What Does a Radiometric Date Mean?

At high temperatures, isotopes in a crystal lattice vibrate so rapidly that chemical bonds can break and reattach relatively easily. As a consequence, parent and daughter isotopes escape from or move into crystals, so parent-daughter ratios are meaningless. Because radiometric dating is based on the parent-daughter ratio, the "radiometric clock" starts only when crystals become cool enough for both parent and daughter isotopes to be locked into the lattice. The temperature below which isotopes are no longer free to move is called the **closure temperature** of a mineral. The closure temperature is typically significantly cooler than the melting temperature of a mineral. Not all minerals have the same closure temperature; for example, the closure temperature of hornblende (an amphibole) is higher than that of biotite (a mica). When we specify a radiometric date for a rock, we are defining the time at which a specific mineral in the rock cooled below its closure temperature.

With the concept of closure temperature in mind, we can interpret the meaning of radiometric dates. In the case of igneous rocks, radiometric dating tells you when a magma or lava cooled to form a solid, cool igneous rock. In the case of metamorphic rocks, a radiometric date tells you when a rock cooled from the high temperature of metamorphism down to a low temperature. If a rock cools quickly (as when a lava flow freezes), then all minerals yield roughly the same age, but if a rock cools slowly (as when a pluton cools slowly at depth in the Earth), minerals with high closure temperatures give older ages than minerals with low closure temperatures.

Can we radiometrically date a sedimentary rock directly? No. If we date the minerals in a sedimentary rock, we determine only when the minerals making up the sedimentary rock first crystallized as part of an igneous or metamorphic rock, not when the minerals were deposited as sediment or when the sediment lithified to form a sedimentary rock. For example, if we date the feldspar grains contained in a granite pebble in a conglomerate, we're dating the time when the granite cooled below feldspar's closure temperature, not when the pebble was deposited by a stream. The age of mineral grains in sediment, however, can be useful. In recent years, geologists have undertaken studies to determine the ages of detrital (clastic) grains; by doing so, they can learn the age of the rocks in the region where the sediment originated.

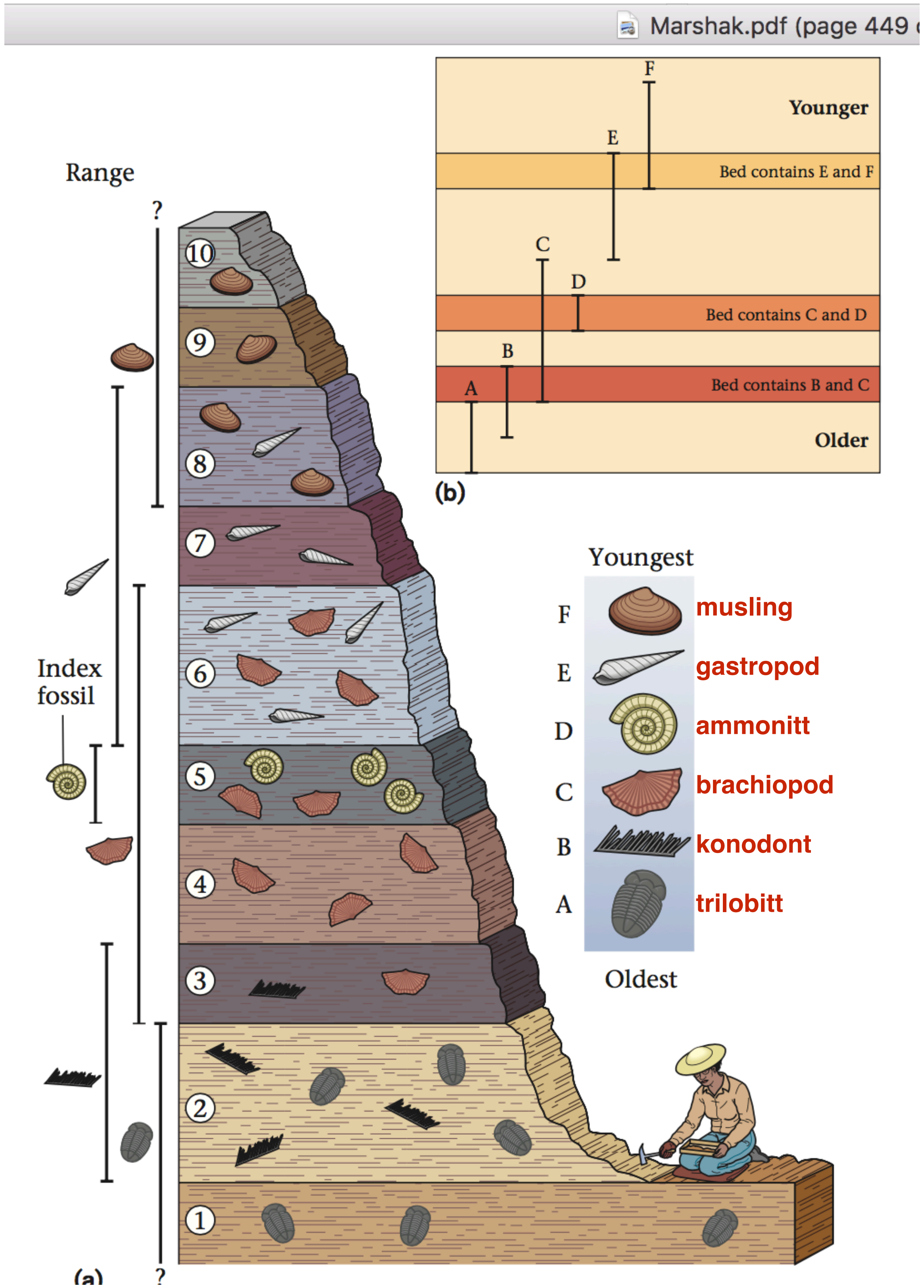
Om systemet er "åpen" eller "lukket" avhenger i stor grad av temperatur. "*Closure temperature*"

(Husk bussmodellen. Hvis temp er høy, åpnes vinduene.)

Parent	Daughter	$t_{1/2}$	Useful Range	Type of Material
^{238}U	^{206}Pb	4.5 b.y	>10 million years	Igneous Rocks and Minerals
^{235}U	^{207}Pb	710 m.y		
^{232}Th	^{208}Pb	14 b.y		
^{40}K	^{40}Ar & ^{40}Ca	1.3 b.y	>10,000 years	
^{87}Rb	^{87}Sr	47 b.y	>10 million years	
^{14}C	^{14}N	5,730 y	100 - 70,000 years	Organic Material

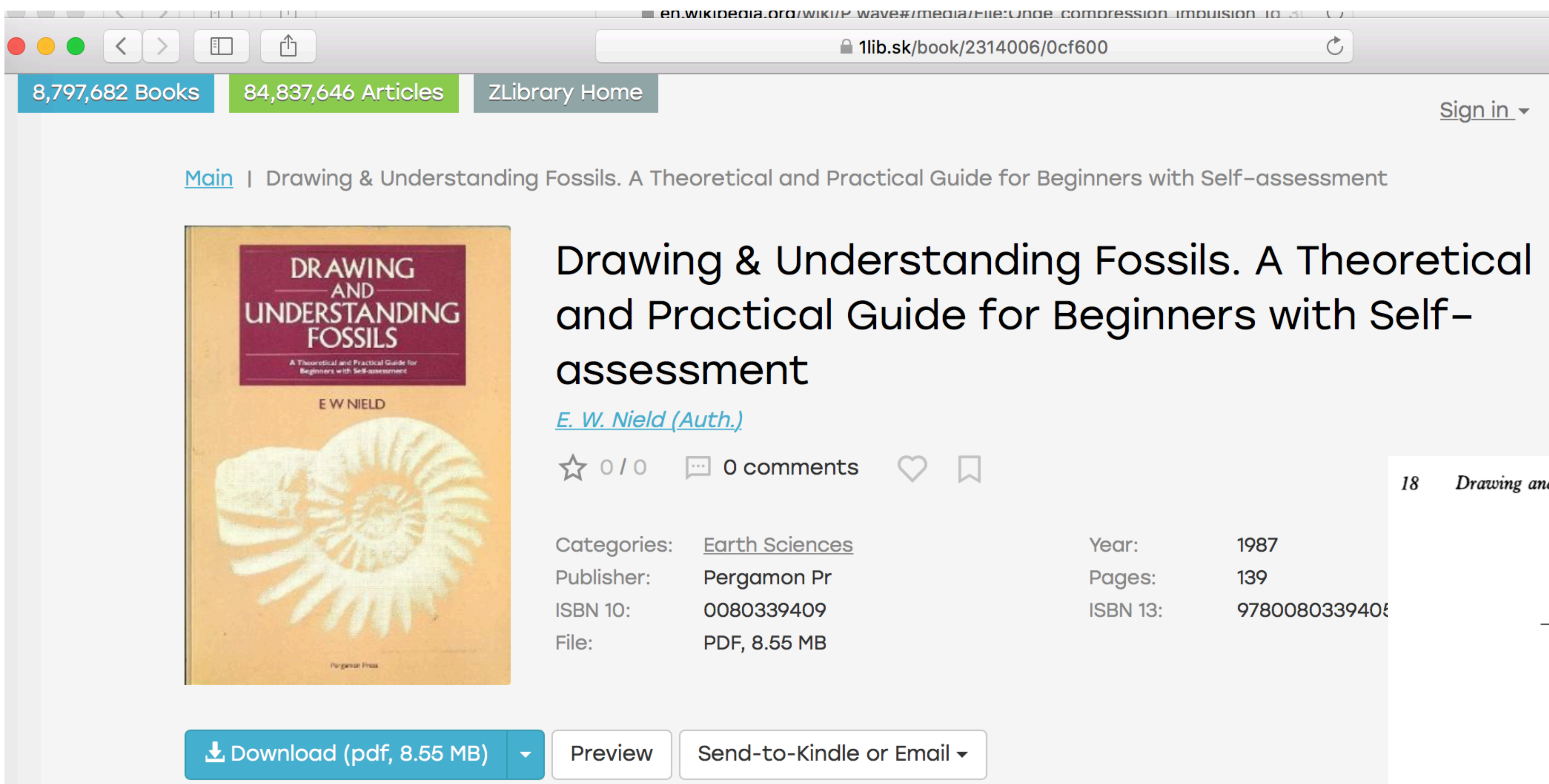
Karbon 14 datering er best kjent hos folk flest.
Men 14C halveringstid er for kort for geologi.
Kan ikke datere noe som er eldre enn ca. 10 halveringstider.
Så ved mer enn ca 57000 år er 14C ikke brukbar.
14C er godt egnet for arkeologi og organisk material.

Vanlige makrofossiler som geologer kjenner til



(Fra forelesning F15)

Det er en lang tradisjon med tegning av fossiler i geologi.



18 *Drawing and Understanding Fossils*

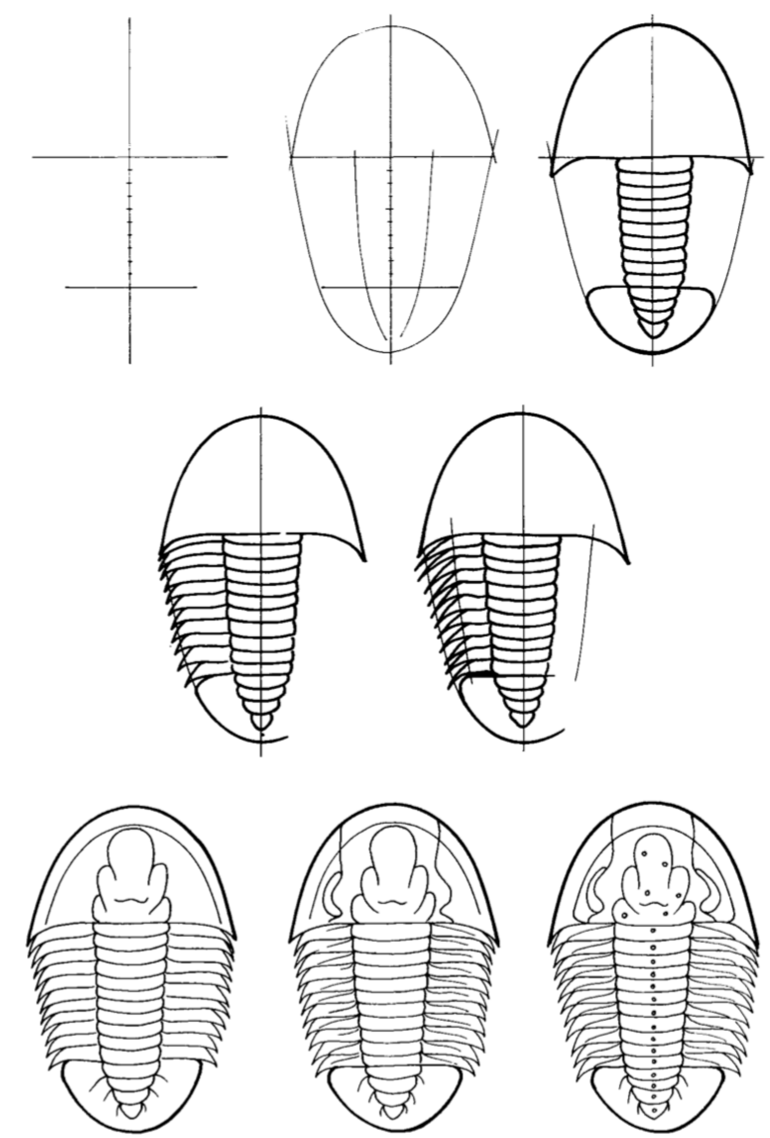


Fig. 4.4. Drawing a trilobite.

