The observance of the 26 forms (including the form *u*(031) noted by Flink without measurement) known for tephroite are given in the preceding tabulation.

The form (371) was given by Flink (1887) without letter. The letter *t* is here assigned to this form. These clear pink tephroite crystals represent very nearly the pure manganese silicate, as evidenced by the analysis given by Palache,[1] and the various properties determined on this material are the best available for tephroite.

[1] Palache, Charles, Mineralogical notes on Franklin and Sterling Hill, New Jersey: *Amer. Mineralogist*, vol. **13,** p. 325, 1928.

CHEMICAL COMPOSITION OF LEUCOXENE IN THE PERMIAN OF OKLAHOMA[1]

FAY COIL

The physical and optical properties of leucoxene, the most common alteration product of ilmenite, have been described but apparently no definite information regarding its chemical composition has been available. Most investigators agree that it is an alteration product of ilmenite, although its occurrence and character may vary somewhat in different formations.

Gümbel,[2] in 1874, was the first to describe the substance as he found it in diabase and named it leucoxene. However, he thought it was a primary constituent of the rock.

An analysis made by Cathrein,[3] in 1881, of aggregate material, apparently erroneously referred to as leucoxene, gave a composition of: SiO_2 33.26, TiO_2 41.12, and CaO 25.62. It seems that the material analyzed was essentially titanite. From this analysis, apparently, subsequent writers have thought that leucoxene is a variety of titanite.

Iddings[4] states that the substance has been considered by vari-

[1] Abstract of thesis presented for the M.S. degree in geology, University of Oklahoma, June, 1932.

[2] Die Paleolith Eruptivgesteine der Fichtelgebirges, 22, **1874.**

[3] *Zeit. Kryst.* **6,** 244, 1881. Quoted from Zirkel. F., Lehrbuch der Petrographie, vol. 1, p. 423.

[4] Iddings, J. P., Translation of Rosenbusch, Microscopic Physiography of the Rock Forming Minerals, pp., 167–168, **1893.**

ous observers as equivalent to titanite ($CaTiSiO_5$), anatase (TiO_2), and even siderite ($FeCO_3$). He believed that leucoxene forms at the expense of ilmenite and is often pseudomorphic after it.

Milner[5] probably gives the most complete description of the physical and optical properties of leucoxene, but he is doubtful about its chemical composition. He states that in sediments leucoxene occurs as an alteration of ilmenite, formed largely "in situ" and is at a maximum in coarse sediments. All grains of the substance are translucent to opaque in transmitted light, and white to yellowish white ("unglazed porcelain appearance") in reflected light. The surface of most grains appears rough by microscopic pits. He gives the specific gravity as varying from 3.5 to 4.5.

In a recent paper McCartney,[6] in describing the leucoxene in the Chester sandstone of Indiana, found the substance gave no *x*-ray pattern, but due to the small size of the sample, he did not consider the lack of a pattern as sufficient proof of its amorphous character. He found grains of ilmenite partly altered to leucoxene, with the leucoxene in turn altered to brookite and possibly to anatase.

The leucoxene in the red sandstones of the Permian of Oklahoma is apparently similar to that found elsewhere. Its common associates among the heavy minerals are: zircon, tourmaline, ilmenite, staurolite, garnet, hypersthene, chlorite, muscovite, hornblende, rutile, anatase and ferric oxide. The light minerals are mainly quartz and feldspar, the latter forming 10 to 30 per cent of the sand portion of the sediment. Barite, invariably authigenic, is abundant in some localities in the Permian. The substance, leucoxene, is by far the most common and abundant "heavy mineral" in the Permian sandstones as shown by studies carried on by graduate students in the department of geology at the University of Oklahoma.

Of the heavy minerals of the Stillwater formation Brown[7] finds about 51 per cent to be leucoxene, in the Wellington formation

[5] Milner, H. B., Sedimentary Petrography, 2d. ed., p. 205, **1929**.

[6] McCartney, G. C., A Petrographic Study of the Chester Sandstone of Indiana, *Jour. Sed. Petrology*, vol. **1**, no. 2, pp. 82–90, **1932**.

