NORTH AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE
Note 71 – Application for addition of chemostratigraphic units to the North American Stratigraphic Code: A case for formalizing chemostratigraphic units

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ABSTRACT: Chemostratigraphy has evolved as a significant scientific subdiscipline of the Geosciences during the past seventy years. Chemostratigraphic data have contributed to deciphering deep-time ocean and atmospheric climates and processes, and it has become a practical correlation tool. As new instruments, methods and techniques are developed, geochemical data will add to geoscientific research and applications in new ways. However, some inconsistencies and confusion in use of the terms have developed in practice, in which objective observable data are considered as past events rather than as the record of past events. Chemical excursions documented by samples in measured stratigraphic sections and cores commonly and called "events". The distinction between physical stratigraphic units and geohistorical events is commonly obscured. The North American Code of Stratigraphic Nomenclature is the appropriate venue in which to present guidelines that clarify usage of chemozones as distinct from interpretations about paleoenvironmental conditions and to ensure objective testable correlation practices.

INTRODUCTION: STATEMENT OF PROBLEM

Chemostratigraphy has evolved as a significant scientific subdiscipline of Geosciences for over seventy years since the first application of oxygen isotopes to measure oceanic paleotemperatures (Emiliani 1955; Emiliani and Geiss 1959; Weissert et al. 2008). Numerous examples demonstrate the significant contributions that geochemical data make to geoscientific theories and applications (Appendix). International momentum is growing to develop guidelines for the practice and publication of chemostratigraphic research and applications. New methods and techniques will be developed as new instruments become available.

During the past several years, numerous professional meetings and publications have focused on Chemostratigraphy. In his 2015 book, *Chemostratigraphy*, Mu. Ramkumar recommended chemostratigraphy to be recognized as a formal stratigraphic method with standard terminology. Since 2017, the North American Commission on Stratigraphic Nomenclature (NACSN, 2005) has considered a proposal to define chemostratigraphic units in the NACSN Code. As a result, the Commission sponsored the chemostratigraphic session at the 2019 Geological Society of America annual meeting. Also, an international meeting is scheduled in Europe in 2020.

Some inconsistencies and confusion in use of terms have developed in practice in which objective observable data are intermixed with inferred past events. The term "Event" is used commonly in relation to chemical excursions documented by samples in measured stratigraphic sections and cores. For example, the OAE 2 oceanic event is defined by a positive carbon isotope shift and/or an organic-rich black shale at the Cenomanian-Turonian boundary. The distinction between stratigraphic evidence and the interpretation of marine anoxia should be clear. The Code distinguishes between physical stratigraphic units and chronostratigraphic units, which may be obscured in chemostratigraphic studies. This blurring of concepts should be addressed in the North American Code and the terminology made unambiguous.

Six aspects of chemostratigraphy are relevant and essential to the objective utilization of chemostratigraphic signals as a correlation tool and in the interpretation of geohistory.

1. Chemostratigraphic signals commonly used are: TOC, $\delta^{13}C$, $\delta^{18}O$, $^{87}Sr/^{86}Sr$, and common elements and trace elements among others.

2. Closely spaced sampling relative to section thickness and completeness is required.

3. Many chemostratigraphic signals have distinct identifiable and quantifiable excursions or spikes, although some elements change gradually and progressively.

4. Closely spaced sampling relative to section thickness and completeness is required.

5. Chemostratigraphic signals may be divided into units at the base of a shift, at its inflection, at its peak, or as an interval between excursions.

6. Chemostratigraphic signals commonly are integrated with co-occurring criteria, e.g., bioevents, polarity chrons, or well log properties.

7.Chemostratigraphic signals can be correlated from reference sections to other sections.

The addition of Chemostratigraphic Units to the Code is timely and a necessary guideline to stabilize concepts of this stratigraphic tool. Also, a distinction needs to be made between the objective chemical signal – chemozone – and the interpretive event in the sense of a time-rock unit. A Chemozone is proposed as a new category under the subtitle "FORMAL UNITS DISTINGUISHED BY CONTENT, PROPERTIES, OR PHYSICAL LIMITS AS LITHOSTRATIGRAPHIC UNITS" (p. 1566). As such, chemostratigraphic units can be defined in a new Article and inserted into the Code following Article 54 (re-numbered 55 following the addition of Submembers). Lithodemic units. The equivalent "FORMAL UNITS EXPRESSING OR RELATING TO GEOLOGIC AGE" are Chemochrons.

PROPOSED REVISIONS

The proposal of formal Chemostratigraphic units requires changes in the NACSN Code (2005), by additions to the OVERVIEW section and Article 2; and by renumbering Articles 53 and 54 as 52 and 53, respectively; by replacing Articles 54 and 55 with new chemostratigraphic text; and by renumbering subsequent articles by adding one number to each, for example present Article 55 becomes Article 56 and present Article 97 becomes Article 98.