Fossiloppgave. Alle skal tegne disse 16 fossilene på et A4 ark

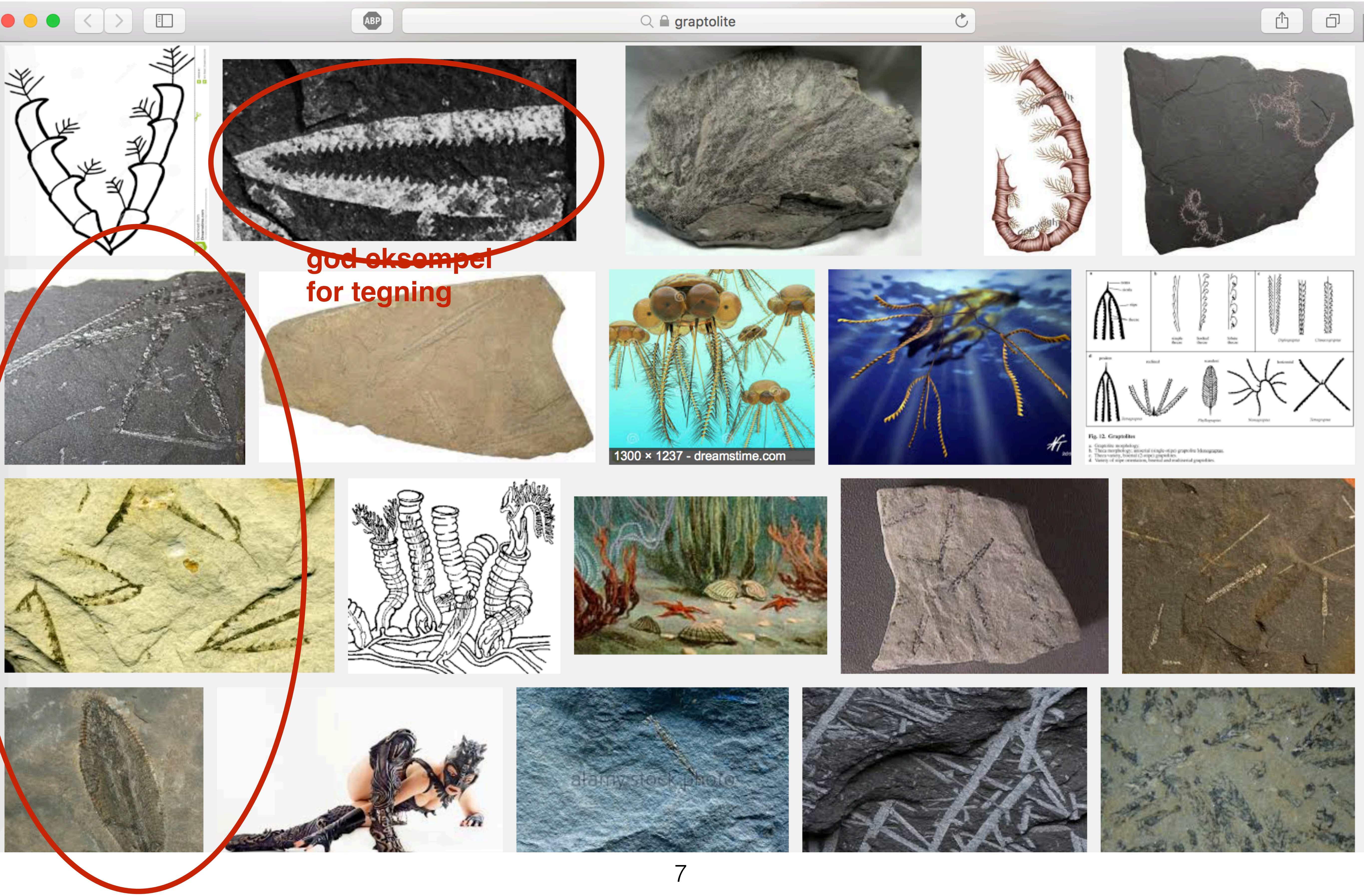
Brett A4 ark i 16 ruter. Tegn fra et foto, ikke tegn fra tegninger. (Vær original: ikke tegn fra mine eksempler.)

Send bilde av ditt A4-ark med dine originale tegninger til: krill@ntnu.no .

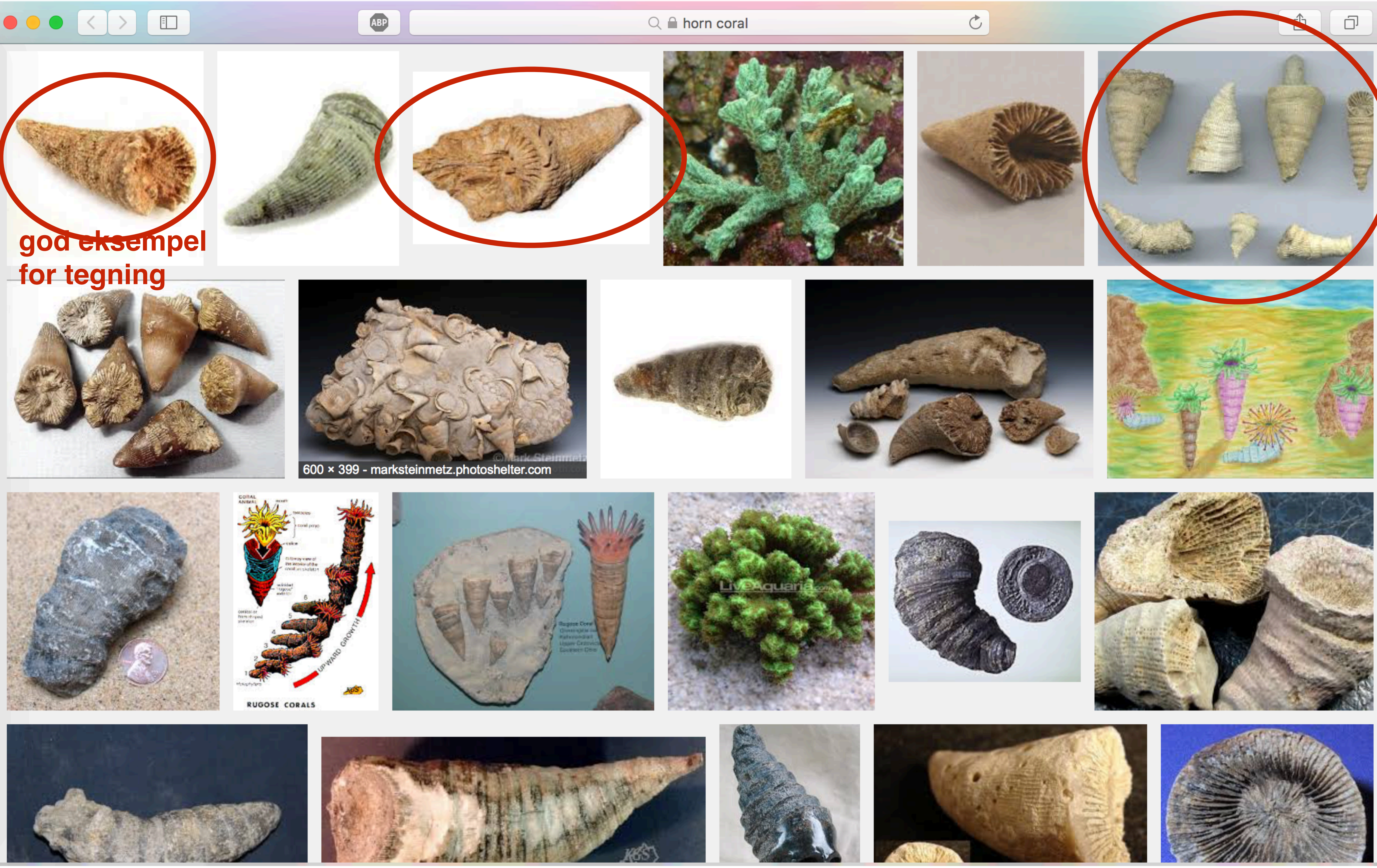
trilobitt havdyr med tre kroppsdeler, mest i kambro-silur, utdødd slutt paleozoikum
graptolitt kolonidyr, mest i ordovicium, utdødd slutt paleozoikum
hornkorall enkelkorall (korall i "enebolig")
bikakekorall kolonikorall (koraller i "blokkleiligheter")
ortoceras ikke-spiral blekksprut, utdødd slutt paleozoikum
ammonitt spiral blekksprut, utdødd slutt mesozoikum
belemnitt blekksprut med missil-lignende haleballast, utdødd slutt mesozoikum, beslektet med akkar
brachiopode overskall er større enn underskall, men begge er symmetriske, vanlig i paleozoikum
musling høyre og venstre skall er speilvendt, vanlig i mesozoikum, kenozoikum
snegler (gastropode) både marine og ferskvannsfossiler er vanlige
echinoid som kråkebolle, de fleste lever faktisk under sediment, 5-punkts symmetri
crinoid / "sjøliljer" oppdelte stilker (ossicles) er vanlige fossiler, 5-punkts symmetri
haitann vanlig marine fiskefossiler, kenozoikum (hai har brusk i stedet for bein, og mister tennene lett)
nummulitt en typ foraminifer, som vanligvis er mikrofossil, men nummulitter var gigantiske
konodont mikrofossil "tenner" til mystisk "konodontdyr" (selve dyret er ikke bevart som fossiler)
kokkolitt mikrofossil som utgjør krittstein, består av $CaCO_3$

trilobitt havdyr med tre kroppsdeler (hodeskjold, thorax, haleskjold), mest i kambro-silur, utdødd slutt paleozoikum

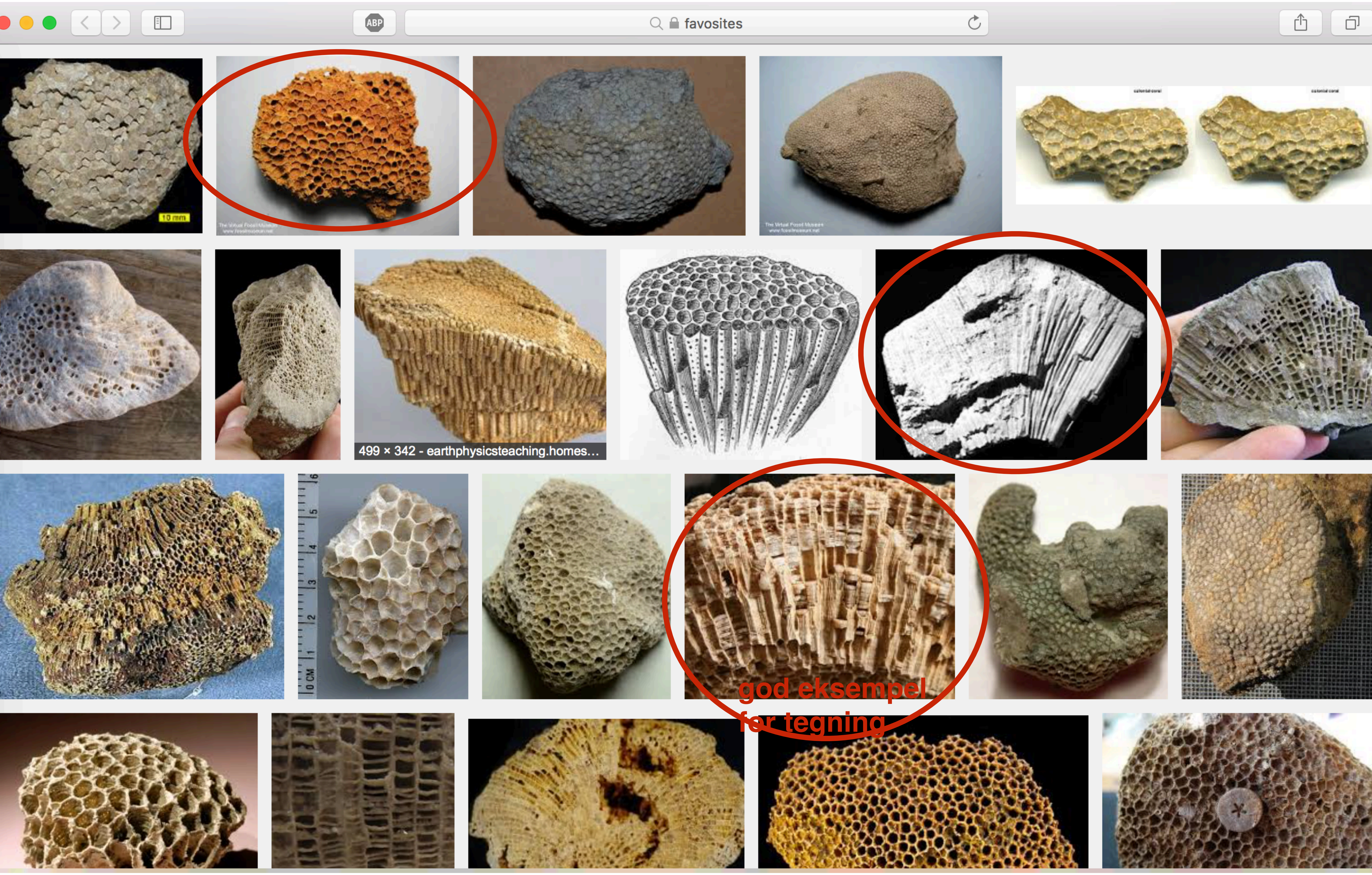
graptolitt kolonidyr, mest i ordovicium, utdødd slutt paleozoikum.
Et graptolittdyr (zooid) bor i hvert theca (som ser ut som et sagbladtann)



hornkorall enkelkorall (koralldyr i “enebolig”)



bikakekorall kolonikorall (koraller i “blokkleiligheter”, ett zooid bor i hvert hull)



Blekkspruter (heter også cephalopoder, som betyr “hodefotinger”)

ammonitt spiral blekksprut, utdødd med dinosaurene, slutt mesozoikum
ortoceras rett (ikke spiral) blekksprut, utdødd slutt paleozoikum
belemnitt blekksprut med missil-lignende haleballast, utdødd med dinosaurene, slutt mesozoikum

