Senonian Elasmobranch teeth from Israel Biostratigraphic and paleoenvironmental implications

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With 2 figures in the text

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Abstract: Rich and varied Elasmobranch (Neoselachii) tooth associations were collected from Late Santonian to Middle Maastrichtian phosphatic beds in south-eastern Israel, improving our knowledge of the local fossil record and contributing to the biostratigraphic and the paleoecologic analyses of these Senonian deposits. The position of the Campanian-Maastrichtian boundary in Israel is briefly discussed.

Zusammenfassung: Arten- und individuenreiche Zahn-Faunen von Neoselachii aus Phosphatlagen des Santoniums bis Mittleren Maastrichtiums in Südost-Israel tragen zur genaueren Kenntnis der jungmesozoischen Wirbeltierfaunen dieser Region und zur biostratigraphischen und palökologischen Analyse der Ablagerungen bei.

Résumé: Des associations riches et variées de dents d'Elasmobranches (Neoselachii), récoltées dans des niveaux phosphatés du Sud-Est d'Israël s'étageant du Santonien terminal au Maastrichtien moyen contribuent à une meilleure connaissance des vertébrés fossiles de cette région et à une analyse biostratigraphique et paléoécologique de ces dépôts sénoniens.

Introduction

Layers of phosphatic chalk and phosphorites are quite common in the Senonian (Late Cretaceous) sequence of central and southern Israel (e.g. NATHAN et al. 1979, REISS et al. 1985). In addition to the phosphatic peloids and the bone fragments in these deposits, teeth of various marine fishes and reptiles may occur. Previous studies on the Senonian stratigraphy in Israel have mentioned the occurrence of fish teeth, especially the large ones (over 1 cm), which were easily collected in the field (e.g. A. PARNES, in REISS 1962). Such an assemblage of large marine fish and reptile teeth from the Zefa-Ef'e phosphate field (Fig. 1) was described and illustrated by RAAB (1963). The teeth studied by this author originate from the uppermost phosphate bed (No. V) at the top of the Mishash Formation (herein level 4; Fig. 2). They belong to eight teleost fish species and to four elasmobranchs: *Lamna biauriculata ?maroccana*, *L. caraibaea ?africana*, *Corax pristo-*

dontus and *C. kaupi*. In 1967 RAAB described a nearly complete lower jaw of *Enchodus elegans* DARTEVELLE & CASIER from a phosphatic chalk layer in the middle part of the Menuha Formation (underlying the Mishash Fm.; herein level 1; Fig. 2) at Wadi El Qilt (east of Jerusalem; Fig. 1).

During the detailed survey of the Senonian phosphate deposits in Israel (e.g. NATHAN et al. 1979; with references) other levels with concentrations of fish teeth were discovered apart from the sporadic occurrence of such teeth throughout the Upper Campanian – Lower Maastrichtian phosphatic sequence of the Mishash Formation and the lower part of the overlying Ghareb Formation (Fig. 2). The fish teeth collected from certain levels during the present study range from the latest Santonian to the Middle Maastrichtian. Many species new for Israel were identified (by H. CAPPETTA), contributing to the biostratigraphy of these fishes in comparison with records from the neighbouring countries and North Africa (ARAMBOURG 1952; AVNIMELECH 1949, 1957; DOMINIK & SCHAAL 1984; GEMMELLARO 1920; SIGNEUX 1959a, b).

The present report will be followed by a comprehensive paleontological study (by H. CAPPETTA).

The investigated succession

The sampled levels of the the present study exhibit several sedimentological affinities by which they can be traced over large distances within the same stratigraphic position. Thus they represent regional sedimentological events as a result of regional or global causes.

The lowermost level (1) is a chalky phosphate bed usually overlying marl with the Late Santonian *Spinaptychus spinosus* (COX), and underlying chalk of Early Campanian age (*Globotruncanita elevata* Zone). In other regions this phosphatic layer separates a lower (Santonian) from an upper (Campanian) chalk sequence of the Menuha Formation without an intermediate marly unit, forming a good guide level close to the Santonian-Campanian stage boundary. Local sedimentological evidence suggests that the phosphatic layer represents the peak of a regional shallowing event, probably during earliest Campanian times. The marly unit which yielded most of the fish teeth at Nahal Gemalim (level 1 a, 3 kms south of the Zefa-Ef'e site; Fig. 1) contains *Dicarinella asymetrica* (SIGAL) of Late Santonian age. In all other localities of level 1 the teeth originate from the phosphatic chalk only. The localities sampled are in Nahal Hazera near Makhtesh Hazera (1 b), near the Nahal Zin phosphate plant (1 c) and in Nahal Kabir (1 d; northwest Makhtesh Ramon; Fig. 1).

