries. However, many of these quarries contain high-calcium limestone layers and identification and mapping of those layers will help direct the industry to the right source for their high purity sorbent needs.

It should be noted that high-purity alone is not a primary factor in determining which limestone is the most suitable sorbent for desulfurization purposes. Previous studies have shown that numerous factors other than purity affect the reactivity of limestone during desulfurization (e.g., Borgwardt and Harvey, 1972; Harvey et al., 1974). These studies, along with the results of recent ICCI-funded projects (Lasemi et al., 2004, 2005), demonstrated that limestones with certain physical properties, such as softness, low abrasion resistance, high water absorption capacity, and low specific gravity generally had relatively high reactivity toward sulfur oxides. The softest, finest-grained limestones had significantly higher reactivity indices for SO₂ than hard but relatively fine crystalline limestone, even though the latter had the highest purity. Also, fine-grained, dense limestones appeared to be generally more reactive than coarse-grained, highly crystalline
limestones. Differences in the type and size of grains in the rocks and the amount and size of intergranular calcite cement or microcrystalline calcite matrix may also cause significant variations in the ability of a limestone to capture sulfur oxides from coal-burning power plants, as demonstrated by experimental studies (Borgwardt and Harvey, 1972; Harvey et al., 1974; Lasemi et al., 2004).

Porosity and permeability are among other factors to consider when characterizing high-calcium limestones as these may significantly affect desulfurization process due to their influence on surface area and the ease of flue gas transport to the reaction site. Most ancient limestones generally have low porosity and permeability. However, some ancient limestones may still have substantial amounts of residual porosity and permeability due to incomplete cementation, selective dissolution of grains during later diagenesis, or differences in the precursor mineralogy of the limestone components (Lasemi and Sandberg, 1984, 1991). Some fossil remains, for example, contain substantial amounts of residual microporosity within their shells. A high-calcium limestone that contains a significant amount of such fossil remains will have increased reactivity with respect to sulfur dioxide. Microcrystalline limestone may appear very dense with no measurable porosity. However, when viewed under SEM, these limestones show significant variations in the amount of intercrystalline porosity, thus resulting in their variable reactivities.

The foregoing discussion highlights the fact that not all high-calcium limestones are the same, despite the fact that they may all be chemically pure (>95 percent CaCO₃). Variations in grain size, the amount of sparry calcite cement and cement crystal size, the relative proportion of microcrystalline matrix, the types of constituent grains, and the amounts of residual porosity all have significant influences on sulfur capture efficiency in FGD scrubbers. Fossil remains in limestones may also contain some residual organic matter. It is also known that both organic matter and microporosity are important for selectively adsorbing various forms of mercury. Microcrystalline limestone (also called micrite) also is known to contain some residual organic matter. These micrites may also contain some residual microporosity, which could make them very effective multipollutant sorbents.

Most common impurities in limestone generally include silicon dioxide (SiO₂), iron oxides, aluminum oxides, and magnesium carbonate (as dolomite). Some of these impurities come from clay minerals. Bench- and pilot scale-experiments, however, have shown that some impurities such as iron oxides/hydroxides and clay minerals may act as catalysts for the oxidation of elemental mercury and its subsequent removal in FGD scrubbers (Kim et al., 2004; Diaz-Somoano et al., 2005; Kairies et al., 2006). Laboratory tests also have shown that impurities such as iron oxides/hydroxides and certain clay minerals can chemically bind the mercury removed in FGD units and prevent re-emission once captured in the scrubber (Kairies et al., 2006).
REFERENCES


Table 1. Sample location and approximate geology of quarries containing limestone zones with 90 percent or higher CaCO₃.

<table>
<thead>
<tr>
<th>County</th>
<th>Project Code</th>
<th>Quarries with &gt;95% CaCO₃</th>
<th>Approximate location</th>
<th>1/4 Sec</th>
<th>Sect.</th>
<th>Twp.</th>
<th>Range</th>
<th>Quad</th>
<th>Approximate Geology &amp; Percent CaCO₃</th>
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<td>Adams</td>
<td>QNC-2</td>
<td>X</td>
<td>Quincy Mine; 1.5mi S of Quincy, IL; Huber Engineering Minerals</td>
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<td>13</td>
<td>2S</td>
<td>9W</td>
<td>Quincy West</td>
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<td>NW</td>
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<td>9E</td>
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<td>NW</td>
<td>8</td>
<td>12S</td>
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<td>CSQ-5</td>
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<td>Mississippian, Ste. Genevieve Ls., oolitic lens</td>
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<td>FRMTQ-</td>
<td>AgL</td>
<td>Fairmount Quarry; 2mi W of Fairmount on Catlin-Homer Rd.; Material Service Corp.</td>
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<td>Oakwood</td>
<td>Pennsylvanian Livingstone (Millersville) Ls.</td>
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</table>