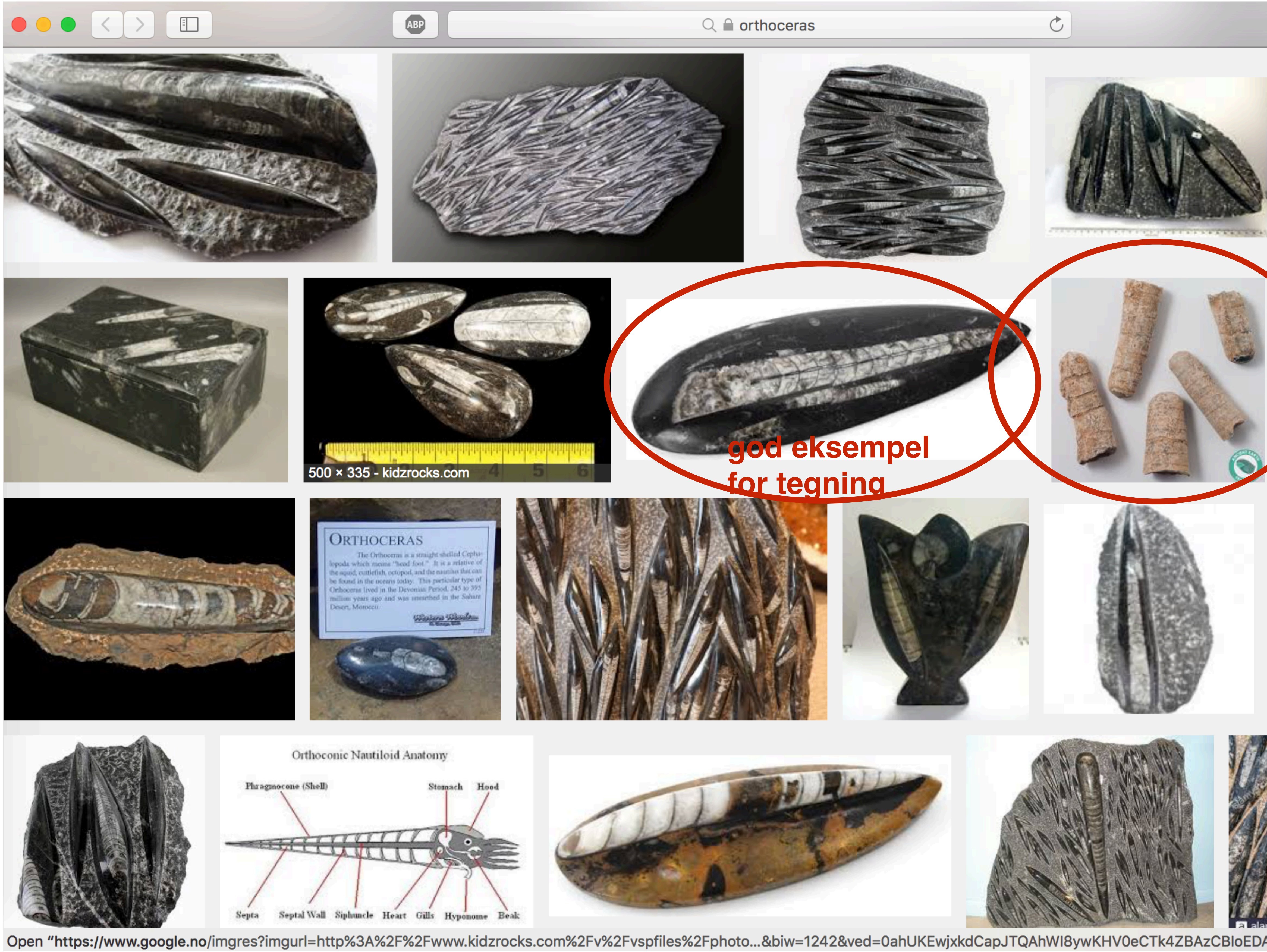
Merkelig nok, døde ikke Nautilus bleksprutt ut.
Den lever i Det Indiske Havet ved Australia.
Er nær beslektet med ammonitt,

https://www.youtube.com/watch?v=hcyzr3zJol4
(nautilus svømmer rundt)

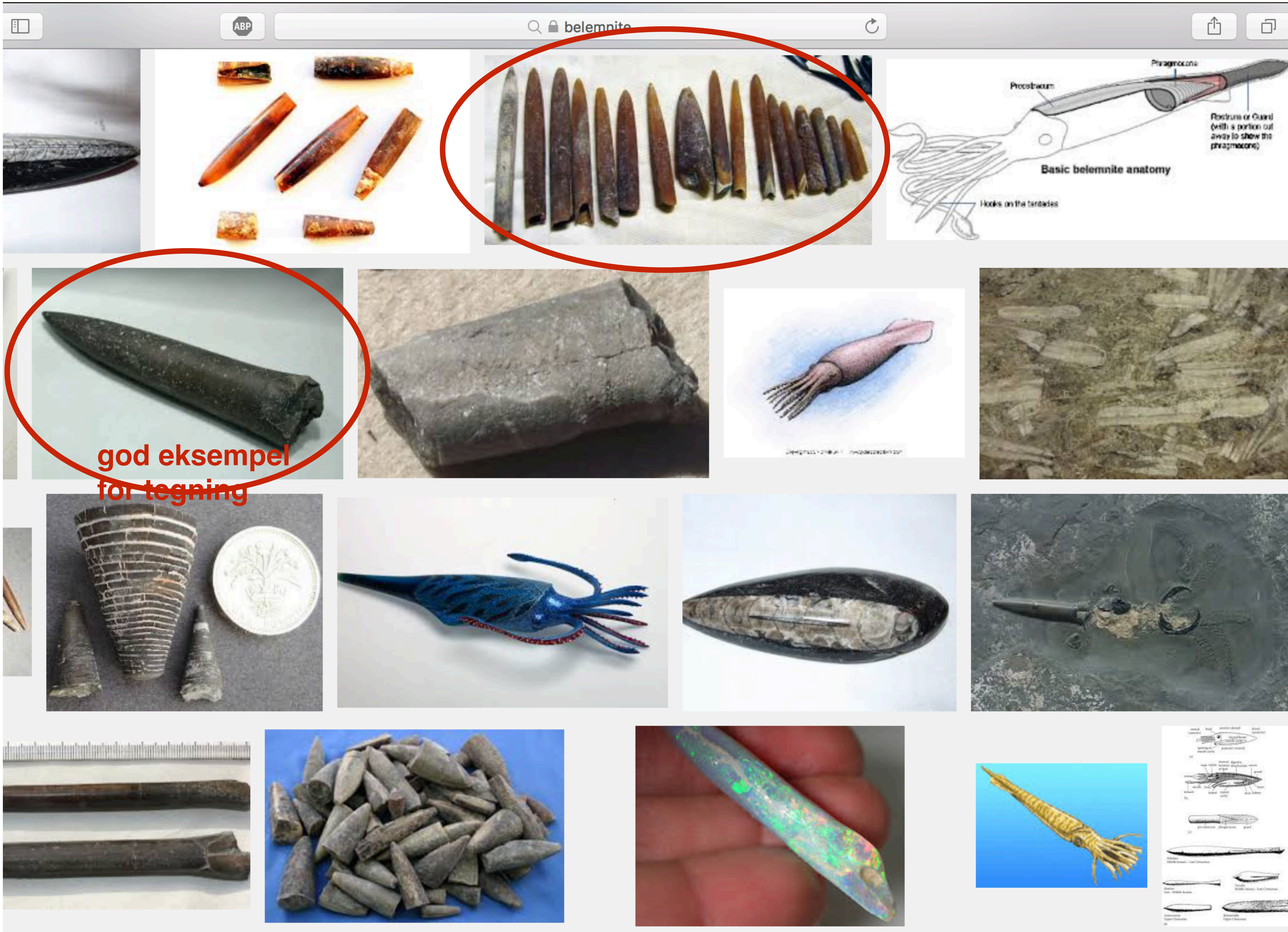
https://www.youtube.com/watch?v=vR6G-ANma1w
(nautilus spiser krill)

ammonitt spiral blekksprut, utdødd slutt mesozoikum

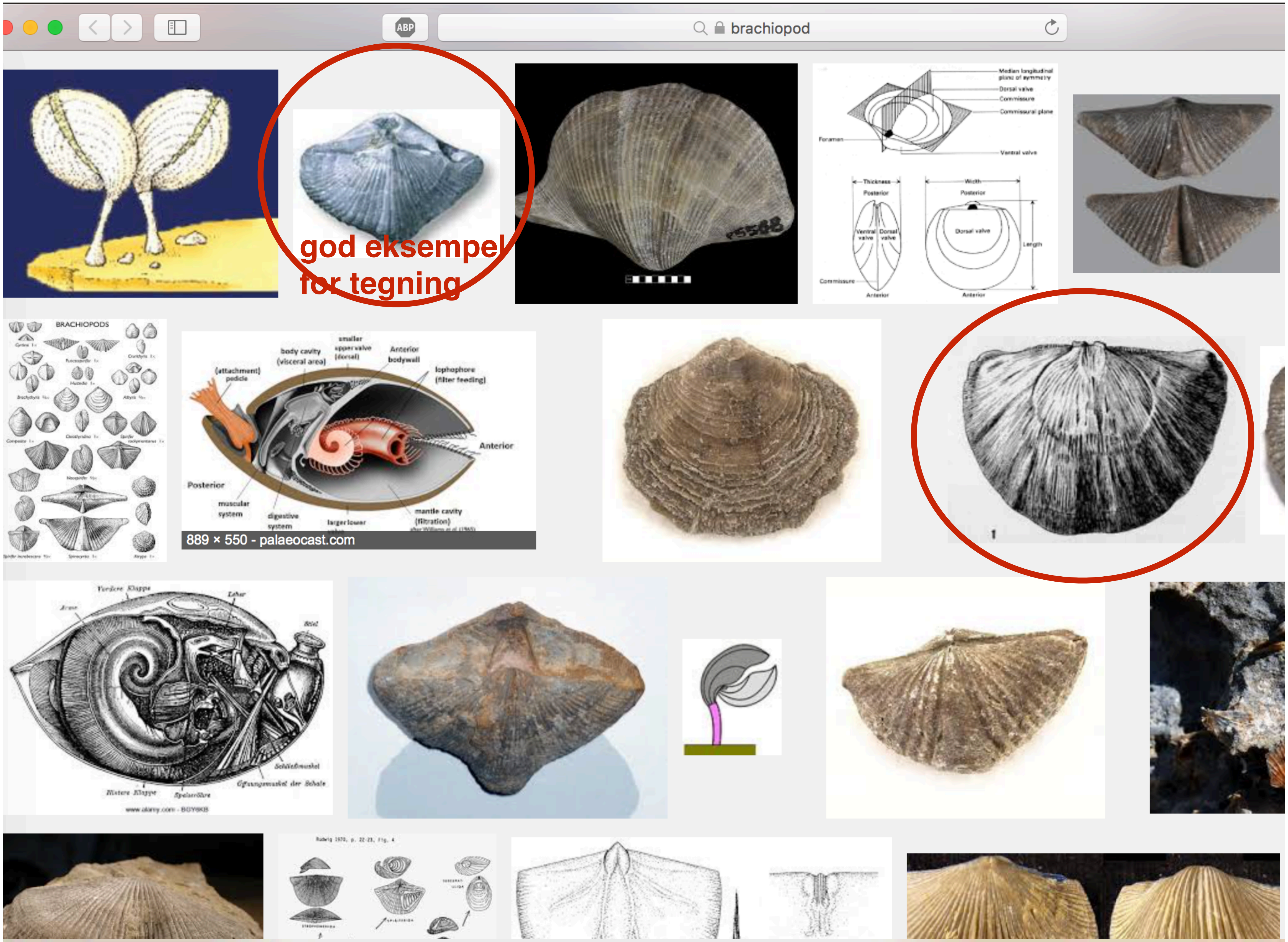
[ortoceras](#) rett (ikke spiral) blekksprut, utdødd slutt paleozoikum



belemnitt blekksprut beslektet med akkar, med missil-lignende haleballast, utdødd slutt mesozoikum