Level 2 is a phosphate bed (No. 0) at the base of the Phosphate Member of the Mishash Formation, overlying the Chert Member (Fig. 2). The upper part of the Chert Member in central and southern Israel consists of brecciated chert, exhibiting in places an irregular upper surface bored by bivalves (before silicification) and overlain by a conglomerate of chert pebbles cemented by phosphate (Lewy 1985). Thus the phosphate bed (No. 0) above the Chert Member represents shallow marine, high-energy conditions at the beginning of a relative sea-level rise. This phosphate layer was sampled 12 kms southwest of the Oron phosphate plant (Fig. 1; Israel grid coord. 1427/0268).

Level 3 is a phosphate layer (No. II) at the base of the Phosphorite Unit (upper Mishash Fm., Fig. 2), starting the main phase of phosphorite accumulation. The rather few specimens (and thus the low specific diversity) collected result from the small size of this single fossiliferous outcrop at Nahal Zinim (southwest of Oron, coord. 1411/0204; Fig. 1).

Level 4 actually represents two successive levels which seem to have been joined together into a single layer in the Zefa-Ef'e region (Fig. 1), from where Raab (1963) described his material. In the Oron region (8 kms southwest of the Oron phosphate plant; coord. 1442/0301) and in Nahal Zin (near the phosphate plant, coord. 1568/0272) abundant fish teeth occur at the very top of phosphate layer No. V (top Mishash Fm.) and in the lower phosphatic chalk of the overlying Ghareb Formation. Most of the teeth are found lying free on the hard phosphorite but a few stick out from it.

Phosphate layer V in the Oron and Nahal Zin regions, 80–100 cm thick, directly overlies a more finely laminated phosphate layer (IV) of the same thickness, in which *Lyropecten (Aequipecten) acuteplicatus* (Alth) (= *Pecten farafrensis* Zittel) first appears, known in Europe from the Maastrichtian only (Dhondt 1972). In southern Israel it overlies another phosphate complex of 3 m, which decreases in thickness northwards to a few centimeters in the Oron region. Calcareous beds in this complex contain *Baculites* cf. *B. anceps* Lamarck (ornate form).

The basal part of the Ghareb Formation also contains bones and teeth so we have to assume that the assemblage as collected at level 4 is a mixture of the above mentioned closely connected levels of two successive formations. However, this interval represents a short period at the end of high-energy conditions (top phosphorite) and the beginning of relative sea-level rise (increase of planktic elements).

Level 5 occurs in the upper part of the Oil Shale Member, lower Ghareb Formation. This level is characterized by the occurrence of phosphate nodules, phosphatized invertebrate moulds and vertebrate remains, indicating increase in water energy and improved living conditions for benthic organisms (normal aeration) during late Early Maastrichtian times.

At Nahal Zin a higher level with a concentration of phosphate nodules occurs 6–8 m above the lower level. This latter level contains the brachiopod *Gyrosoria gracilis* (Schlotheim) of Maastrichtian age (sensu NW European stratigraphers; Surlyk 1984), other benthic invertebrates and very few fish teeth. The presence