**Indiana**

<p>| Owen | GSPTQ-1 | X | Gosport Quarry (Martin Marietta Aggregates) | 24 11N 3W | | Mississippian Harrodsburg Mbr. (Ullin Ls.). |
| Owen | GSPTQ-1 | X | Gosport Quarry (Martin Marietta Aggregates) | 24 11N 3W | | Mississippian Salem Ls. |</p>
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<th>Quarry Code</th>
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<td>Devonian Otis Mbr. Of Wapsipinicon Limestone</td>
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<td>Chemical Lime Company, Tower Rock Quarry</td>
<td>SW NW 7 38N 9E Prairie du Rocher</td>
<td>Mississippian Salem Ls.</td>
</tr>
<tr>
<td>BRKQ-1</td>
<td></td>
<td>Old Brickeys Quarry, Near Bloomdale, MO, APC Industries.</td>
<td>SW 13 39N 7E Ste. Genevieve</td>
<td>Upper Ordovician Kimmswick Ls.</td>
</tr>
<tr>
<td>GRP-1</td>
<td></td>
<td>Gray’s Point Plant; Tower Rock Stone Company</td>
<td>22/23 30N 4E Thebes</td>
<td>Ordovician Kimmswick Ls.</td>
</tr>
<tr>
<td>HTN-1&amp;2</td>
<td></td>
<td>Huntington Quarry near Huntington; Central Stone Co.</td>
<td>NE 17 56N 6W Rensselaer</td>
<td>Ordovician Kimmswick Ls., upper 55 feet</td>
</tr>
<tr>
<td>St. Louis</td>
<td></td>
<td>Bussen Quarries Inc., Jefferson Barracks Plant; 5000 Bussen Road, St. Louis, MO</td>
<td></td>
<td>Mississippian Warsaw Formation</td>
</tr>
</tbody>
</table>

*See Masters et al. (1999) for an explanation of Quarry Code and additional information on quarry locations in Illinois.*

*See Appendices A, B and C for XRD and XRF data tables and charts showing high-calcium limestone zones.*

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Figure 1. Statewide limestone and dolomite resource map showing active quarries and mines and location of quarries/underground mines studied.
Figure 2 & 3. Example XRD traces showing a high-purity limestone above (Figure 2) and a more impure dolomitic limestone below (Figure 3).
Figure 4. Example XRD trace showing an impure limestone with significant amounts of quartz and other impurities.
Figure 5. Stratigraphic column for the Illinois Basin. Intervals highlighted in blue indicate rock formations that contain high-calcium limestone.
Figure 6. Geologic map showing the distribution of various bedrock units in southern Illinois. Areas designated by A, M, and S generally contain significant amounts of high-calcium limestone. Modified from Lamar and Harvey, 1966.
Limestone, pure, more than 30 feet thick (Kimmawick); thick dolomitic limestone (Decorah, Rattin, Joachim) (Ordovician System)

Chiefly cherty limestone more than 30 feet thick (Kokuk-Burlington, Fern Glen and Sedalia Limestones, Mississippian System)

Limestone, pure, more than 30 feet thick (Wapsipinicon); impure limestone with interbedded shale (Cedar Valley) (Devonian System)

Chiefly limestone, in places more than 30 feet thick, in part cherty; shale or dolomite locally (Warsaw Formation, Salem, St. Louis and Ste. Genevieve Limestones, Mississippian System)

Shale and limestones, the latter generally less than 30 feet thick (Hannibal Shale and Chouteau Limestone, of Kinderhookian Series, Mississippian System)

Shale, dolomite, dolomitic limestone and limestone, the latter generally less than 30 feet thick (Maquoketa Shale, Ordovician System; Silurian and Devonian Systems undifferentiated in Calhoun and Jersey Counties)

Shale and sandstone; thin limestones locally (Carbondale Formation and Trivoli Sandstone Member, Pennsylvanian System)

Clay, shale and sandstone; thin limestones locally (Spoon Formation, Pennsylvanian System)

Silt, clay and gravel (Alluvium and till, Quaternary System)

Figure 7. Geologic map showing the distribution of various bedrock units in Western Illinois. Areas designated by O, G and D are potential sources of high-calcium limestone. O includes the high-purity Dolbee Creek, G, the Kimmswick, and D the Otis, all of which are high-purity limestones. Modified from Lamar and Harvey, 1966.
Figure 8. Geologic map showing the distribution of various bedrock units in Union County, southern Illinois. Areas designated by UL and SG have the highest potential for high-calcium limestone mining at the present time. Modified from Lamar, 1959.
Figure 9. Geologic map showing the distribution of various bedrock units in southwestern Illinois (modified from Willman and others, 1967). Areas designated by Mvm has the highest potential for high-calcium limestone mining. High-purity limestone also exists in the Kimmswick (Og) where it was previously mined. Some potential also exists in the areas covered by Mc.
Figure 10. Regional cross section showing lateral and vertical variations in high-calcium limestone zones (HC) in southwestern Illinois.
Figure 11. Geologic column from a quarry in Hancock County showing the high-purity Dolbee Creek Member of the Burlington Limestone. This same unit is currently produces high-purity limestone from an underground mine in Quincy, Adams County, Illinois.
Figure 12. Thickness of the Dolbee Creek member of the Burlington in western Illinois. Modified from Cloos and Baxter, 1981
Figure 13. Depth to the top and thickness of high-calcium limestone beds in the Rocher Member, Salem Limestone, Monroe County, Illinois (modified from Goodwin and Baxter, 1981).
Figure 14. Geologic map showing the distribution of various bedrock units in Pulaski County, southern Illinois. Areas designated by UL (Ullin) and SG (Ste. Genevieve) have the highest potential for high-calcium limestone mining. Modified from Lamar, 1959.
Figure 15. Geologic map showing the distribution of various bedrock units in Hardin County, southern Illinois. Areas designated by SG has the highest potential for high-calcium limestone mining. Several quarries currently operate in the County. Modified from Lamar, 1959.
Figure 16. Geologic Column from a quarry in Union County showing well-developed oolite beds in the Ste. Genevieve Limestone. These oolitic beds are often very high-purity and an excellent source of high-calcium limestone.
Figure 17. An example of mineralogical data (based on x-ray diffraction) obtained from a core from Monroe County. High-calcium limestone zones (indicated by high calcite content) are clearly identified based on mineralogy. Chemical analysis shows that the actual CaCO3 content may be a few percent higher than the amount measured by XRD.
Figure 18. An example of chemical data (based on XRF) obtained from a core. High-calcium limestone zones are clearly identified based on high CaO and CaCO$_3$ contents.
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