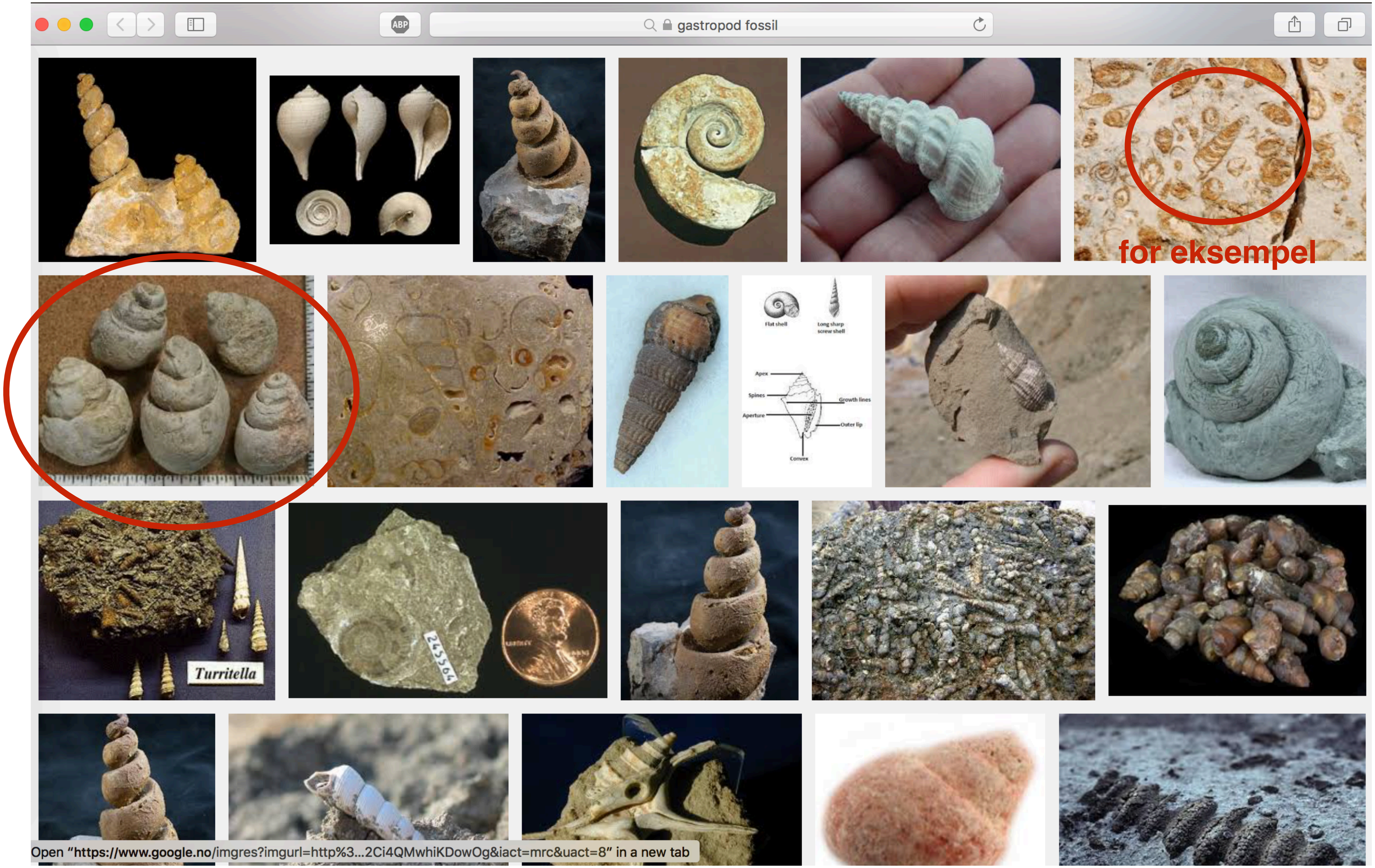


[brachiopode](#) har to skall. **Overskall** er større enn **underskall** og har et hull for en kjøttarm som festes til hvabunnen. Begge skall er symmetriske. Vanlig i paleozoikum

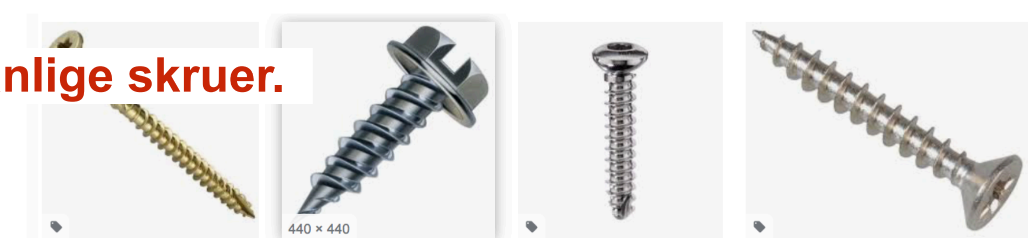


musling har to skall. **Høyre** og **venstre** skall er speilvendt. Vanlig i mesozoikum og kenozoikum

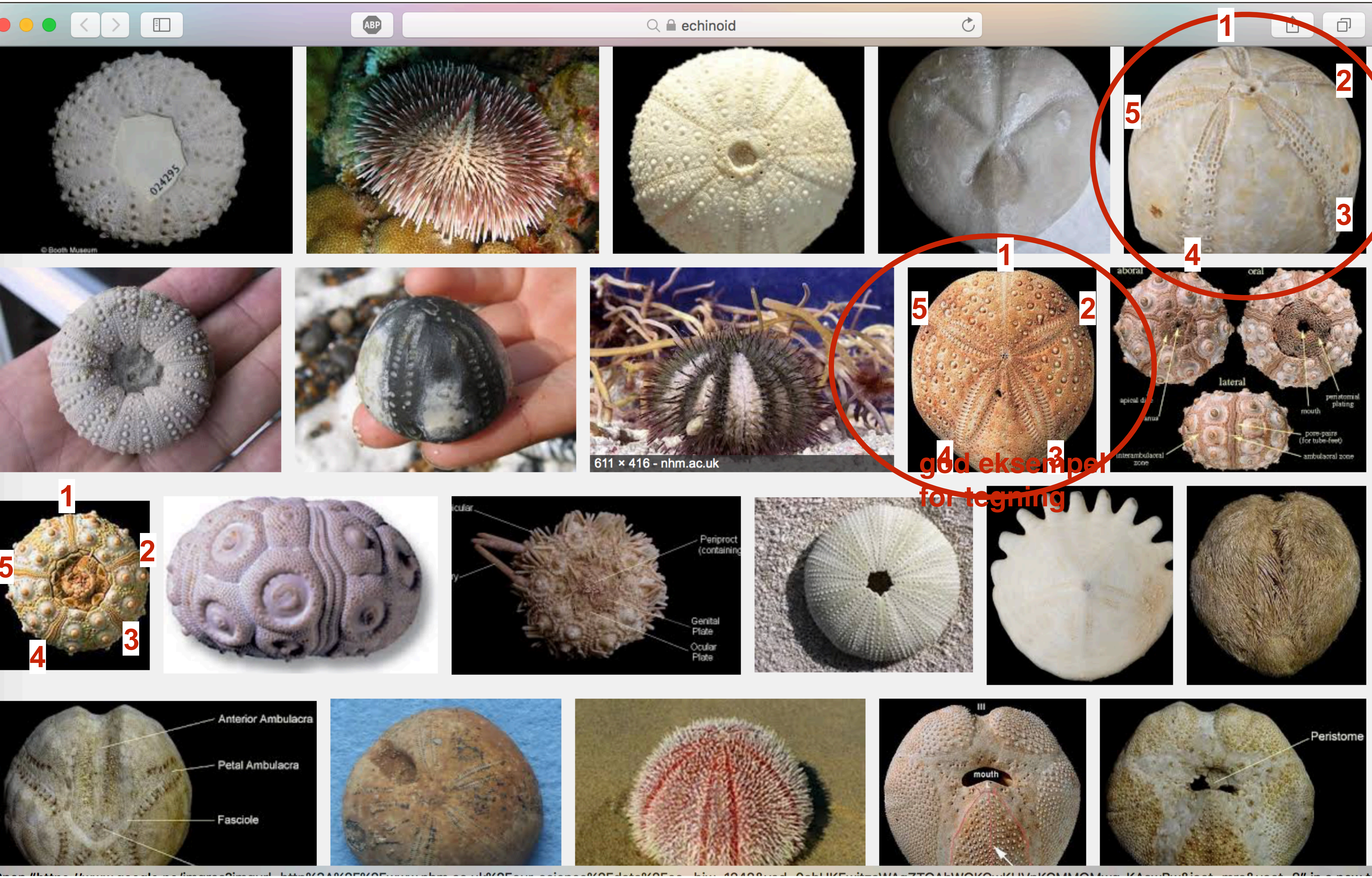
[snegle](#) (heter også gastropoder, som betyr magefotinger). Marine eller ferskvann eller terrestrisk.



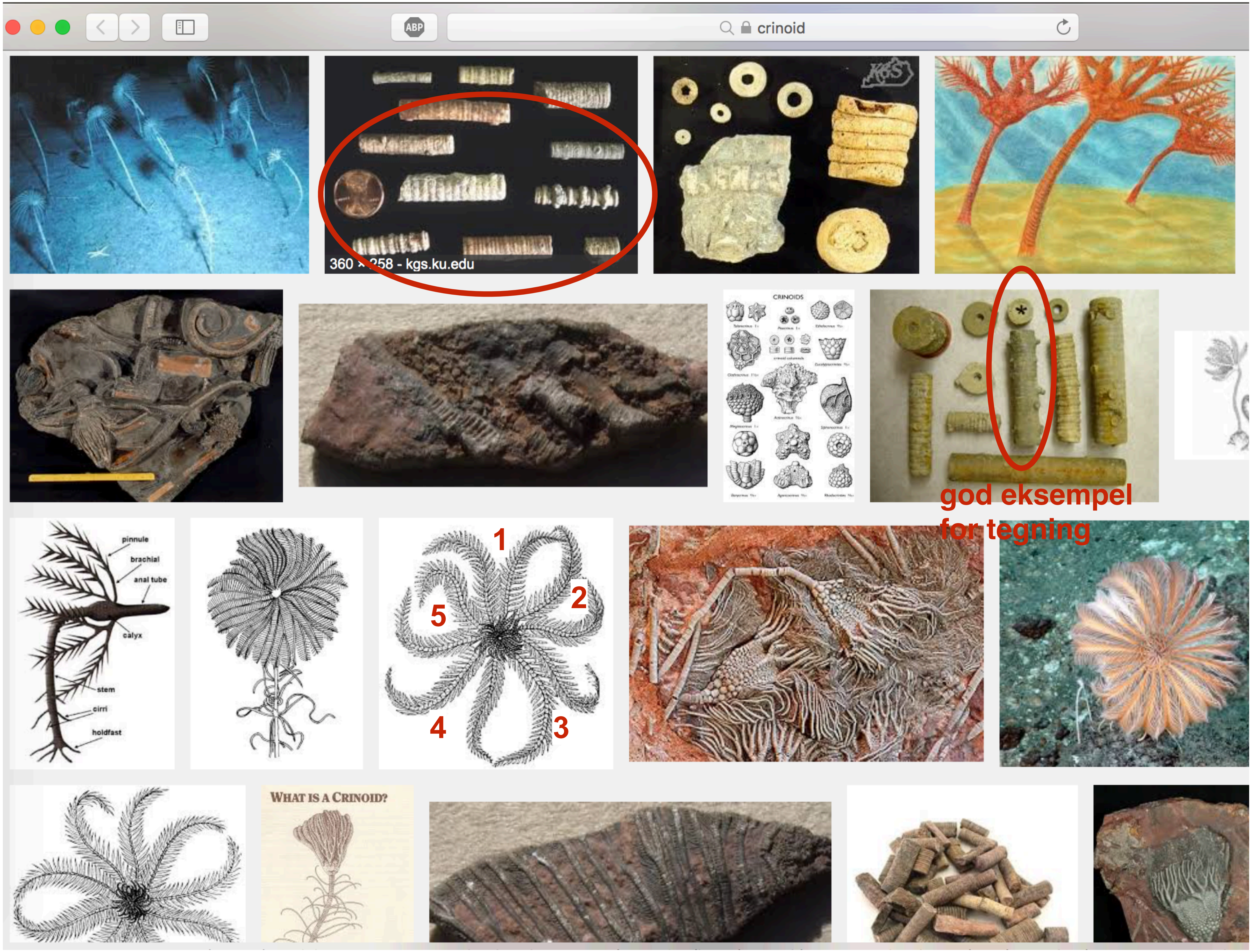
De aller fleste snegler har spiral som som vanlige skruer.
Du dreier dem med klokka for å skru inn.
(men noen få sneglearter er omvendt)



echinoid heter også kråkebolle. Mange arter lever nede i sediment, ikke oppe i vannet.
5-punkts symmetri. beslektet med sjøstjerner og crinoider.

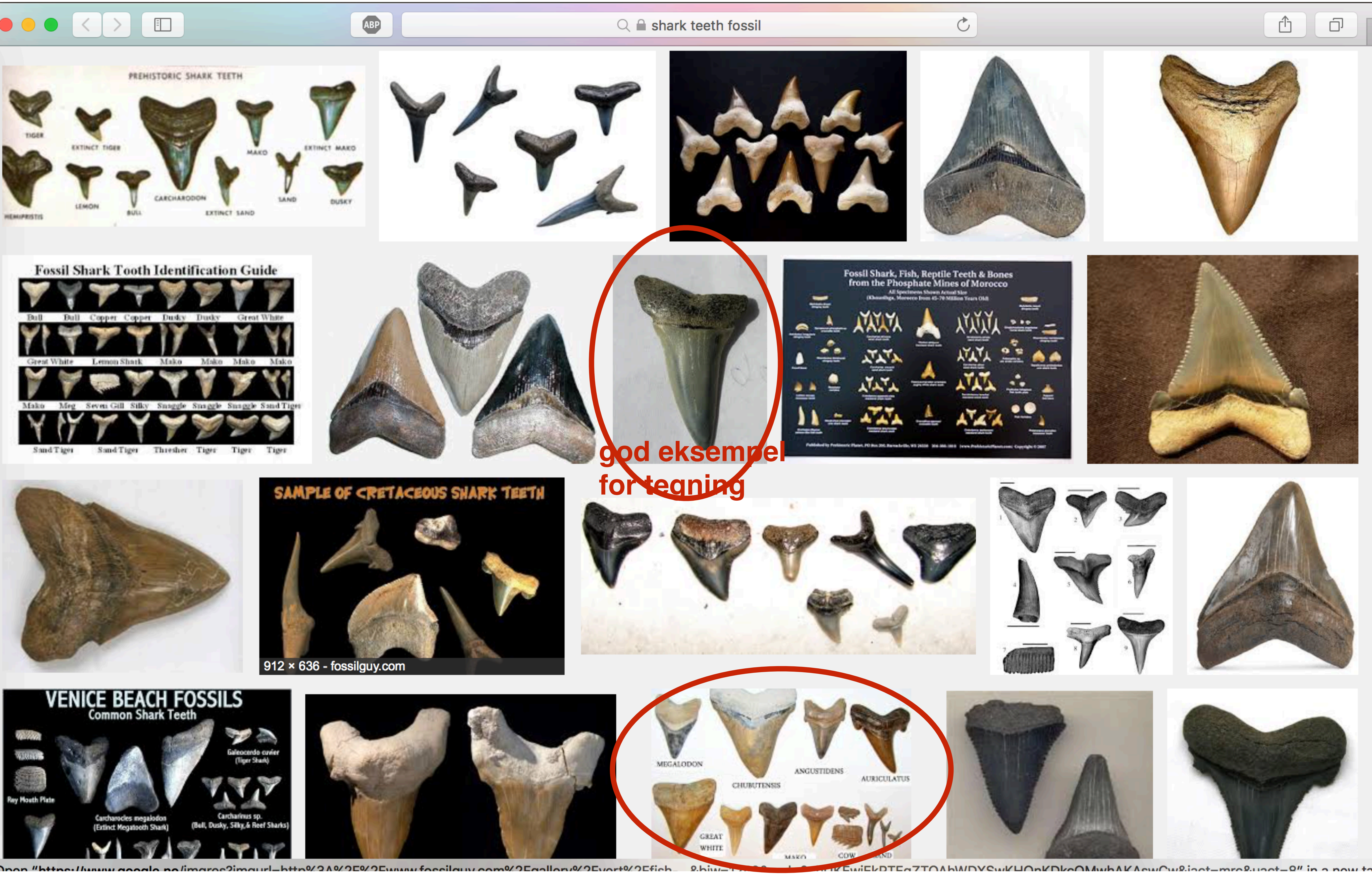


crinoid / heter også “sjøliljer”. Er dyr, ikke planter. oppdelte stilker (ossicles) er vanlige fossiler

