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## Kehoeite is *not* a valid species

KEHOEITE, found at the Merritt mine, Galena, Lawrence County, South Dakota, was originally described as a hydrated zinc aluminium phosphate by William P. Headden (1893). A very generous sample labelled 'from Wm. P. Headden' (Fig. 1) was acquired by Washington A. Roebling, the great American collector whose personal mineral collection of about 16000 specimens was donated to the U.S. National Museum of Natural History, Smithsonian Institution, in 1927 (Roe, 1990). This specimen, NMNH catalog number R5652, is regarded by the museum staff as the *type* kehoeite, a valid designation in spite of the fact that kehoeite is most certainly not a valid species.

In his description Headden referred to kehoeite as 'amorphous', a condition which surely influenced subsequent compilers of mineral data, causing them to relegate Headden's mineral to the status of doubtful validity, and as such it is recorded in most mineralogical literature. In contrast, evansite, another 'amorphous' hydrated phosphate of aluminium, has been granted loftier status, that of species, for reasons that may become apparent as the reader continues. Kehoeite likely would have remained a doubtful species had not Duncan McConnell, in 1964, published results of his X-ray study of a small sample of type kehoeite sent to him by the U.S. National Museum of Natural History in 1963. As a result of an X-ray study of that sample he concluded that kehoeite is structurally analogous to analcime (McConnell, 1964), a conclusion which persuaded Fleischer to upgrade kehoeite to species status (1966). In fact, as will be described in this paper, the diffraction pattern obtained by McConnell was not that of a crystalline kehoeite, but of a mixture of other minerals, the identities of which were not previously recognised.

As early as 1956 one of us (RCE) studied the same type specimen by X-ray diffraction, an effort that included an attempt to alter or enhance the crystallinity of kehoeite through heat treatment. The diffraction patterns obtained were interpreted as mixtures and no detectable changes occurred upon heating. A colleague at the U.S. Geological Survey, Laura E. Reichen (pers. communication, 1956), analysed the same sample and obtained results that are satisfyingly close to the original analysis of Headden. Another colleague, C. M. Taylor (pers. communication, 1967), performed electron microprobe homogeneity studies of this sample, and his results include observations that (1) sulfur correlates with calcium, (2) phosphorus correlates very well with aluminum and to a lesser degree with calcium, (3) zinc shows no correlation with phosphorus, sulfur, aluminium or calcium, and (4) the zinc content of the sample is 'fairly uniform' while those of phosphorus, calcium and sulfur vary considerably. It is clear, therefore, that since zinc

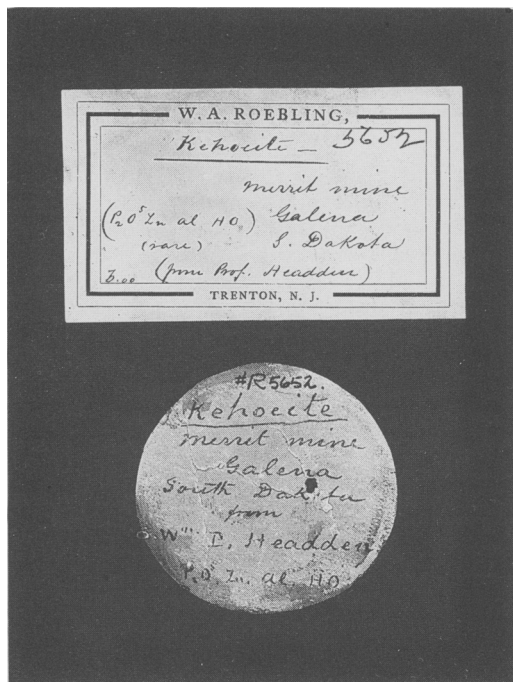


FIG. 1. The labels which accompanied type kehoeite (NMNH #R5652) when it came to the museum as part of the Roebling collection in 1927.

lacks a direct correlation with aluminum and phosphorus, kehoelite cannot be a hydrated zinc aluminum phosphate as postulated by Headden and reasserted by McConnell (1964). Among the 'numerous mineral phases which make up kehoelite' enumerated by Taylor are gypsum, quartz, pyrite, sphalerite and a finely-divided, unidentified calcium magnesium mineral.

Some years later one of the authors (JSW), in an effort to obtain a reference diffraction pattern of kehoelite, X-rayed some of the type sample but, in the course of working with it, discovered that it was gritty and that the grittiness was due to the admixture of discrete particles, some of the largest of which were readily seen and dark in colour. Using heavy liquids, two different types of particles were separated from the white powdery bulk of the sample. When X-rayed, these proved to be sphalerite and quartz. Individual particles of black sphalerite as large as 2 mm were found and some of the quartz grains reached 4 mm. No other physically separable phases were found.