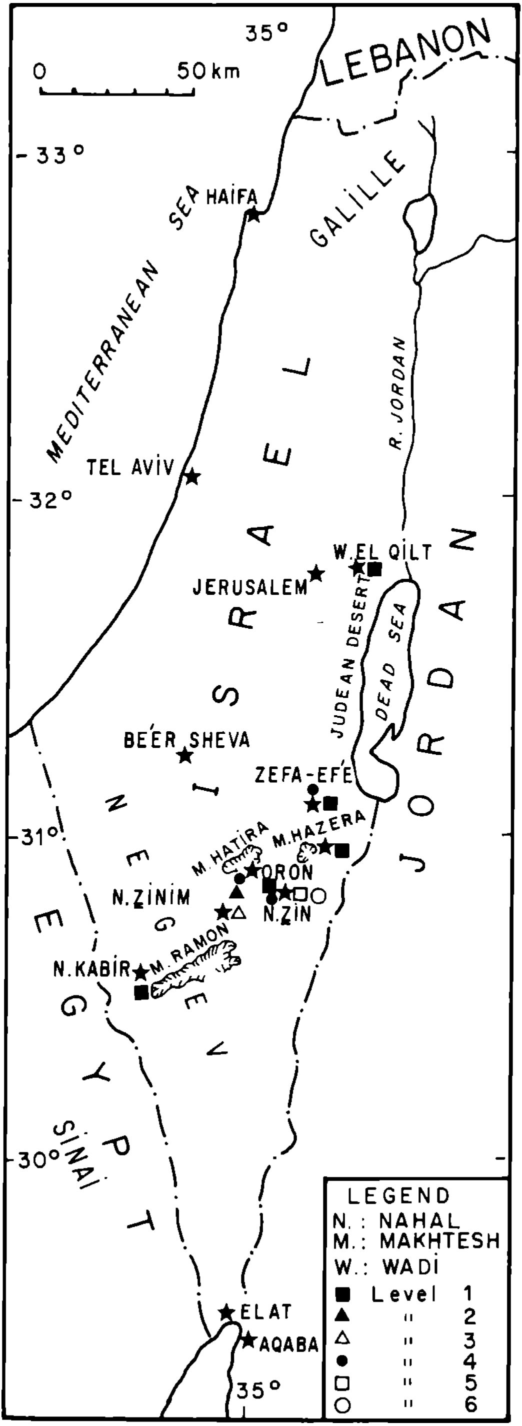

Fig. 1. Location map of the levels sampled.

of the planktic foraminifer *Gansserina gansseri* (BOLLI) indicates a Middle Maastrichtian age.

Faunal content

A few hundred teeth belonging to 45 selachian species were obtained by field surface collecting and from washed and sieved sediment sampled at the above mentioned sites. Fig. 2 presents the stratigraphic distribution of these shark and ray species, whereas the associated teleost teeth (mainly Enchodontidae and some Trigonodontidae) are not dealt with in this study.

Bio- and chronostratigraphy

Level 1 (phosphate bed, middle Menuha Fm.) is characterized by the occurrence of *Microcorax* sp., *Squalicorax kaupi, Pseudocorax* aff. *granti, Galeorhinus* sp. and *Scapanorhynchus* aff. *rapax;* large *Cretolamna* and *Squalicorax pristodontus* are missing. Compared to faunas known from Texas (CAPPETTA & CASE 1975) and Morocco (CAPPETTA 1987) this assemblage in sites 1 b–d suggests an Early Campanian age, as also derived from the micropaleontological data (REISS et al. 1985). The faunal assemblage of the level 1 a (Latest Santonian) is less rich but not different from those of the levels 1 b–d; yet, it must be pointed out that it contains the most ancient *Ganopristis* collected untill now.

Level 2 (Phosphate Bed No. 0) contains many *Squalicorax pristodontus* of small and medium size, whereas large *Cretolamna* teeth are missing. Although this assemblage can be easily distinguished from that of the other levels it does not contain age-indicative elements. Its Late Campanian age is indicated in other regions where the last *Hoplitoplacenticeras marroti* (COQUAND) occurs just below this phosphate bed so that this level is of the same age as the lower *Bostrychoceras polyplocum* Zone of Europe. In the Wadi El Qilt region (Fig. 1) *Globotruncanita calcarata* (CUSHMAN) first appears 10 m above this level, ranging along 8 m to the base of the Porcellanite Unit (Fig. 2).