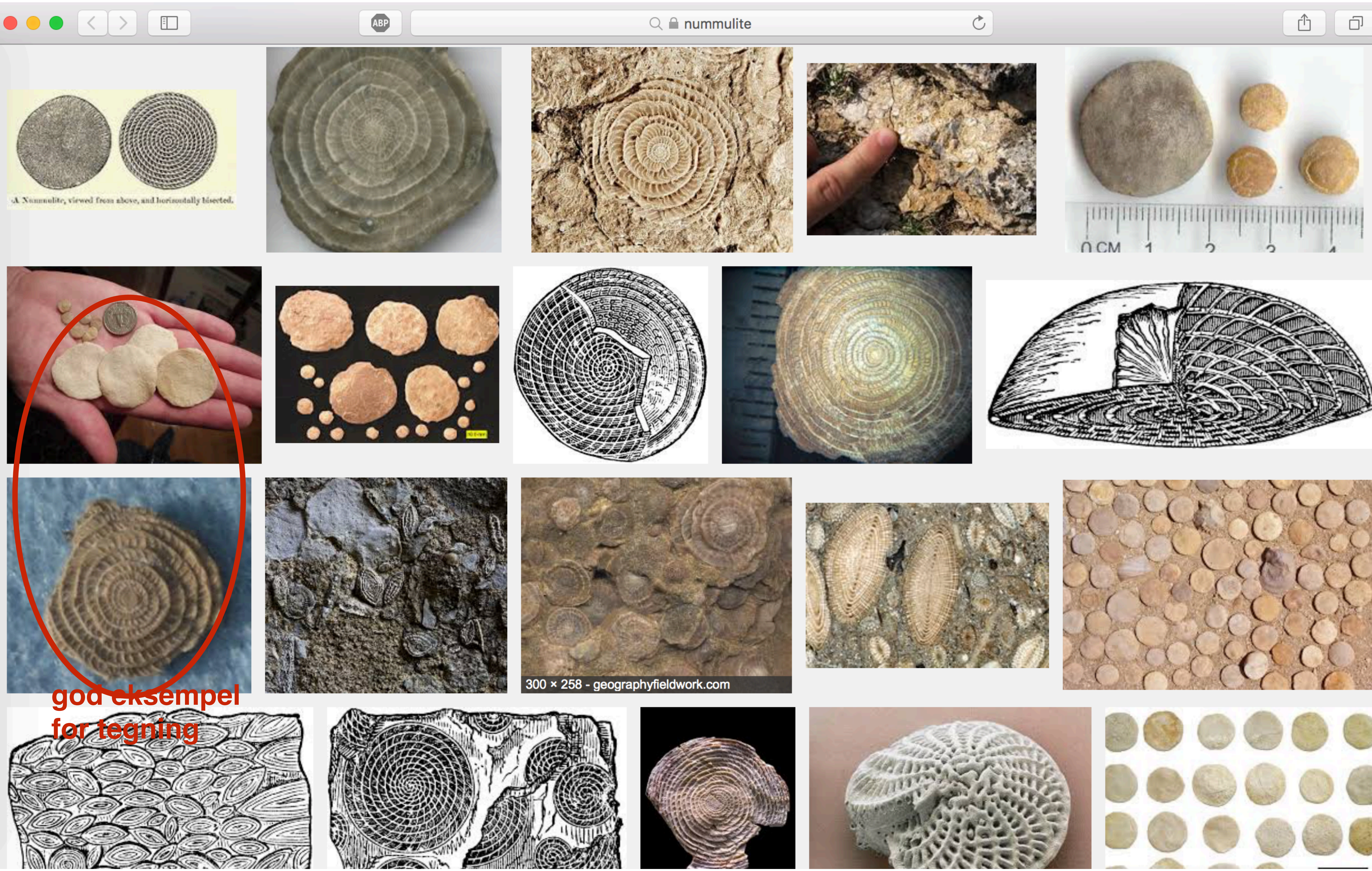


[haitann](#) vanlig marine fiskefossiler, kenozoikum

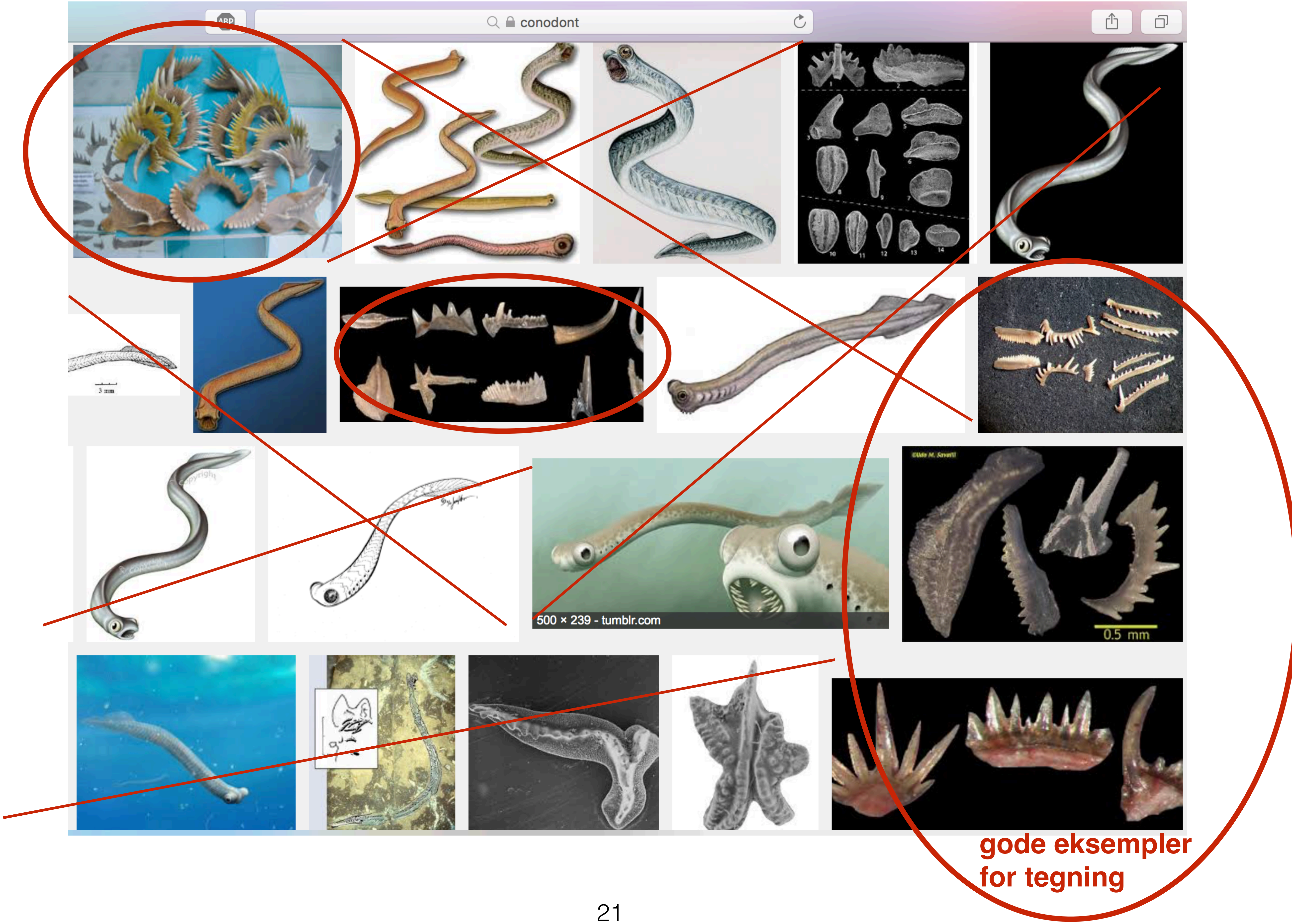
Haier har skjelett av brusk, ikke av ben, og derfor mister haier sine tenner veldig lett, og må vokse nye..



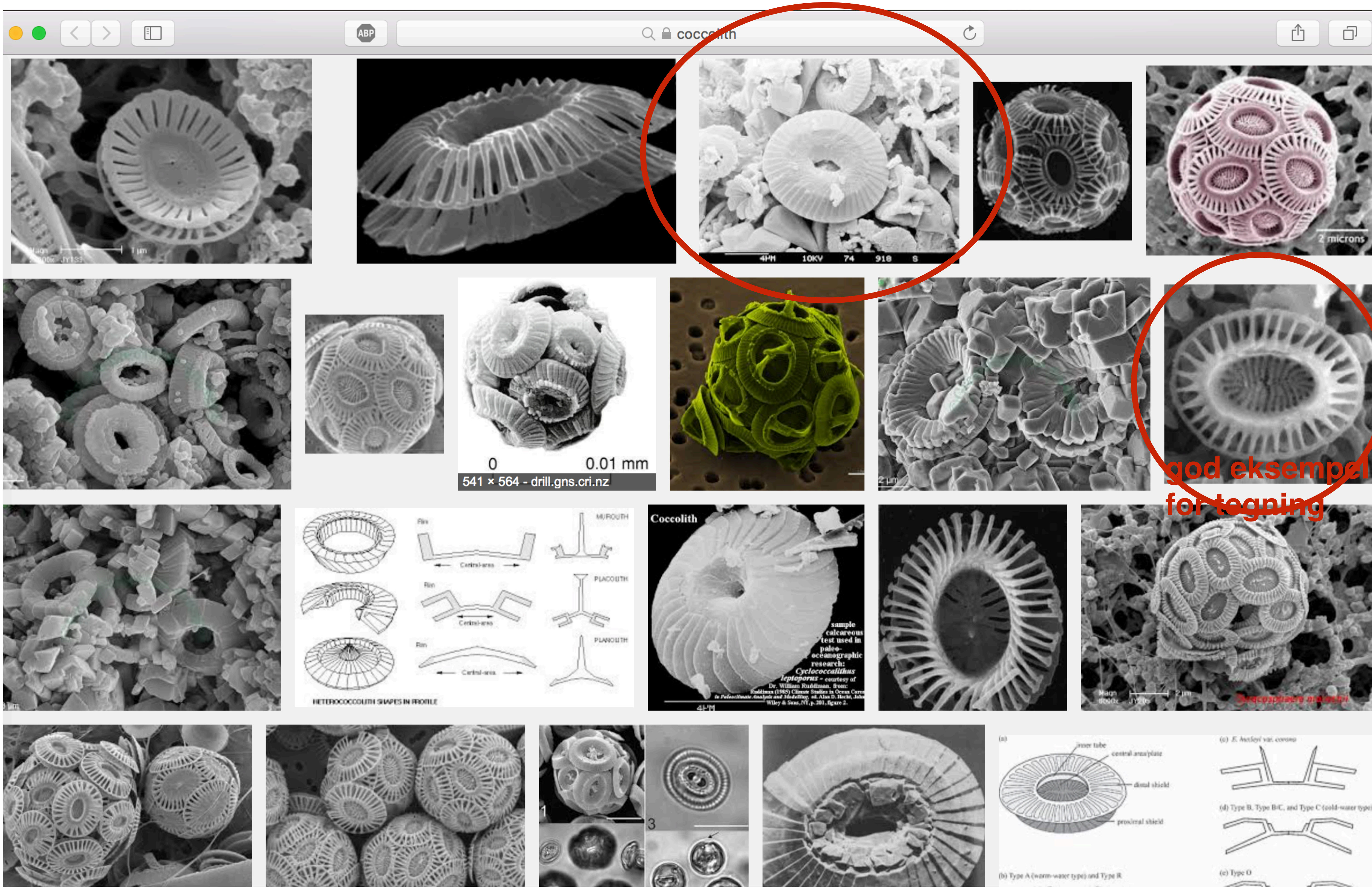
nummulitt er foraminiferer, som vanligvis er mikrofossil,
men nummulitter er gigantiske foraminiferer. fossilverdens største en-cellede dyr



konodont mikrofossil “tenner“ til mystisk “konodontdyr” (tegn “tenner,” ikke dyret. Dyret er omtrent aldri funnet som fossil)



kokkolitt mikrofossil som utgjør kritt(stein) av kritt(alder). Består av $CaCO_3$