Of the 13 diffraction lines reported for kehoelite by McConnell (1964) with intensity of 2 or more (10 = strongest), 8 match those of either quartz or sphalerite. This includes every line in McConnell's pattern with an intensity greater than 3 (Table 1). Additionally, at least two of the remaining weaker lines coincide closely with those of gypsum, a not altogether surprising

observation as Headden reported about one-half percent sulfate in his analyses. Other weaker lines appear to match those of the calcium aluminum phosphate/sulfate woodhouseite, so that virtually all of the diffraction lines tabulated by McConnell can be accounted for by a mixture of quartz, sphalerite, gypsum and woodhouseite, or a very similar phase.

It is quite clear, therefore, that the white powdery kehoelite cannot be a crystalline isomorphous phase having any discernible structure, let alone one that is analogous to analcime. If it were an isometric mineral, it surely would generate a strong pattern. Instead the white material, after sphalerite and quartz were removed, gave only a very weak pattern that appears to come closest to matching woodhouseite, even after a long (22+ hours) exposure. These lines specifically do not match analcime.

Although these results (except for woodhouseite which hadn't been recognised at the time) were communicated to McConnell in an exchange of letters in 1969, and again in 1973, McConnell and Foreman (1974) published a short paper in which additional X-ray diffraction data were presented to support the analcime hypothesis. These 'new' data were collected using a 'cleaned' sample supplied by one of the authors (JSW), and again the major diffraction lines turned out to be those of quartz, sphalerite and gypsum. The perfect match of these lines for a mixture of the three minerals is discounted by McConnell and Foreman, who again present the pattern as that of kehoelite and reassert their claim that it has an analcime-like structure. The continued insistence by McConnell that kehoelite is a valid mineral structurally analogous to analcime is all the more remarkable because McConnell himself (1942), described kehoelite as 'amorphous with respect to X-rays'. He listed kehoelite as one of the substances he studied which failed to 'produce resolvable diffraction lines during exposures up to four times those normally employed under comparable conditions'. It is not surprising, therefore, that McConnell failed to reference this paper in his 1964 publication.

Most recently McConnell (1990) challenged Fleischer's (1987) classification of kehoelite as a doubtful species as misleading and possibly erroneous. He claims that Fleischer indulged in 'unsupported speculation' because the most recent reference available to Fleischer was the McConnell and Foreman (1974) paper in which kehoelite was depicted as a valid species. The present authors feel, therefore, that it is time to provide unassailable evidence for discounting the analcime analogy for 'kehoelite' put forth by

Table 1. Comparison of diffraction pattern for "kehoelite" with diffraction lines for phases comprising the mixture.

QUARTZ		KEHOELITE		SPHALERITE		KEHOELITE	
4.26	35	4.28	50	3.12	100	3.13	100
3.34	100	3.35	100	2.705	10	2.708	30
1.818	17	1.816	20	1.912	51	1.916	70
1.672	7	1.669	10	1.633	30	1.633	60
GYPSUM		KEHOELITE		WOODHOUSEITE		KEHOELITE	
7.63	100	7.63	30	5.67	12	5.68	30
4.28	100	4.28	50	4.85	16	4.85	10
				3.49	37	3.49	30
				2.94	100	2.96	10
				2.19		2.223	20
				2.16			
				1.89	94	1.993	20
				1.74	78	1.749	10

\* Intensities for kehoelite from McConnell (1964) multiplied by 10

\*\* Strongest lines and intensities for other minerals from JCPDS data

McConnell. On the basis of our studies of type kehoeite we have proved that the substance, whether classed as an amorphous mineral or a non-mineral, has no identifiable crystal structure, but is instead a heterogeneous mixture of many phases, none of which bear any relationship to analcime. Kehoeite is not a valid species.

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## Occurrence of bassanite in Lower Lias rocks of the Lyme Regis area, England\*

REPORTED occurrences of bassanite ( $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ) are rare, and are of two principal kinds. The first is related to the precipitation of sulphate minerals in arid or semi-arid environments, where its genesis is controlled by climate. Bundy (1975) found bassanite as a very minor component of some gypsum and anhydrite deposits in south-western Indiana. He believed it to be a metastable mineral in the transition zone between gypsum and anhydrite. It has also been reported as an evaporite mineral from the coastal sabkhas of Baja California and Abu Dhabi (Kinsman, 1969). Gunatilaka *et al.* (1985) have described a significant occurrence of bassanite

from the continental sabkha zone pans and gypsum dune complexes of Al-Khiran, Kuwait. It is considered as practically topotactic after gypsum and occurs as a dissolution and reprecipitation product.

The second main mode of occurrence of bassanite is associated with leaching products of sulphides. Palache *et al.* (1951) reported bassanite in cavities of leucite-tephrite blocks ejected during the April 1906 eruption of Vesuvius. It also occurs with gibbsite in fumaroles as a reaction product of sulphurous vapours with calcium-bearing minerals.

The Lower Lias, extensively exposed along the English Channel in the Lyme Regis area, is dominantly composed of alternating beds of

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