CLASSIFICATION AND ASSOCIATION OF THE CARBONATE MINERALS OF THE GREEN RIVER FORMATION*

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ABSTRACT. About one fourth of all known carbonate minerals occur in the Green River formation of Wyoming, Utah, and Colorado, a sequence of Eocene lacustrine deposits. Most are alkali (sodium) or alkali-earth (calcium, magnesium, strontium) or alkali-alkali earth carbonates; a few contain rare earths, or aluminum, chlorine, or phosphate. Twenty well-defined species are listed, and arranged in accordance with Dana's System, 7th Edition. The particular assemblage found in each of the three States implies corresponding variation in the over-all geochemical and geological conditions affecting their deposition.

The Green River formation of Wyoming, Utah, and Colorado (map, fig. 1) is a sequence of essentially lacustrine deposits of early to middle Eocene age, whose unique characteristics were first systematically explored by Wilmot H. Bradley in a series of classical papers (Bradley 1926, 1930a, 1930b, 1931, 1936, 1948, 1959). This formation, now known to contain the world's largest reserve of hydrocarbons, in the form of oil shale, also contains a tremendous reserve of trona (Na₂CO₃·NaHCO₃·2H₂O), conservatively estimated at several

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billions of tons. Trona is readily converted to soda ash (sodium carbonate), a basic industrial commodity; and within a few years development of the Wyoming deposits will increasingly supersede soda ash manufacture by the Solvay process. The mineralogy of the Green River formation thus is a matter of great interest, in particular because of the remarkably varied carbonate minerals found—some twenty distinct species. Actually about a fourth of all carbonate species known occur in the Green River formation.

Because data on the Green River carbonates are widely scattered and much information is yet unpublished, it is thought that the synoptic review of their mineralogy here presented—necessarily skeletal though it be—will be helpful to the student of these matters. A similar summary discussion of the remarkable silicate mineralogy of the Green River formation—including twelve species—has been submitted for publication in the proceedings of the XXI International Geological Congress at Copenhagen in 1960.

In this limited paper, it will not be possible to give any detailed account of the mineralogy or geochemistry of individual species, or of their geological relationships to the Green River formation; for this the reader is referred to the literature listed in part in the references cited below.

Table 1 lists the carbonate minerals of the Green River formation, and indicates their occurrence in three western states. The tabulation follows the classification of Dana’s System of Mineralogy, 7th edition, volume 2.

The distribution indicated under the heading Occurrences in table 1 appears to be much more than merely geographic or chance discovery; it is significant of specialization of geological history in Green River time in the three major sub-basins of the Eocene lakes, known as the Green River basin in southwestern Wyoming, the Uinta basin in northeastern Utah, and the Piceance Creek basin in northwestern Colorado. Milton and Eugster (1959) have attempted to relate the difference in sodium carbonate mineralogy of Wyoming (characterized by trona) and the other two states (characterized by nahcolite) to limnologic considerations; here we may say only that in each of the three states, so far as our present knowledge goes, there is a distinctive carbonate (and other) mineralogy.

Calcite and dolomite are the dominant minerals of the Green River formation. These, with quartz and organic matter, and lesser but significant amounts of pyrite, albite feldspar, analcite, detrital mica, and clay minerals, constitute the major rock-forming minerals of the Green River beds in all three states. Doubtless calcite is in general more abundant than dolomite, although locally in some beds or series of beds dolomite may exceed calcite. In outcrop the once present sodium-containing carbonates are invariably replaced by calcite; this is particularly true of shortite. The so-called "oil shale" of the Green River is largely dolomite or limestone with varying organic content, as is also most of the "marlstone" of various writers.

Shortite is the most abundant of the sodium-containing carbonates in the Wyoming Green River beds, and followed by trona and northupite is the most abundant carbonate (other than calcite and dolomite) found in the John Hay
Jr. No. 1 well in Wyoming; study of the core from this well has recently been completed by J. J. Fahey, and the data submitted for publication as a professional paper of the U. S. Geological Survey. Much shortite, but no trona, is also found in the Uinta basin in Utah; neither mineral has been found in the Piceance basin in Colorado. Nahcolite, abundant in Utah and Colorado, is found only as traces in Wyoming.¹

Microscopically disseminated barytocalcite is found rather widely but never abundantly in Utah and Wyoming; accompanied by barb ankite, as a microscopic rarity. In Utah, barytocalcite is found with eitelite and a unique assemblage of silicate minerals. In a well core from Colorado, dawsonite occurs through several hundred feet; cryolite is present also.