Level 3 (base Phosphorite Unit, just above the Porcellanite Unit; Phosphate Bed No. II) is approximately of the same age as the North American *Didymoceras stevensoni* Zone (above *D. nebrascense* Zone) 6–8 m below *Anaklinoceras reflexum* STEPHENSON (in the Oron region) of the *Baculites compressus* Zone (N. America). This level occurs well above *G. calcarata* (2 million years apart) and, accordingly belongs already to the Early Maastrichtian in the sense of some micropaleontologists (e.g. ROBASZYNSKI 1987), but not as defined in northwestern Europe. These two versions of the Campanian-Maastrichtian stage boundary in the Boreal and Tethyan Provinces affect our correlations with those published records, for which the exact basis of their dating is not well known. For example, the West European exclusively Maastrichtian occurrences of *Rhombodus binckhorsti* (holotype from Upper Maastrichtian of Maastricht; DAMES 1881)

STRATIGRAPHY	SANTONIAN CAMPANIAN	CAMPANIAN			MAASTRICHTIAN		
	L Upper Lower	Upper			Lower		Middle
	MENUHA FORMATION	MISHASH FORMATION			GHAREB FORMATION		
	CHALK I MARL & PH. CHALK II	CHERT MBR PHOSPHATE MEMBER			OIL SHALE MEMBER		MARLY CHALK MEMBER
		PHOSPHATIC CARBONATES PORCELLANITE	PHOSPHORITE				
TAXA	Level 1 a, bcd	2	3	4 a	b	5	6
Ptychodus sp.	+						
Paraorthacodus aff. *nerviensis*				+	+		
Hexanchus microdon		+		+	+	+	
Hexanchus sp.							+
Squatina hassei				+			
Pristiophorus sp.				+			
Echinorhinid indet.				+			
Squalus sp.				+			
Centrosqualus sp.				+			
Cretascymnus sp.				+			
cf. *Centroscymnus*				+			
Squalicorax pristodontus		+	+	+	+	+	+
Squalicorax bassanii				+	+		+
Squalicorax cf. *kaupi*	+						
Squalicorax sp.		+	+	+	+		
Pseudocorax aff. *affinis*				+	+	+	
Pseudocorax aff. *granti*	+						
Microcorax sp.	+						
Paranomotodon sp.	+						
Scapanorhynchus rapax	+						
Scapanorhynchus cf. *raphiodon*				+			
Anomotodon plicatus				+	+		
Anomotodon sp.			+				
Cretolamna appendiculata	+			+			
Cretolamna biauriculata maroccana			+	+	+		
Cretolamna caraibaea			+	+			
Cretolamna sp		+					
Cretodus sp. (small size)		+					
Heterodontus sp.				+			
Chiloscyllium sp.		+					
Ginglymostoma sp.					+		
Pteroscyllium sp. 1				+			
Pteroscyllium sp. 2		+					
Scyliorhinus sp.		+		+			
Galeorhinus sp.	+						
Triakid 1				+			
Triakid 2				+			
Ganopristis leptodon				+	+	+	
Ganopristis sp.	+	+					
Sclerorhynchus sp.				+			
Rhinobatos sp. 1				+			
Rhinobatos sp. 2				+			
Rhinobatos sp. 3		+					
Rhinobatoidei n. g.		+		+	+		
Rhombodus binckhorsti			+			+	

Fig. 2. Stratigraphic distribution of Senonian elasmobranch teeth in southern Israel (sites in Fig. 1; levels described in the text).

suggest a Maastrichtian age for Phosphate Bed No II (Fig. 2). However, its exclusively Maastrichtian age (in the W. European sense) outside the Boreal Province is uncertain although this species was not recorded hitherto from unequivocal Campanian rocks.

The first appearance of *Belemnella lanceolata* (SCHLOTHEIM), defining the Campanian-Maastrichtian stage boundary in northwestern Europe, is associated there with the earliest *Neoflabellina reticulata* (REUSS). This latter benthic foraminifer is rather rare in Israel and its local first occurrence in the middle part of the Oil Shale Member (Ghareb Fm.; Fig. 2) in the Oron region suggested to emplace there the Campanian-Maastrichtian boundary (REISS 1962), or a few meters below, at the base of the Ghareb Formation (within level 4), where a major microfaunal change is evident (REISS et al. 1985). This latter level nearly coincides with the first appearance of *Aequipecten acuteplicatus,* common and well known in North Africa and the Middle East as *Chlamys farafrensis,* serving as a guide fossil for correlation. The exclusive Maastrichtian age of *A. acuteplicatus* in Europe (DHONDT 1972) must be confirmed in the Middle East by associated *N. reticulata.* Meanwhile, the Campanian-Maastrichtian boundary in the West European sense (followed by planktic foram zonation; ROBASZYNSKI 1987) is tentatively placed in Israel at the local first occurrence of *N. reticulata* (middle Oil Shale Mbr.; Fig. 2), requiring further study of the chronostratigraphic significance of *A. acuteplicatus* and the herein discussed elasmobranch teeth.