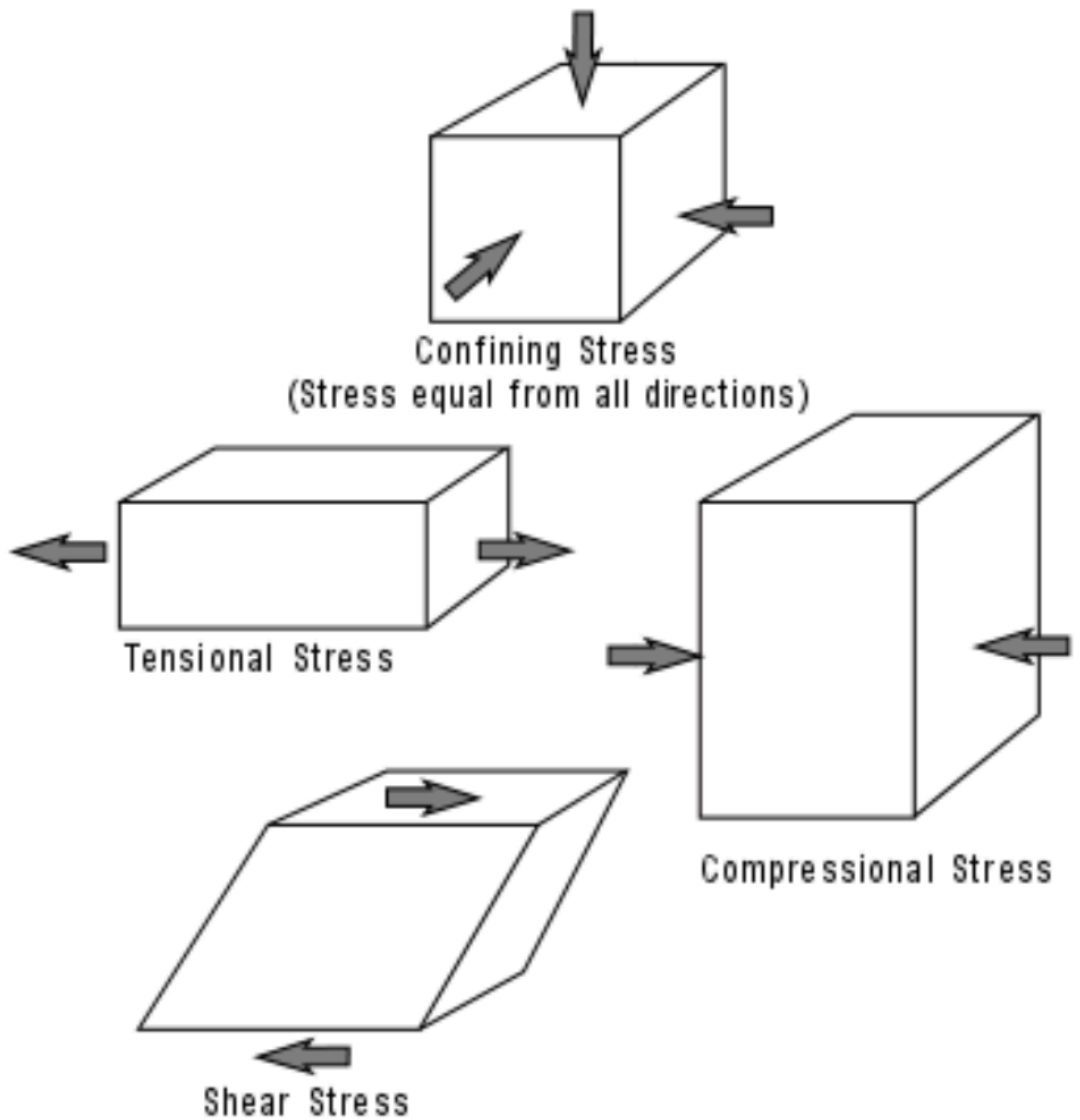
Jordskjelv

**(Nelson repeterer:
bergarter utsettes for stress)**

1. ***Tensional stress (or extensional stress)***, which stretches rock;

2. ***Compressional stress***, which squeezes rock; and

3. ***Shear stress***, which result in slippage and translation.

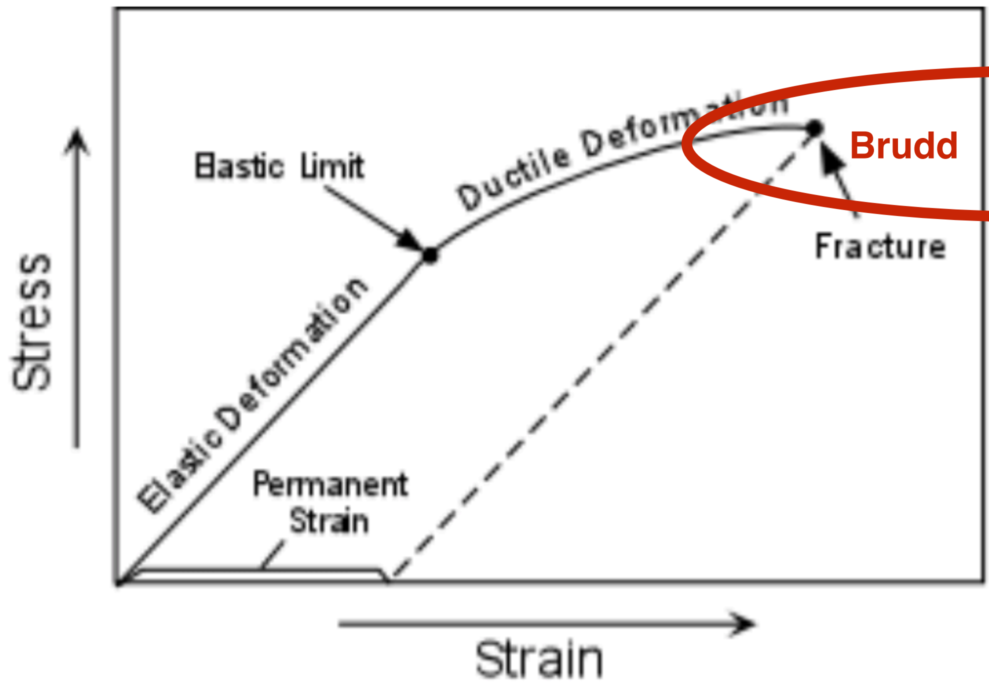


Alle bergarter er delvis elastisk, delvis duktil, og kan “gå til brudd” (sprekke).

Nelson 1-248 (page 90 of 248)

When a rock is subjected to increasing stress it changes its shape, size or volume. Such a change in shape, size or volume is referred to as ***strain***. When stress is applied to rock, the rock passes through 3 successive stages of deformation.

- ***Elastic Deformation*** -- wherein the strain is reversible.
- ***Ductile Deformation*** -- wherein the strain is irreversible.
- ***Fracture*** -- irreversible strain wherein the material breaks.



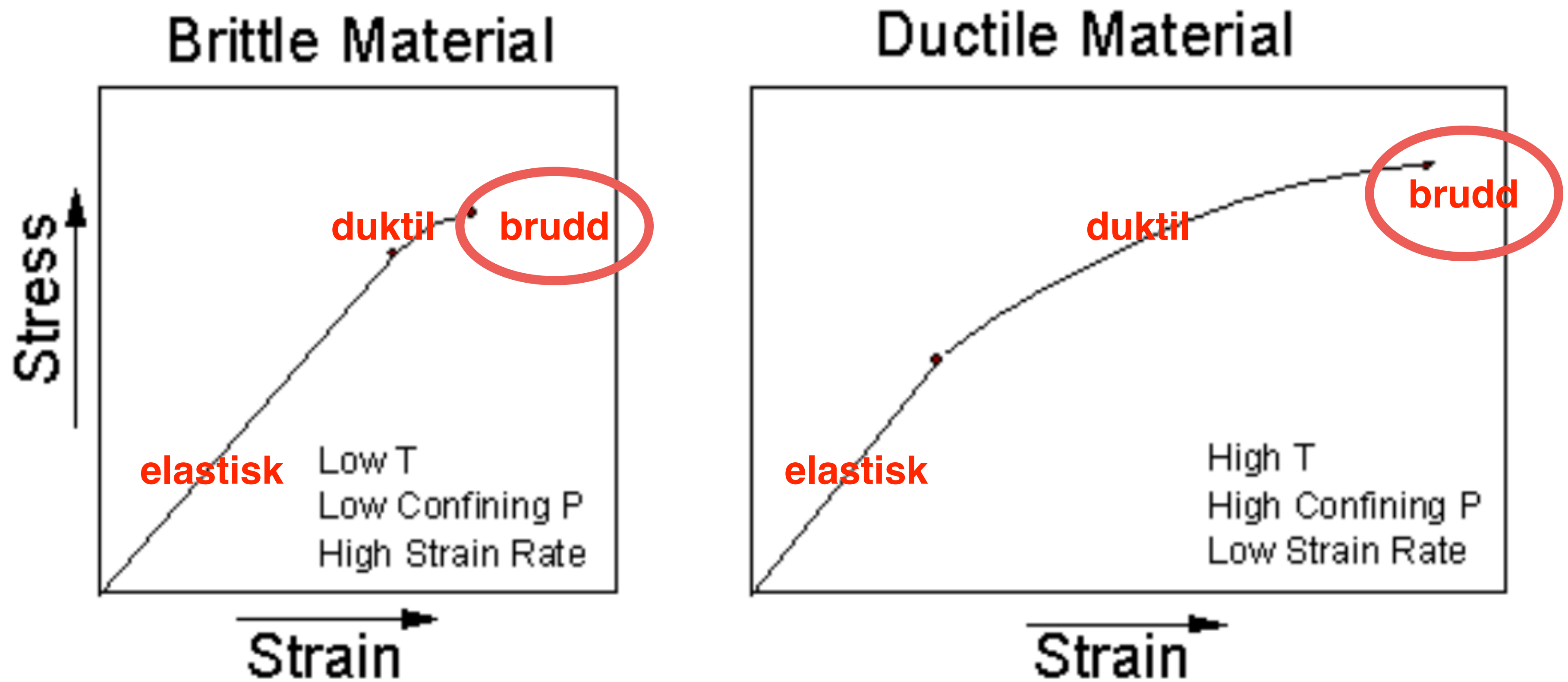
We can divide materials into two classes that depend on their relative behavior under stress.

sprø materialer

- ***Brittle materials*** have a small to large region of elastic behavior, but only a small region of ductile behavior before they fracture.

duktil materialer

- ***Ductile materials*** have a small region of elastic behavior and a large region of ductile behavior before they fracture.



How a material behaves will depend on several factors. Among them are:

- Temperature - At high temperature molecules and their bonds can stretch and move, thus materials will behave in more ductile manner. At low Temperature, materials are brittle.
- Confining Pressure - At high confining pressure materials are less likely to fracture because the pressure of the surroundings tends to hinder the formation of fractures. At low confining stress, material will be brittle and tend to fracture sooner.
- Strain rate -- Strain rate refers to the rate at which the deformation occurs (strain divided by time). At high strain rates material tends to fracture. At low strain rates more time is available for individual atoms to move and therefore ductile behavior is favored.
- Composition -- Some minerals, like quartz, olivine, and feldspars are very brittle. Others, like clay minerals, micas, and calcite are more ductile This is due to the chemical bond types that hold them together. Thus, the mineralogical composition of the rock will be a factor in determining the deformational behavior of the rock. Another aspect is presence or absence of water.

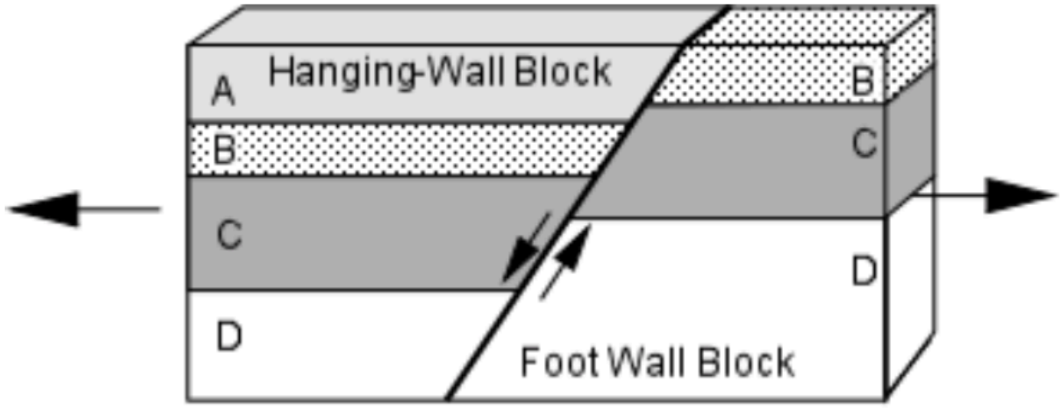
(Nelson repeterer)

Brudd langs en forkastning utløser jordskjelv

Dip Slip Faults - Dip slip faults are faults that have an inclined fault plane and along which the relative displacement or offset has occurred along the dip direction. Note that in looking at the displacement on any fault we don't know which side actually moved or if both sides moved, all we can determine is the relative sense of motion.

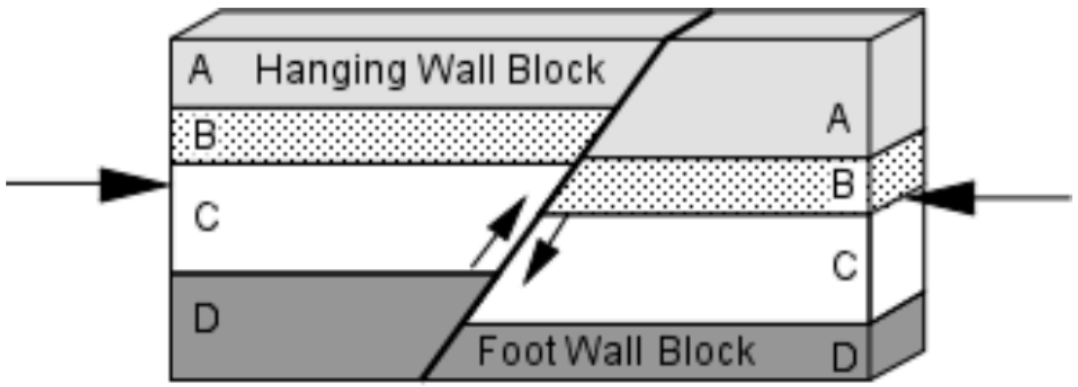
For any inclined fault plane we define the block above the fault as the ***hanging wall block*** and the block below the fault as the ***footwall block***

- ***Normal Faults*** - are faults that result from horizontal extensional stresses in brittle rocks and where the hanging-wall block has moved down relative to the footwall block.