In Wyoming, all of the carbonates occur in a series of calcareous or dolomitic beds containing bedded trona. Also in Wyoming, and only there, in addition to shortite, trona, and northupite, the following have been identified: pirssonite, gaylussite, bradleyite, witherite, thermonatrite, barytocalcite, narsethite, natron, and a new unnamed species with the composition Na₂CO₃·3NaHCO₃. Trona, thermonatrite, natron, and the new Na₂CO₃·3NaHCO₃ are all phases in the Na₂O·CO₂·H₂O system; and similarly shortite, pirssonite, and gaylussite are phases of the more complex Na₂O·CaO·CO₂·H₂O system. The phase relationships in these comparatively simple systems are summarized by Milton and Eugster (1959). Carbonate minerals known to exist in these systems, and in the CaCO₃·MgO·BaCO₃ system are shown in figures 2, 3, and 4. The chlorine in locally abundant northupite, and the phosphate in bradleyite indicate that the actual physical chemistry of the trona deposits involves a good deal more than these three simple systems. It may also be mentioned in this connection that study of these carbonates, e.g. trona and northupite, has shown remarkable intergrowths with silicates. Thus trona crystals enclose loughlinite Na₈.₃MgO·₆SiO₂·₈H₂O (Fahey, Ross, and Axelrod, in press) and labuntsovite (K.Ba.Na.Ca.Mn) (Ti.Nb) (Si.Al)₂(O,OH)₂H₂O (Milton, Mrose, Fahey, and Chao, 1958); and northupite encloses magnesioriebeckite Na₆(Mg.Fe)₄(Fe.Al)₆Si₂O₁₉(OH)₂. The relations suggest simultaneous crystallization of carbonate and silicate.

Brief mention may be made of the other minerals of table 1. Magnesite has been noted but once, in an outcrop sample from Utah. It forms good crystals several millimeters long in a dolomite matrix. Siderite is probably more abundant than can now be shown; it has been noted in microscopic spheroids in well cuttings from Utah, as yellow microscopic rhombohedra in a well core from Colorado and in an outcrop sample from Wyoming.

To be considered as a phosphate rather than a carbonate mineral is carbonate fluor-apatite (Love and Milton, 1959). This mineral constitutes a significant portion of certain beds in the Green River of Wyoming, some of which have been traced continuously over scores of miles. Almost invariably it carries traces of uranium. The mineral is cryptocrystalline and invariably submicroscopically intergrown with dolomite, calcite, analcrite, and quartz.

¹ Since this was written, recent drilling has exposed massive nahcolite with trona and halite in Wyoming.
TABLE 1

Green River carbonates

(Arranged according to Dana’s System, 7th ed., v. 2, p. 132-133)

Class 13 Acid carbonates Type 1 Miscellaneous

<table>
<thead>
<tr>
<th>Occurrence</th>
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<td>Utah, Colorado</td>
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13.1.1 Nahcolite NaHCO₃
13.1.4 Trona Na₂CO₃·NaHCO₃·2H₂O
13.1.5 New species, unnamed Na₂CO₃·3NaHCO₃

Class 14 Anhydrous normal carbonates Type 1 A(XO₃)

<table>
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<tr>
<th>Type 2 AB(XO₃)₂</th>
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14.1.1 Calcite group
14.1.2.1 Dolomite group
14.1.2.3 Barroisite group
14.1.3.1 Siderite group
14.1.3.2 Witherite group

14.1.2.4 Norsethite MgBa(CO₃)₂
14.1.3.2 Eitelite Na₂Mg(CO₃)₂

14.2.1 Shortite Na₂Ca₂(CO₃)₃
14.2.2 Hydrated normal carbonates Type 1 A(XO₃)·xH₂O

15.1.1 Thermomartrite Na₂CO₃·H₂O
15.1.8 Natron Na₂CO₃·10H₂O

15.2.2 Pissonite Na₂Ca(CO₃)₂·2H₂O
15.2.3 Gaylussite Na₂Ca(CO₃)₂·5H₂O

Class 16 Carbonates containing hydroxyl or halogen

16.2.1 Dawsonite NaAl(CO₃)·(OH)·2
16.2.2 Northupite Na₂Mg(CO₃)·4Cl

Class 17 Compound carbonates

17.1.2 Bradleyite Na₂Mg(CO₃)·(PO₄)

1 References to Table 1

1 New species, unnamed Na₂CO₃·3NaHCO₃, unpublished data.
2 Norsethite, see Milton, Mrose, Chao and Fahey, 1959.
3 Eitelite, see Milton, Axelrod, and Grimaldi, 1954.
4 Burbankite, see Pecora and Kerr, 1953; and Milton and Eugster, 1959.

REFERENCES CITED


Milton, Charles, Axelrod, J. M., and Grimaldi, F. S., 1954, New minerals, reedmargnerite ($\text{Na}_2\text{O}_2\text{B}_2\text{O}_5\cdot 6\text{SiO}_2$) and eitelite ($\text{Na}_2\text{O}\cdot \text{MgO}\cdot 2\text{CO}_3$), associated with leucosphenite, shorlite, seariesite, and crocidolite in the Green River formation, Utah (abs.): Geol. Soc. America Bull., p. 1286.


Milton, Charles, Mrose, M. E., Chao, E. C. T., and Fahey, J. J., 1959, Noresmithite, $\text{BaMg(CO}_3)^2$ a new mineral from the Green River formation, Wyoming Program (abs.): Ann. meeting, Mineralog. Soc. America Pittsburgh, p. 88A.