[7] Brown, Levi S., Unpublished thesis, Univ. of Okla., **1928**, p. 46. See also, The occurrence of leucoxene in some of the Permian Mid-Continent Sediments, *American Mineralogist*, vol. **13**, p. 115, 233.

57 per cent, and in the Garber formation 68 per cent. The average ilmenite content of these three formations is about 2.5 per cent.

Sampson,[8] in samples from the Duncan, Chickasha, Dog Creek, Whitehorse, Hennessey, Garber, Wellington, and Stillwater formations finds the heavy minerals to contain an average leucoxene content of 49.7 per cent, and of ilmenite 9.7 per cent.

North of the area covered by Sampson, Spencer[9] finds the average content of leucoxene to be about 50 per cent and of ilmenite 7 per cent of the heavy minerals. These percentages were determined on 69 samples taken from the Wellington, Garber, Stillwater, Hennessey, Duncan, Whitehorse, and Quartermaster formations.

From this it seems that leucoxene is common throughout the Permian. Since no radical differences in physical and optical properties have been noted, it is assumed that samples from any of the formations mentioned would furnish leucoxene that will be representative of the Permian. On this assumption the Garber sandstone was chosen to furnish samples. The samples were collected from an outcrop of this formation, seven and one-half miles east of Norman, the rock exposed being a buff-colored, cross-bedded sandstone, well indurated and fairly free from iron oxide stain.

After crushing about 15 kilograms of the rock the heavier material was concentrated by panning. This concentrate was boiled in dilute HCl, dried and screened. From the material which passed the 100-mesh screen, but rested on the 200-mesh screen, the heavy minerals were extracted by using bromoform as a separatory liquid. In this way about 10 grams of heavy minerals were collected. The ten grams were given further treatment, using Clerici solution as a separatory liquid, until the final sample, mainly leucoxene, weighed slightly more than one gram and had a density of 3.65 to 4.005. Under the microscope it was seen to contain considerable quartz, about 20 to 25 per cent, and some hematite (stain), and ilmenite, attached to the characteristic leucoxene.

Qualitative and quantitative analyses were made of this material. For the latter, two samples were treated in order to check results. The average of these results was as follows:

[8] Sampson, Edw. W., Unpublished thesis, Univ. of Okla., **1929**, p. 40.

[9] Spencer, Marie, Unpublished thesis, Univ. of Okla., **1930** pp. 42–54.

TiO_2	72.12
SiO_2	24.49
Al_2O_3	0.00
Fe_2O_3	0.50
FeO	1.35
CaO	0.00
MgO	0.00
H_2O	1.66
Total	100.12

No CaO, MgO, or Al_2O_3 were present in the sample.

It was assumed that the iron was in the sample as impurities of hematite and ilmenite. The SiO_2, estimated as quartz under the microscope and determined chemically, was also assumed as an impurity. These assumptions leave only titanium oxide and water for the composition of leucoxene. The mineral composition of the sample is approximately as follows:

Leucoxene	$TiO_2 \cdot nH_2O$	72.20
Quartz	SiO_2	24.46
Hematite	Fe_2O_3	0.50
Ilmenite	$FeTiO_3$	2.84

Assuming the average density of quartz as 2.655, hematite as 5.1, ilmenite as 4.75, and of the sample analyzed as 3.828, the approximate density of the leucoxene would be 4.17.

Summary

The so-called leucoxene, from the Permian, is a white earthy, opaque substance of varying density (by computation the approximate density is 4.17). Qualitatively the impure sample was found to contain the elements titantium, silicon, iron, and hydrogen. These elements were determined quantitatively as their respective oxides, viz: TiO_2, Fe_2O_3, FeO, and H_2O. The oxide molecules were further computed to give the compounds: leucoxene 72.20; quartz 24.46; hematite 0.50; and ilmenite 2.84. The last three minerals in the analyzed sample are considered impurities.

The optical and chemical investigation indicates that leucoxene is an amorphous, hydrous titanium oxide ($TiO_2 \cdot nH_2O$). It was apparently deposited or left as a residue from the alteration of ilmenite by carbonate waters.