Normal Fault
Extensional Stress

- ***Reverse Faults*** - are faults that result from horizontal compressional stresses in brittle rocks, where the hanging-wall block has moved up relative the footwall block.



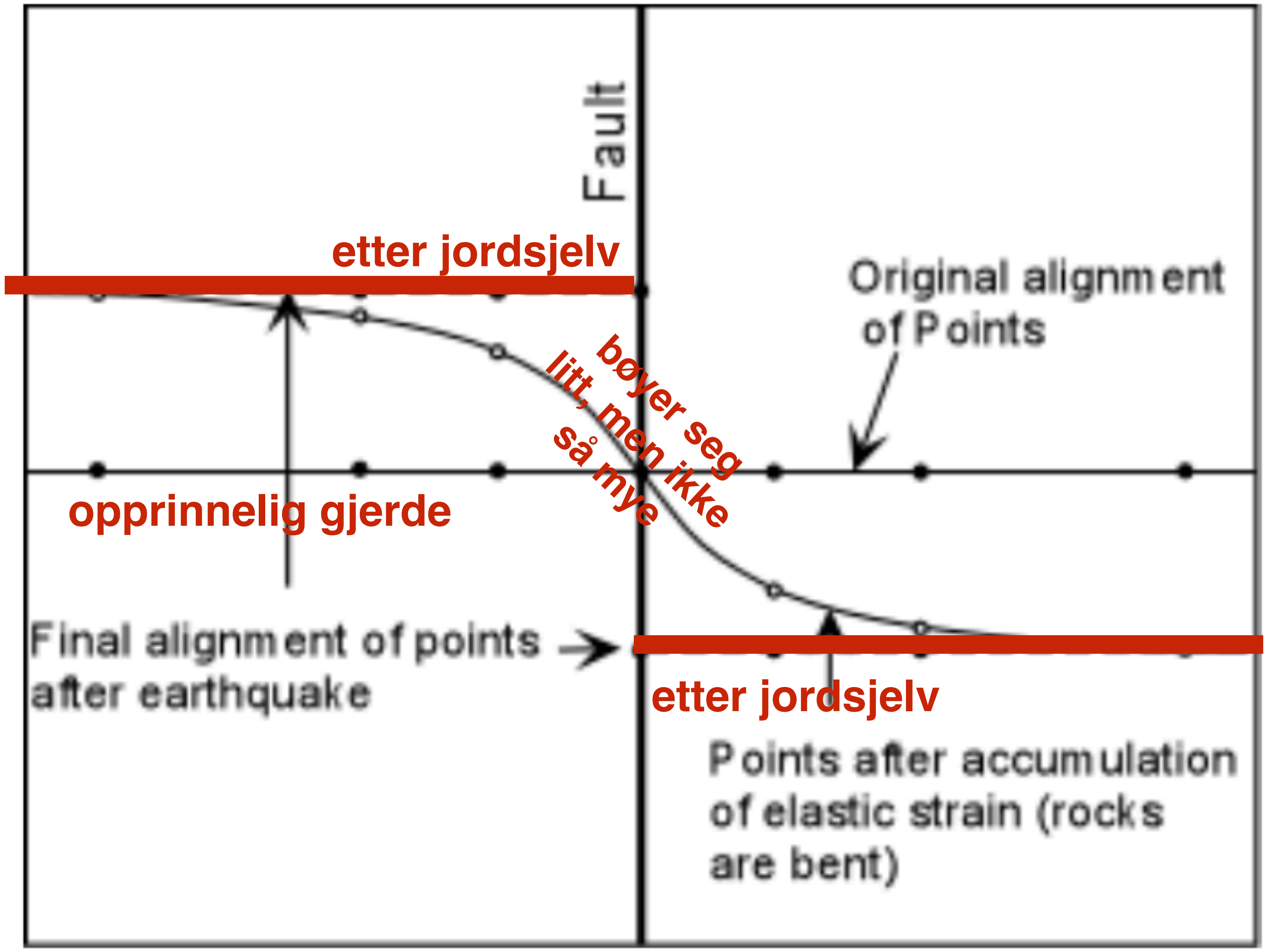
Reverse Fault
Compressional Stress

"Elastic rebound theory"

Dette viser at bergarter er noe elastisk før brudd

Nelson.pdf (page 94 of 248)

This theory was discovered by making measurements at a number of points across a fault. Prior to an earthquake it was noted that the rocks adjacent to the fault were bending. These bends disappeared after an earthquake suggesting that the energy stored in bending the rocks was suddenly released during the earthquake.



Den røde linjen skal være et gjerde i en åker.
Det blir deformert av en dekstral sidelengsforkastning.

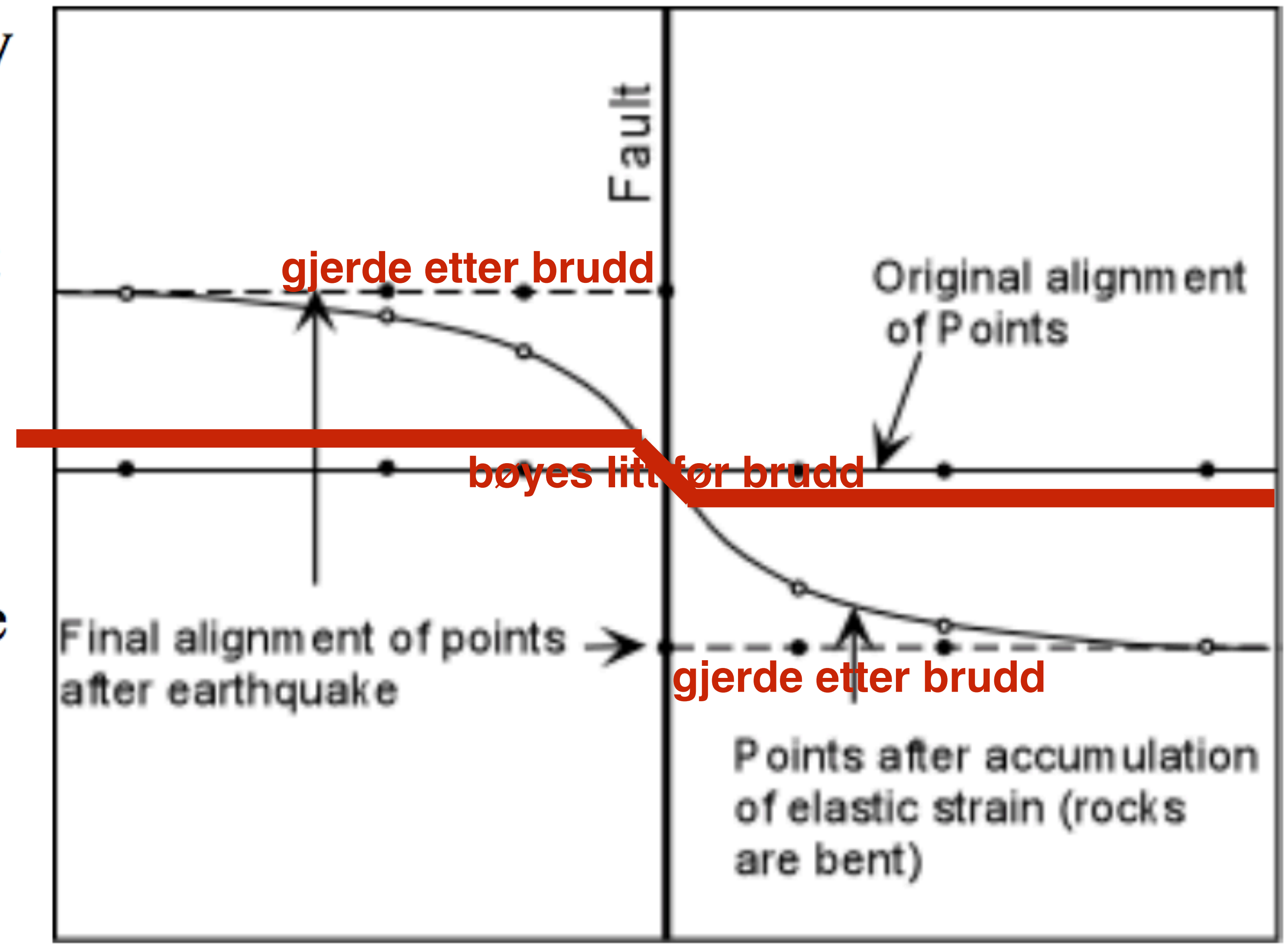
Først er deformasjonen duktil, uten brudd.

"Elastic rebound theory"

Dette viser at bergarter er noe elastisk.

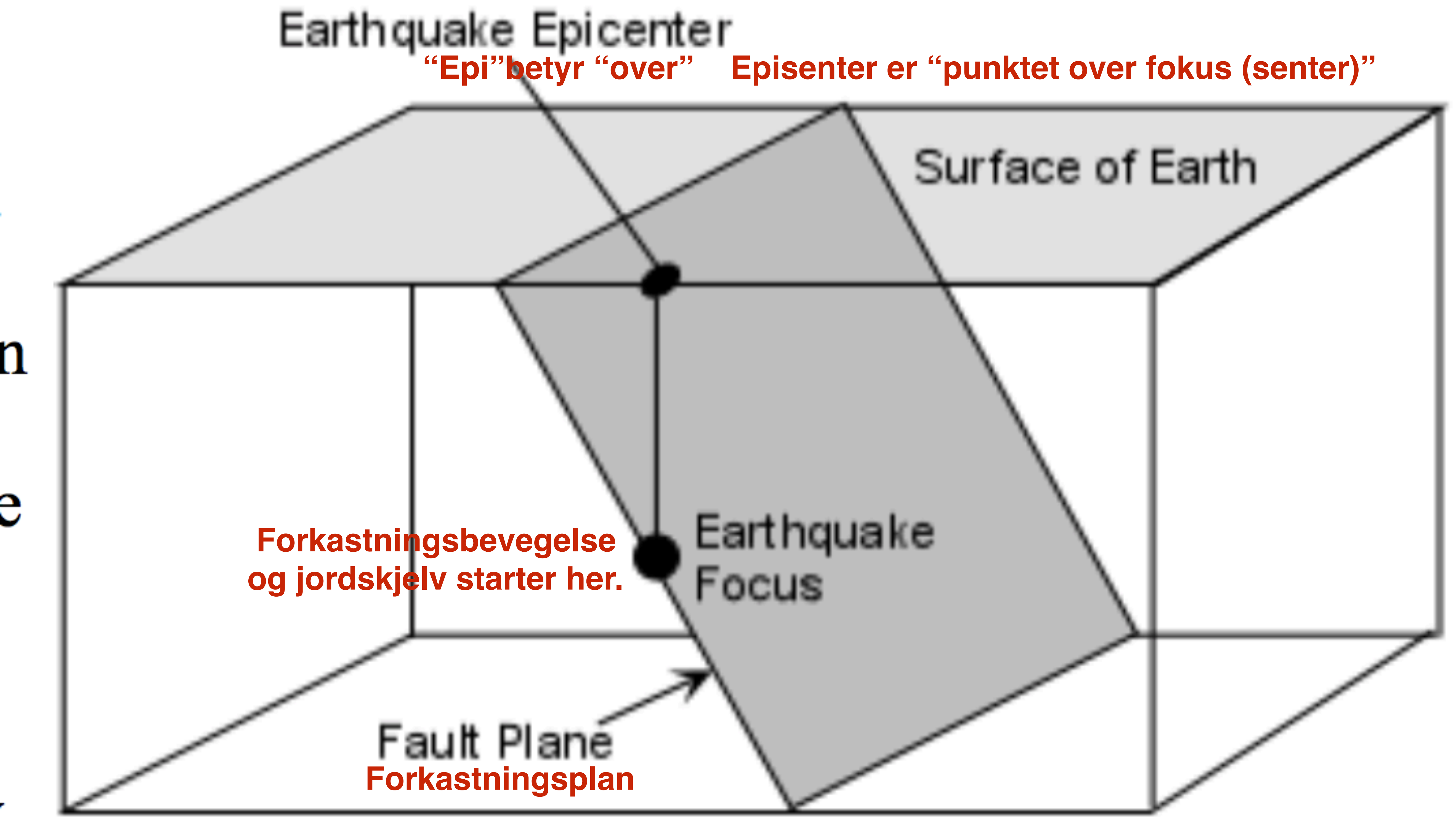
Nelson.pdf (page 94 of 248)