Under the general discussion of OVERVIEW, CATEGORIES RECOGNIZED (p. 1556) and under the subheading "Material Categories Based on Content or Physical Limits" (p. 1557) insert a new paragraph between paragraphs on biostratigraphic and pedostratigraphic units (p. 1558):

Chemical properties, such as isotopes of carbon, oxygen and strontium, as well as common elements, trace elements, rare earth elements, or total organic content, vary spatially and temporally in the rock record. Geochemical properties, or combinations of properties, provide the basis for defining and recognizing material units (*chemostratigraphic units*, Article 55). Because geochemistry commonly varies with concomitant changes in the ambient environmental conditions or reflects changes in the sediment source area, geochemical changes in the rock record are important tools for correlation and deciphering Earth history.

Under "**PART II. ARTICLES, INTRODUCTION**, Article 2" (p. 1561), insert "chemostratigraphic" in the second sentence to read:

Article 2. — **Categories**. Categories of formal stratigraphic units, though diverse, are of three classes. The first class (I on Table 1) is of rock-material categories based on content, inherent attributes, or physical limits, and includes lithostratigraphic, lithodemic, magnetopolarity, biostratigraphic, chemostratigraphic, pedostratigraphic, and allostratigraphic units.

Under "PART II. ARTICLES, **FORMAL UNITS DISTINGUISHED BY CONTENT, PROPERTIES, OR PHYSICAL LIMITS"**, which begins on p. 1566, insert on p. 1576, following "Biostratigraphic Units" and before "Pedostratigraphic Units," the following section.

CHEMOSTRATIGRAPHIC UNITS

Nature and Boundaries

Article 54. — **Nature of Chemostratigraphic Units**. A chemostratigraphic unit is a body of rock that is defined or characterized by its specified geochemical properties such as isotopes of carbon, oxygen and strontium, as well as common elements, trace elements, rare earth elements, total organic content, or biomarkers. Unit boundaries may be sharp and distinct or gradual. Units may be associated with independent stratigraphic markers such as polarity chrons, magnetic susceptibility zones, marker beds, or biostratigraphic zones, which aid in their identification.

Remarks. (a) **Definition. –** *Chemostratigraphy* is the study of the temporal and spatial geochemical variability of the sedimentary rock record with a goal to establish correlative, mappable rock intervals and facies, defined in terms of their unique geochemical properties. The measurements of geochemical changes in a stratigraphic succession may vary, forming a curve trace that can be divided into intervals of rock having higher and lower magnitudes.

(b) **Contemporaneity of rocks and geochemical signals**. — Geochemical properties of stratified rocks may result from the chemical composition of water bodies in which the sediments were deposited, from diagenetic alterations during or after burial, from sedimentary provenance, and/or from weathering processes during subsequent subaerial or submarine exposure. Thus, chemical elements, ions, compounds or isotopes may be evidence of such processes. Geochemical properties not contemporaneous with the enclosing body of rock should be avoided in defining, characterizing, or identifing a chemostratigraphic unit.

(c) **Boundaries.** — Boundaries of chemostratigraphic units are placed at distinctly identifiable, quantifiable, high-to-low changes or excursions of geochemical properties that divide the stratigraphic data trend into segments separated by inflection points, peaks of maximum or minimum measurements, changes in curve gradient, or by excursion shape. Abrupt changes in geochemical composition may also serve to define boundaries. The nature of the boundary must be unambiguously specified in formal definition of chemozones.

(d) **Reference sections**. — Chemostratigraphic units typically do not have stratotypes in the sense of Article 3, item (iv), and Article 8, because they are based on geochemical signature or content. Nevertheless, it is desirable to designate one or more reference sections or a single composite section, in which the chemostratigraphic unit is characteristically developed. Reference sections may be either in outcrops or drilled cores, and appropriately spaced samples are required. Reference sections should be publicly accessible for future re-sampling to increase sample spacing and/or to test other properties of the sedimentary section.

Chemostratigraphic Nomenclature

Article 55. — **Fundamental Unit.** A *chemozone* is the fundamental local unit in chemostratigraphic classification. It is the stratigraphic rock interval characterized by unique geochemical properties that distinguish the interval from underlying and overlying intervals. The geochemical properties may consist of specific elements, isotopes, or ratios of elements. The property values may change in a stratigraphic succession resulting in excursions, fluctuations, perturbations, shifts, or anomalies.