Paraorthacodus aff. *nerviensis* which appears in level 4 (a and b) was first described from the Upper Campanian of Belgium and later found to range into the Maastrichtian, although it does not reach the top of this stage. The cusp of the Maastrichtian Belgian teeth has stronger, longer and more prominent folds on the labial face than those from the Campanian. Accordingly, the two teeth from level 4 are closer to the Maastrichtian forms,than to the Campanian ones.

The tooth size of *Cretolamna biauriculata maroccana* from the Negev is slightly smaller than the one of the teeth occurring in the Middle and Upper Maastrichtian of Morocco. However, this species is very rare in Morocco in the Lower Maastrichtian of Oued Erguita (north of Taroudant) and is completely missing in the Lower Maastrichtian of Ganntour Basin (CAPPETTA 1987) rendering such a comparison highly questionable.

The genus *Pseudocorax* is represented in the Upper Senonian by the *P. laevis* – *P. affinis* lineage. The former species (Upper Turonian-Campanian; LERICHE 1929; HERMAN 1977) does not possess indented cutting edges. Teeth of *P. affinis,* first described from the »Tuffeau of Maastricht« (= Upper Maastrichtian) are characterized by teeth with regularly, clearly indented cutting edges. Many teeth of *Pseudocorax* occur in level 4 a (Oron), exhibiting an intermediate stage between *P. laevis* and *P. affinis,* evidenced by their irregularly and weakly indented cutting edges. This suggests an age between the Late Campanian and the Late Maastrichtian.

Teeth of *Squalicorax bassanii* occur in levels 4a at Oron and 4b at Nahal Zin (yet, they are much scarcer in the Oron region) and were reported as rather abundant in the Zefa-Ef'e region (RAAB 1963). This species has been defined by GEMMELLARO (1920) on the basis of teeth from the phosphate beds of the Nile Valley and the Red Sea (Egypt) which were regarded by him as of Maastrichtian age. Although this species is well distinguished by its peculiar morphology (strongly gibbous mesial cutting edge and broad bulge at the base of the labial face of the crown) from other species, it has been considered as a synonym of *S. kaupi* by most of authors (e.g. ARAMBOURG 1952, RAAB 1963, DOMINIK & SCHAAL 1984). In Morocco *S. bassanii* occurs in the Lower Maastrichtian only, in Ouled Abdoun and Ganntour Basins, and in Oued Erguita where it is rather abundant. DOMINIK & SCHAAL (1984) attributed this species (under the name of *S. kaupi*) from the Western Desert (Egypt) to the Upper Campanian.

Level 5 (4 m below top Oil Shale Mbr., Ghareb Fm. at Nahal Zin) yielded phosphatized moulds of *Baculites* „*anceps*“ LAMARCK like other localities in the Negev, where it is associated with the Maastrichtian *G. gracilis* (SOUDRY & LEWY 1988).

Level 6 (middle Ghareb Fm., upper nodular phosphate level at Nahal Zin) contains *G. gracilis* and the planktic foraminiferid *Gansserina gansseri* regarded as a Middle Maastrichtian guide fossil in the Tethyan Province.

According to the herein presented ranges and chronostratigraphy, the range of the genus *Pristiophorus* is extended to the latest Campanian (Early Maastrichtian?) of the southern Tethys (previously: Upper Santonian of Sahel Alma, Lebanon); the range of *Ganopristis* is extended to the Late Santonian (previously: Maastrichtian).

Palaeoecology and palaeogeography

The diversity and abundance of the herein recorded taxa is undoubtedly affected by the nature of the rock in which these teeth occur or weather-out, as well as the time spent for collecting. Nevertheless we dare to point out a few ecological aspects which agree with the sedimentological and structural setting.

The elasmobranch association of levels 1–3 characterizes neritic paleoenvironments. Such shallow marine, rather high-energy environment of deposition for these levels was suggested by the detrital nature of these phosphates, representing sea-level low stands: in earliest Campanian times (level 1) close to the North American R-7 lowstand (KAUFFMAN 1977); at the beginning of the Late Campanian transgression over a partly exposed shelf (on top Chert Member, Mishash Fm., level 2), and at the beginning of the main phase of phosphorite accumulation (level 3).

