which has the lowest alumina content, has a maximum firing temperature below 1,670°C (Hosterman, 1972).

A comprehensive discussion of underclay origin(s) is beyond the scope of this paper. Several origin theories have been proposed since Logan presented his fossil soil theory in 1842. McMillian (1956), Huddle and Patterson (1961), Hosterman (1972), and Rimmer and Eberl (1982) gave excellent literature summaries of the various origin theories since Logan (1842). Bolger and Weitz (1952) and Burst (1952) proposed that some underclays are formed from colloidal material derived from subaerial erosion and deposition in swamps. Seiders (1965) and others proposed that some underclays form from the alteration of volcanic ash beds. Other authors propose that in situ leaching of fine-grained sediments in acid swamps is an important process. The origin of underclay has stimulated a number of studies by geologists and clay mineralogists for more than 150 years, and their work suggests a complex origin.

PREVIOUS INVESTIGATIONS

Significant clay/shale reserves occur throughout central and eastern Oklahoma. In 1997, Oklahoma produced 772,000 metric tons of clay/shale with a value of $3.55 million (Johnson, 1998). The clay was produced from 10–12 mines mostly in central and eastern Oklahoma. Oklahoma clay/shale is primarily used in the manufacture of cement and brick.

Snider (1911) did the first comprehensive study of clays/shales in Oklahoma. Ceramic firing tests were performed on more than 80 samples. Six samples, clay numbers 10, 45, 47, 172, 286, and 287, were collected beneath coal seams in eastern Oklahoma (Snider, 1911). Sheerar (1932) presented ceramic test fire data for more than 200 shale samples collected throughout the State of Oklahoma. Knox (1948) and Chase and Burwell (1952) conducted clay studies of kaolin and montmorillonite clays in the Wichita Mountains in southwestern Oklahoma. Several of the more comprehensive and/or detailed studies of clays and shales in Oklahoma include Bellis (1972), Bellis and Rowland (1976), Laguros (1972), Funnell (1949), and several student theses.

GEOLOGIC SETTING

Figure 1 (index map) shows the eastern Oklahoma coal belt, and delineates its two general regions: (1) the northeastern Oklahoma shelf area, and (2) the Arkoma basin. Figure 2 is a generalized geologic column showing Pennsylvanian coal-bearing strata in northeastern Oklahoma.

The Croweburg coal underclay is one of the principal underclays of eastern Oklahoma. These coals are of bituminous rank and are in beds of Middle and Late Pennsylvanian age. They occur in an area of about 8,000 mi^2, within the southern part of the Interior Coal Province (Fig. 1) (Averitt, 1967; Friedman, 1974, 1978; Wood and Bour, 1988). The rocks of the area consist of a thick series of sandstones, shales, underclays, coals, and limestones.

The Croweburg coal occurs only in the extreme northwestern part of the Arkoma basin (Hemish, 1994, 1998a). However, it is present, and has been mined extensively by both surface and underground methods throughout the northeastern Oklahoma shelf area (Hemish, 1986, 1989, 1990, 1994, 1998a,b). The Croweburg coal and its underclay have not been investigated south of the Okfuskee county line. The Croweburg coal splits into several beds just north of the Hughes-Okfuskee county line, and in that area has little commercial potential owing to interstratified shale layers (Hemish, 1988a, 1994). However, core-drilling by the OGS shows that the Croweburg coal underclay is 1.6–2.5 ft thick in this area (Hemish, 1988a).

In general, rocks of the shelf area dip to the west and northwest away from the axis of the Ozark uplift at about 25–50 ft/mi (Huffman, 1958). Strata in the Arkoma basin are much more faulted and folded, and, in many areas, the coal beds are not as amenable to surface mining as they are in the shelf area.

STRATIGRAPHY OF THE UNDERCLAYS

There are more than 40 beds of bituminous coal in the state (Friedman, 1974; Hemish, 1987), but only 12 of these have been mined over large areas. The 12 are, from oldest to youngest: the lower Hartshorne, upper Hartshorne, McAlester (Stigler), upper McAlester, Cavanal, Rowe, Secor, Weir-Pittsburg, Mineral, Croweburg, Iron Post, and Dawson coals (Fig. 2). None of the underclay associated with these coal beds is known to have been exploited commercially.

Nine samples of the underclay from beneath the Croweburg coal bed were collected over a wide area in the eastern Oklahoma coal field for purposes of this study (Fig. 3; Table 1). The Croweburg coal underclay occurs in the Senora Formation within the Cabaniss Group of the Desmoinesian Series (Fig. 2).

SAMPLE COLLECTION AND ANALYSES

Channel samples of underclay were collected at active-coal-mine locations, whenever possible, to minimize the effects of surface weathering. The sampling procedures as outlined by Friedman (1978) were followed.

The Chemistry Section of the OGS analyzed the Croweburg underclay samples. Values in percent of oxides of silica, alumina, iron, magnesium, calcium, sodium, potassium, and manganese are given in Table 2, along with the percent of water and loss on ignition (LOI).

The types and relative abundances of clay minerals were determined by X-ray diffraction methods. Oriented and unoriented slides were prepared and analyzed on a Norelco diffractometer using Cu-Kα radiation and scanned over the interval from 2 through 50 degrees 2 theta. All oriented slides were treated with ethylene glycol to test for the presence of expandable clay. No attempt was made to determine the amount of individual mineral constituents present in each sample.