Chemical Geology 415 (2015) 118–125

Contents lists available at ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

Calcium isotopes reveal the trophic position of extant and fossil elasmobranchs

Jeremy E. Martin [a,*], Théo Tacail [a], Sylvain Adnet [b], Catherine Girard [b], Vincent Balter [a]

[a] Laboratoire de Géologie de Lyon: Terre, Planète, Environnement, UMR CNRS 5276 (CNRS, ENS, Université Lyon1), Ecole Normale Supérieure de Lyon, 69364 Lyon cedex 07, France
[b] Institut des Sciences de l'Evolution, Université Montpellier, UMR 5554 CNRS, IRD, C.C. 64, Place Eugène Bataillon, F-34095 Montpellier, France

ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form 9 September 2015
Accepted 12 September 2015
Available online 24 September 2015

Keywords:
Stable isotopes
Calcium
$\delta^{44/42}$Ca
Ecology
Elasmobranchs
Marine ecosystems

ABSTRACT

Recent calcium isotope studies recovered a trophic level effect in marine ecosystems. However, elasmobranchs are virtually absent from such studies despite their important ecological role, their diversity and their extensive fossil record. Enameloid of extant elasmobranchs representing differing known ecologies were measured for $\delta^{44/42}$Ca. The results reveal that their calcium isotope values have a distribution (from −0.27 to −0.78‰) that follows a stepwise decrease ($\Delta^{44/42}$Ca) of about −0.14‰ across recognized trophic levels: zooplanktivores, primary, secondary, and tertiary consumers. Although the recovered calcium isotope distributions partly match the ecological divisions of extant elasmobranchs, data for marine mammals are more variable and cannot be explained by trophic segregation alone. Nevertheless, our results reopen perspectives for the study of ancient marine assemblages using calcium isotopes. As a case study, the calcium isotope values of a Pliocene fish assemblage parallel the results obtained from extant elasmobranchs and allow inferring that the giant shark *Megaselachus megalodon* fed at a slightly higher trophic level than the contemporaneous Great White shark.

1. Introduction

The isotope reconstruction of dietary ecology and foraging preferences in living marine animals is mostly restricted to carbon and nitrogen isotopes in soft tissues (Minagawa and Wada, 1984). The elemental strontium/calcium (Sr/Ca) and barium/calcium (Ba/Ca) ratios offer an alternative for the fossilizable mineral phase of bone and teeth (Peek and Clementz, 2012). However, diagenesis (Balter et al., 2011) and seawater temperature (Balter and Lécuyer, 2010) are two independent parameters that can overprint the primary dietary Sr/Ca and Ba/Ca signatures. To date, there is little work on alternate isotope markers such as calcium, which is particularly bioavailable in the ocean (average concentration of ~ 420 ppm e.g. Elderfield and Schultz, 1996) and incorporates the shell and bioapatite skeleton of both invertebrate and vertebrate organisms. Moreover, the isotope composition of seawater is identical at the global scale due to the relatively long residence time of calcium in the ocean (~ 1 Ma e.g. Zhu and Macdougall, 1998) and seawater calcium composition has not significantly changed in the last 5 Ma (De La Rocha and De Paolo, 2000; Fantle and DePaolo, 2005; Griffith et al., 2008) relative to the biological variation measured in previous work (Clementz et al., 2003). Early work on calcium isotopes showed a significant decrease in calcium isotope ratios with increasing trophic level in both terrestrial and marine ecosystems (Skulan et al., 1997; Skulan and DePaolo, 1999). Subsequently, Clementz et al. (2003) analyzed a number of extant and fossil marine mammals and showed that their calcium isotope values also matched the first noted trend in decreasing values with increasing trophic level.

Because of their high diversity and abundance worldwide, elasmobranchs play an important role in marine ecosystems and previous studies have shown that large sharks have the potential to shape marine communities (Ferretti et al., 2010). But elasmobranch calcium isotope data are virtually absent from the literature. Due to their breadth of feeding ecology (from zooplanktivores to tertiary consumers), the various species of elasmobranchs provide a testable mean to assess the utility of calcium isotopes in dietary reconstruction. If there is a trophic effect on calcium isotopes for marine invertebrates and mammals, then this should also be reflected in extant elasmobranchs, which have high modern diversity, and are also abundant in the fossil record.

Here, we examine the calcium isotope composition of tooth apatite from 18 extant species of elasmobranchs of known ecologies (Table 1) using Multi-Collection Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS). We show that significant differences exist between elasmobranch groups with different feeding ecologies. We discuss the calcium isotope variability of elasmobranchs in the context of marine food webs and finally assess the utility of this geochemical tool in paleoecology with a case study from two Pliocene (*ca.* 5 Ma) fish assemblages.

* Corresponding author.
E-mail address: jeremy.martin@ens-lyon.fr (J.E. Martin).

http://dx.doi.org/10.1016/j.chemgeo.2015.09.011
0009-2541/

Table 1
Ca stable isotope values of elasmobranch teeth, fish teeth and marine mammal bone and teeth analyzed in this study together with taxonomic and ecological information. [1]: consumer level inference from this study; for body lengths: *: estimate; ** extrapolation from Adnet et al. (2010); ***extrapolation from Gottfried et al. (1996). Abbreviations: n, replicates; TL: total length for sharks; DW: disk width for rays.