Remarks. (a) **Ranks.** — Chemozones may be formally subdivided into *subchemozones*. Chemozones may be grouped together to form *superchemozones*. The rank of a chemostratigraphic unit may be changed when deemed appropriate.

(b) **Thickness and duration.** — The thickness of a chemozone rock interval or the amount of time represented by the zone should play no part in the definition of the zone.

(c) **Nomenclature**. — The formal name of a chemostratigraphic unit typically consists of a geographic name, other proper names or a mnemonic set of letters with or without numbers, combined with the term "chemozone." A chemozone name may represent its stratigraphic position such as the carbon isotope inflections, *B1-B8 Chemozones*, of the Barremian Stage. The rock record of the Cretaceous positive carbon isotope excursions represents oceanic anoxic events and have been termed OAE 1, OAE 2 and OAE 3. *Chemozone OAE 1* has been subdivided into OAE 1a, 1b, 1c, and 1d *Subchemozones*. Sets of chemozones may be grouped into a *superchemozone*. Names typically reflect the discovery history of the corresponding event or phenomenon that imprinted the chemostratigraphic signature in the rock record. Subsequent usage of the chemozone and its stratigraphic position should be consistent with the original concept to the extent practical. Formal chemozone names should not duplicate pre-existing names for bioevents.

(d) **Events.** — An "event" is a specific geological, environmental, or other phenomenon that occurred in geologic time, even if the details or the type of this phenomenon are not known or understood. Volcanic eruptions, flows and ash falls are examples of events. When an event leaves evidence of its occurrence in the rock record, it may prove useful to name the product of this event. The event process must be clearly distinguished from its rock record. An event is NOT a stratigraphic unit but is interpreted from the rocks. A chemostratigraphic signal allows the recognition of an event; for example, the Ordovician Guttenberg isotopic event (GICE) could be formally re-designated as the Guttenberg excursion, or GICE Chemozone. A reference section could be designated in Guttenberg, Iowa.

(e) **Stratigraphic significance.** —The stratigraphic succession of chemostratigraphic units reflects concomitant changes in the ambient environmental conditions of the chemical processes or the sediment source area. These changes in the chemical composition record the timing of changing environmental conditions and thus become correlation tools between sections.

The following are additions to the existing sections:

FORMAL UNITS EXPRESSING OR RELATED TO GEOLOGIC AGE (p. 1579)

CHRONOSTRATIGRAPHIC UNITS (p. 1581)

Nature and Boundaries

Article 67, remark (c):

(c) **Content**. — A chronostratigraphic unit may be based upon the time span of a biostratigraphic unit, a chemostratigraphic unit, a lithic unit, a magneto-polarity unit, or any other feature of the rock record that has a time range.

Article 69. — **Correlation**. Demonstration of time equivalence is required for geographic extension of a chronostratigraphic unit from its type section or area. Boundaries of chronostratigraphic units can be extended only within the limits of resolution of available means of chronocorrelation, which currently include paleontology, chemostratigraphy, numerical dating, remanent magnetism, thermoluminescence, relative-age criteria.

Article 76. — **Chronozone**. A chronozone is a nonhierarchical, but commonly small, formal chronostratigraphic unit, and its boundaries may be independent of those ranked chronostratigraphic units such as stage or series. Although a chronozone is an isochronous unit, it may be based on a biostratigraphic unit (example: Cardioceras cordatum Biochronozone), a lithostratigraphic unit (Woodbend Lithochronozone), a magneto-polarity unit (Gilbert Reversed-Polarity Chronozone), or a chemostratigraphic unit (B8 Chemochronozone). Modifiers (litho-, bio-, polarity, chemo-) used in formal names of the units need not be used where the meaning is evident from the context, e.g., *Exus albus* Chronozone.

CHANGES TO TABLES (as renumbered following addition of Chemostratigraphic units)

Table 1. Classes of Units Defined* (p. 1557)

FORMAL UNITS DISTINGUISHED BY CONTENT, PROPERTIES, OR PHYSICAL LIMITS

Lithostratigraphic (22)*

Lithodemic (31)**

Magnetostratigraphic (43)

Biostratigraphic (48)

Chemostratigraphic (54)

Pedostratigraphic (56)

Allostratigraphic (59)

*Numbers in parentheses are the numbers of the Articles where units are defined.