The two samples (a, b) of level 4 exhibit different ecological aspects: The richest and most diverse tooth assemblage of level 4a was collected southwest of

Oron (Fig. 1). It (4 a) is characterized by a diversified association of Squaliformes: five species belonging to different genera; the occurrence of *Centrosqualus*, *Cretascymnus*, cf. *Centroscymnus* and echinorhinids suggest rather deep water of the order of 150–300 m. The abundance of hexanchids and *Pseudocorax*, the occurrence of *Pristiophorus*, and the relative scarcity of batoids strengthen this bathymetric interpretation. *S. bassanii* is poorly represented in this site whereas in Nahal Zin (4 b) it is rather common and squaliforms and hexanchids are much scarcer. These differences in the faunal composition and abundance in level 4 of both sites (a, b) suggest shallow marine, rather neritic conditions at Nahal Zin (4 b) in contrast to much deeper waters in the Oron region (4 a).

The main pattern of the present-day structural configuration of central and southern Israel was created during the Senonian-Early Tertiary times when the Syrian Arc System (KRENKEL 1924) was developed by folding and some faulting. Younger movements tilted some areas, mainly in connection with the rifting of the Arava - Dead Sea region. Some of the Late Senonian structures were exposed as islands and exhibit to day ancient shorelines and onlapping Senonian-Early Tertiary sediments. The present elevation of the Late Campanian-Early Maastrichtian shoreline close to the Oron region is about 500–550 m (e.g. Har Teref, 13 kms south of the Oron 4 a site, and approximately same height on the flanks of the Hafira anticline NW the Oron syncline) whereas the coeval sediments (level 4) in the Oron region lie at 290–300 m. Since folding proceeded into the Early Tertiary a smaller depth than 200 m should be assumed for the Late Senonian basin in the Oron region.

The phosphorite bed at the top of the Mishash Formation in the latter region shows concentration of detrital particles by winnowing. The similar character and thickness of this bone-phosphorite in Nahal Zin suggests the dispersal by currents of these components over the rather flattened sea bottom. A Recent analog for such „deep" marine currents (perhaps during short intervals) has been reported from depth of several tens of meters (50–70) to nearly 200 m off the West African coast (off Mauritania; EINSELE et al. 1977: 3, LEWY 1975). The gradually increasing abundance of planktic forams along the lower part of the Ghareb Formation, overlying the phosphorite in the Oron region (REISS et al. 1985), supports a bathymetry of approximately 60–80 m for the deposition of the phosphorite and over 100 m for the lower Ghareb Formation.

This phosphorite bed at the top the Mishash Formation in the Nahal Zin region contains large *Pycnodonte vesicularis* (LAMARCK) with very thick left valves (25–40 mm) in contrast to the rare occurrence of this oyster known by small, thin shelled specimens in the Oron region. This difference suggests high-energy and high rate of sedimentation (or agitation) for the habitat at Nahal Zin, where *P. vesicularis* had to grow faster above the bottom. Thereby it increased the curvature and thus the volume of the left valve which had to be compensated by the filling of the valve's interior with additional deposits. These deposits increased the weight and the sinkage-rate, enhancing upwards growth, and so on and so forth, resulting in large, thick-shelled specimens (LEWY 1976). The ecological interpretation of the differences in the *P. vesicularis* populations of both regions and the teeth assemblages suggest that the Late Senonian basin in the Oron region was deeper (60–80 m or more) than in Nahal Zin (about 40–60 m). This is less than depth interpreted from the shark assemblages; however, it seems that models of open, deep marine environments are not applicable to protected basins on the shelf where high productivity prevailed, attracting these sharks, as is the case of the Senonian of the Negev.

Regarding the more regional paleobiogeography, it is the first record of the palaeospinacid genus *Paraorthacodus* from the southern Tethyan Province. The rich association of Anacoracidae with the abundant *Pseudocorax* aff. *affinis* oppose the previous assumption on the general scarcity of this genus in the south Tethyan Province; locally it can be abundant as a result of suitable environmental conditions.

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