Taxon	Vernacular name	Diet	Provenance	Coll number	Habitat	Consumer level	Total Length or Disc Width (cm)	δ44/42Ca (‰ ICP Ca Lyon)	2SD	replicate analysis	δ44/42Ca (‰ IAPSO SW)	2SD
Extant												
Cetorhinus maximus	basking shark	plankton	North Sea	REC0946M	pelagic	zooplanktivore	383 TL	−0.48	0.08	5	−0.89	0.10
Manta birostris	manta ray (male)	plankton	Baja California	NS83-003	pelagic	zooplanktivore	500* DW	−0.27	0.07	3	−0.68	0.09
Scyliorhinus stellaris	spotted dogfish/nursehound	opportunistic	Mediterranean Sea	REC0185M	benthic	primary	90 TL	−0.51	0.03	3	−0.92	0.07
Mustelus punctalatus	houndshark	crustaceans	Mediterranean Sea	REC0321M	demersal	primary	121 TL	−0.38	0.10	6	−0.79	0.12
Myliobatis aquila	common eagle ray	mainly malacophagous	Mediterranean Sea	REC1119M	benthic	primary	max. 100* DW	−0.50	0.05	4	−0.90	0.08
Oxynotus centrina	angular roughshark	invertebrates	Mediterranean Sea	REC0251M	demersal	primary	72 TL	−0.45	0.05	3	−0.86	0.08
Dasyatis centroura	roughtail stingray	invertebrates	Mediterranean Sea	REC0627M	benthic	primary	85 TL	−0.47	0.06	3	−0.88	0.09
Odontaspis ferox	small-toothed sandtiger shark	fish, crustaceans	Pacific	-	demersal	secondary	max 300* TL	−0.57	0.03	2	−0.98	0.07
Galeorhinus galeus	school shark	piscivorous/opportunistic	Mediterranean Sea	REC0347M	demersal	secondary	146 TL	−0.57	0.07	3	−0.98	0.09
Carcharhinus brevipinna	spinner shark	piscivorous	Mediterranean Sea	REC0270M	pelagic	secondary	95 TL	−0.54	0.06	3	−0.95	0.09
Prionace glauca	blue shark	piscivorous/opportunistic	Mediterranean Sea	-	pelagic	secondary	max 300* TL	−0.59	0.09	4	−1.00	0.11
Lamna nasus	porbeagle shark	piscivorous	Mediterranean Sea	REC0136M	pelagic	secondary	140 TL	−0.58	0.19	4	−0.99	0.20
Squalus acanthias	spiny dogfish	piscivorous/opportunistic	Mediterranean Sea	REC0223M	pelagic	secondary	72 TL	−0.58	0.12	3	−0.99	0.13
Alopias vulpinus	common thresher shark	piscivorous	Mediterranean Sea	REC0159M	pelagic	secondary	404 TL	−0.63	0.15	3	−1.04	0.16
Dalatias licha	kitefin shark	opportunistic (mainly fish)	Mediterranean Sea	REC0254M	demersal	secondary	87 TL	−0.46	0.08	5	−0.87	0.10
Carcharodon carcharias	white shark	fish, turtles, birds, mammals	unknown	-	pelagic	tertiary	300* TL	−0.74	0.07	3	−1.15	0.09
Hexanchus griseus	sixgill shark	opportunistic (inc. dead mammals)	Mediterranean Sea	REC0201M	demersal	tertiary	58 TL	−0.66	0.06	3	−1.07	0.08
Hexanchus griseus	sixgill shark	opportunistic (inc. dead mammals)	Mediterranean Sea	REC0204M	demersal	tertiary	200 TL	−0.68	0.13	3	−1.09	0.14
Carcharodon carcharias	white shark	fish, turtles, birds, mammals	Mediterranean Sea	REC0610M	pelagic	tertiary	max 400* TL	−0.78	0.12	4	−1.19	0.13
Mysticete indet.	whale (vertebra)	plankton	unknown	ISEM-no num	pelagic	zooplanktivore	-	−0.12	0.10	5	−0.53	0.12
Dugong dugon	dugong (tooth)	seagrass	unknown	N170	coastal	herbivore	-	−0.67	0.10	3	−1.08	0.12
Dugong dugon	dugong (bone)	seagrass	unknown	N170	coastal	herbivore	-	−0.83	0.05	4	−1.24	0.08
Odobenus rosmarus	walrus (enamel)	invertebrates, fish	unknown	N374	coastal	omnivore	-	−0.86	0.09	4	−1.27	0.11
Odobenus rosmarus	walrus (bone)	invertebrates, fish	unknown	N374	coastal	omnivore	-	−1.07	0.16	4	−1.48	0.17
Tursiops truncatus	dolphin (tooth)	mainly fish	unknown	ISEM-no num	pelagic	piscivore	-	−1.33	0.07	5	−1.74	0.09
Tursiops truncatus	dolphin (bone)	mainly fish	unknown	ISEM-no num	pelagic	piscivore	-	−1.64	0.11	4	−2.05	0.13
Fossil												
Sphyraenidae indet	barracuda	-	Early Pliocene, Libya	ALA 041	-	primary[1]	max. 100* TL	−0.61	0.13	5	−1.02	0.14
Sparidae indet.	seabream	-	Early Pliocene, Libya	ALA 042	-	primary[1]	max. 200* TL	−0.44	0.08	3	−0.85	0.10
Myliobatis sp.	shell-crushing ray	-	Early Pliocene, Libya	ALA 040	-	primary[1]	max. 70* DW	−0.45	0.05	2	−0.85	0.08
Carcharodon carcharias	white shark	-	Early Pliocene, Libya	ALA 005	-	tertiary[1]	450** TL	−0.72	0.09	5	−1.13	0.11
Megaselachus megalodon	megalodon	-	Early Pliocene, Libya	ALA 001	-	tertiary[1]	700*** TL	−0.87	0.13	5	−1.28	0.14
Megaselachus megalodon	megalodon	-	Pliocene, New Caledonia	-	-	tertiary[1]	900*** TL	−0.87	0.08	3	−1.28	0.10