**Italicized categories are those introduced or developed since publication of the previous Code (ACSN 1970).

No changes on Figure 1, p. 1558:

I. MATERIAL CATEGORIES BASED ON CONTENT OR PHYSICAL LIMITS

LITHOSTRATIGRAPHIC	LITHODEMIC	MAGNETOPOLARITY	BIOSTRATIGRAPHIC	CHEMOSTRATIGRAPHIC	PEDOSTRATIGRAPHIC	ALLOSTRATIGRAPHIC
Supergroup	Supersuite (Complex)					
Group	Suite (Complex)	Polarity Superzone		Superchemozone		Allogroup
Formation	*Lithodeme*	*Polarity Zone*	*Biozone* (Interval, Assemblage or Abundance)	*Chemozone*	*Geosol*	*Alloformation*
Member (or Lens, or Tongue)		Polarity Subzone	Subbiozone	Subchemozone		Allomember
Submember						
Bed(s) or Flow(s)						

IIA. MATERIAL CATEGORIES USED TO DEFINE TEMPORAL SPANS

CHRONO-STRATIGRAPHIC	POLARITY CHRONO-STRATIGRAPHIC
Eonothem	Polarity Superchronozone
Erathem (Supersystem)	
System (Subsystem)	*Polarity Chronozone*
Series (Subseries)	
Stage (Substage) (Superchronozone)	Polarity Subchronozone
Chronozone (Subchronozone)	

IIB. NON-MATERIAL CATEGORIES RELATED TO GEOLOGIC AGE

GEOCHRONOLOGIC	POLARITY CHRONOLOGIC	DIACHRONIC (Diachron)	GEOCHRONOMETRIC
Eon	Polarity Superchron		Eon
Era (Superperiod)		(Subchron)	Era (Superperiod)
Period (Subperiod)	*Polarity Chron*	*Episode*	*Period* (Subperiod)
Epoch (Subepoch)		Phase	Epoch
Age (Subage) (Superchron)	Polarity Subchron	Span	Age (Subage)
Chron (Subchron)		Cline	Chron

*Fundamental units are italicized.

TEXT-FIGURE 1
Modification of Table 2. Categories and Ranks of Units Defined in This Code* (p. 1562).

SUMMARY

Chemostratigraphy has evolved as a significant scientific subdiscipline of the Geosciences during the past seventy years. Chemostratigraphic data has contributed to documenting deep-time ocean and atmospheric climates and processes and it has become a practical correlation tool. The addition of Chemostratigraphic Units to the NACSN Code is timely and necessary to stabilize concepts of geochemistry as a stratigraphic tool. The distinction between an objective chemical signal and the interpretive event in the sense of a time-rock unit is critical. A Chemozone is a category of Formal Units Distinguished by Content, Properties, or Physical Limits, Lithostratigraphic Units. The equivalent "Formal Units Expressing or Relating to Geologic Age" are Chemochrons.

The proposal of formal Chemostratigraphic units requires changes in the NACSN Code (2005). Under the general discussion of OVERVIEW, CATEGORIES RECOGNIZED, under the subheading "Material Categories Based on Content or Physical Limits" insert a new paragraph between paragraphs on biostratigraphic and pedostratigraphic units. In Article 2 add the word chemostratigraphic. The proposal of formal Chemostratigraphic units requires changes in the NACSN Code (2005). In compliance with Article 21 (NACSN 2005), we propose that minor additions be made to the OVERVIEW section of NACSN 2005 and Article 2; furthermore that Articles 53 and 54 be renumbered as 52 and 53, respectively; by replacing Articles 54 and 55 with new chemostratigraphic text; and by renumbering subsequent articles by adding one number to each, for example present Article 55 becomes Article 56 and present Article 97 becomes Article 98 as proposed. The geologic community may submit comments on this proposal to Dr. Robert Scott, Precision Stratigraphy Associates, 149 W. Ridge Road, Cleveland OK 74020; email: rwscott@cimtel.net.

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APPENDIX – Selected Application Examples

1. Marine oxygen isotope stages (MIS), high-resolution isotope chronostratigraphy-oxygen isotope chemozones (Emiliani 1955; Emiliani and Geiss 1959; Shackleton and Opdyke 1973; Lisiecki and Raymo 2005; Weissert et al. 2008)

2. Carbon isotope excursion (CIE) as a potential GSSP marker point of the Eocene Series (Aubrey et al. 2002).

3. Rare Earth elements as evidence of provenance and weathering (Madhavaraju et al. 2015).

4. Sequence stratigraphy: use geochemical peaks to identify "flooding surfaces"; % carbonate, TOC, Total Sulfur (Morath et al. 2015). One example correlates carbonate peak with sulfur peak from basin to shore.

5. "Chemostratigraphy involves the geochemical classification and correlation of sedimentary strata by using major and trace element geochemistry" where biostratigraphic control is wanting (Madhavaraju et al. 2015).

6. Identify stage boundaries, e.g., Ordovician-Silurian (Ainsaar et al. 2015), and Substage boundaries, e.g., intra-Silurian (Saltzman and Thomas 2012).