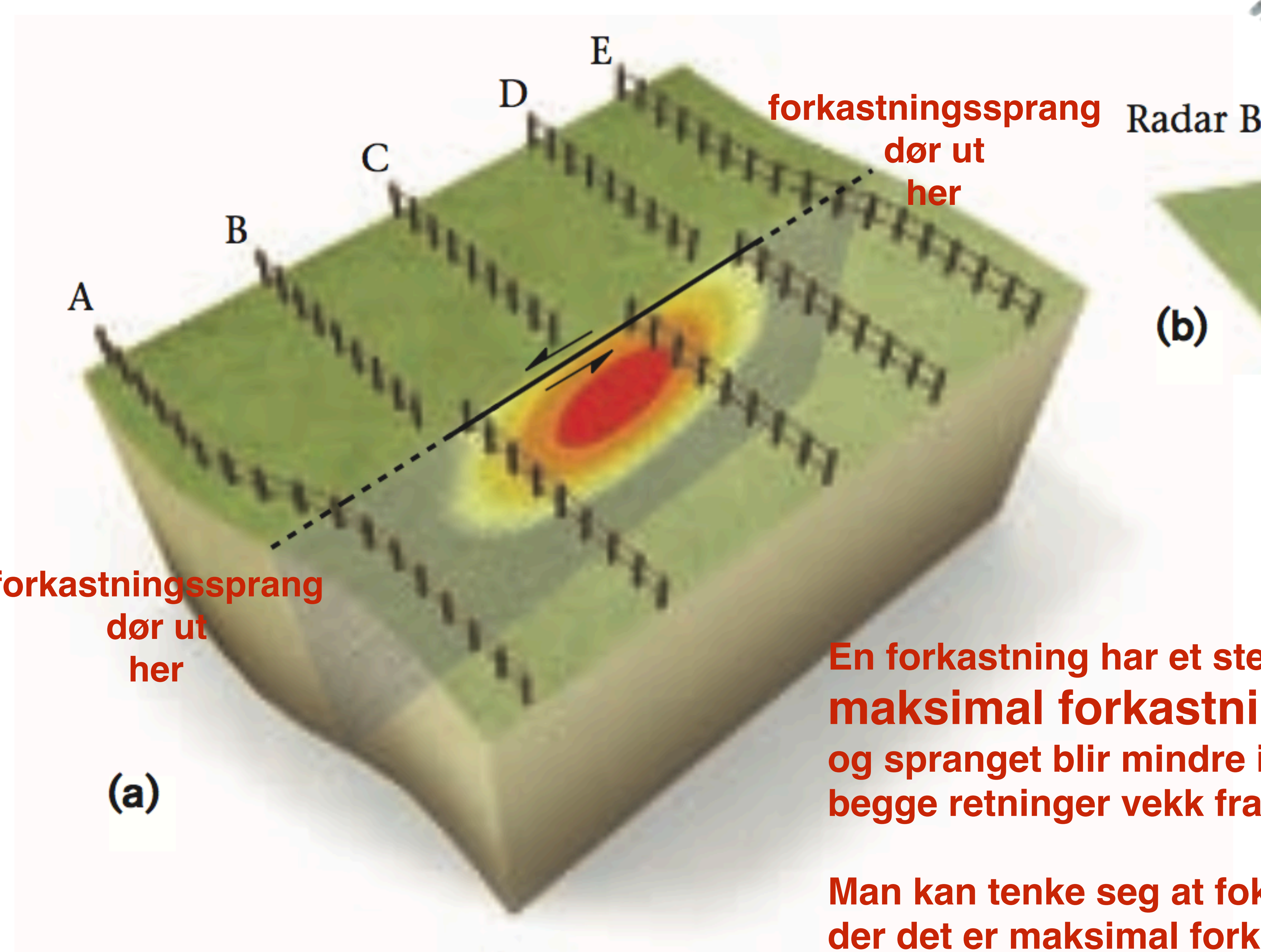
This theory was discovered by making measurements at a number of points across a fault. Prior to an earthquake it was noted that the rocks adjacent to the fault were bending. These bends disappeared after an earthquake suggesting that the energy stored in bending the rocks was suddenly released during the earthquake.



Til slutt blir det brudd og forkastningssprang.

Men bildene er uheldig (overdrevet), fordi bøyning er nesten ikke målbar, mens spranget er mye større.


Earthquake Epicenter
"Epi" betyr "over"
Episenter er "punktet over fokus (senter)"
Surface of Earth
Forkastningsbevegelse
og jordskjelv starter her.
Earthquake
Focus
Fault Plane
Forkastningsplan



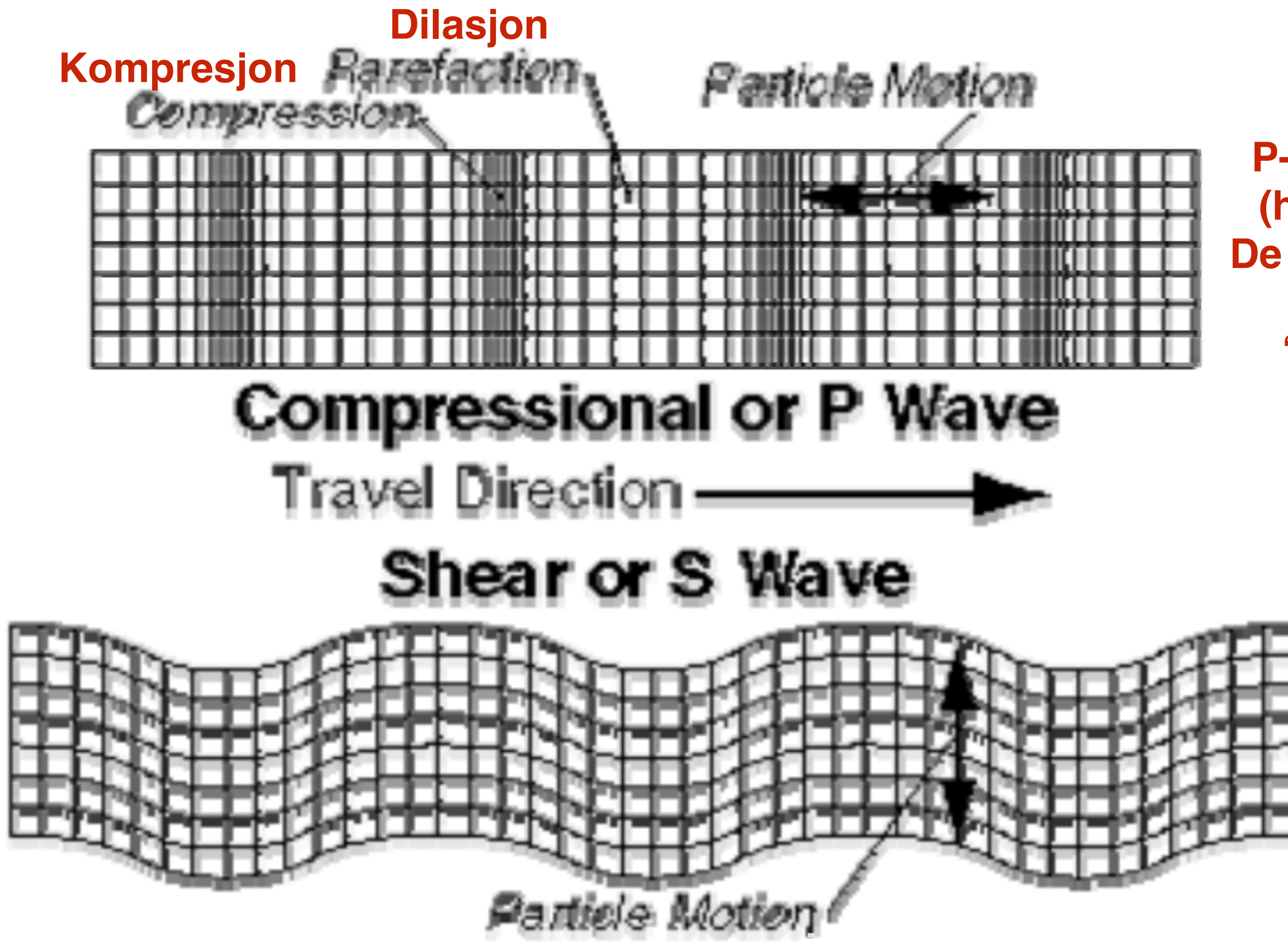
En forkastning har et sted med
maksimal forkastningssprang,
og spranget blir mindre i
begge retninger vekk fra fokus.

Man kan tenke seg at fokus er
der det er maksimal forkastningsprang.
Men hele lengden utløser samme jordskjelv.

FIGURE 10.11 **(a)** During an earthquake on a preexisting fault, n
area grows outward; on a large fault, this growth takes tens of secor
ground surface; fences beyond the end of this intersection have not
to faulting. **(c)** An InSAR map of the hill. Color bands can be thought

Rombølger

Body Waves - emanate from the focus and travel in all directions through the body of the Earth. There are two types of body waves: P-waves and S waves.



P-bølger går fortere (høyere hastighet.) De kommer først fram og heter derfor "Primær-bølger."

S-bølger går saktere (lavere hastighet.) De kommer etter, heter derfor "Sekundær-bølger."

- ***P - waves*** - are Primary waves. They travel with a velocity that depends on the elastic properties of the rock through which they travel.

$$V_p = \sqrt{[(K+4/3\mu)/\rho]}$$

$$(K+1{,}33\mu) / \rho$$

Where, V_p is the velocity of the P-wave, K is the incompressibility of the material, μ is the rigidity of the material, and ρ is the density of the material.

Marshak.pdf (page 340 of 957)

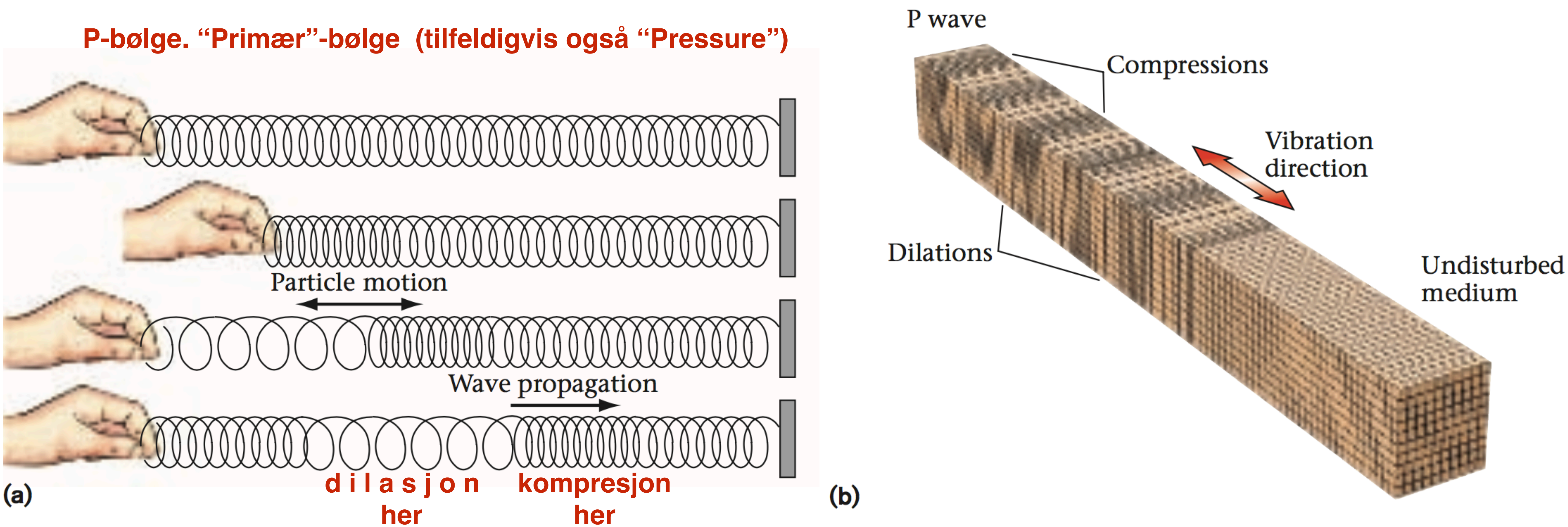


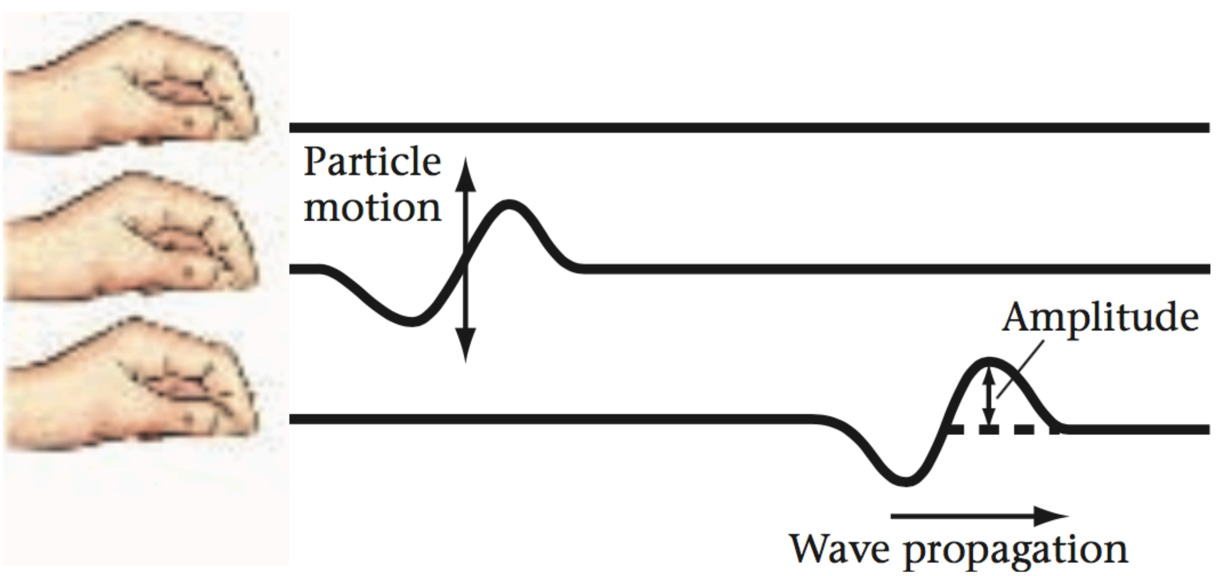
FIGURE 10.12 **(a, b)** Two ways of picturing compressional waves. These waves (P-waves) can be generated by pushing on the end of a spring. The pulse of energy compresses in sequence down the length of spring. Note that the back-and-forth motion of the coils occurs in the same direction the wave travels. The wavelength of P-waves is defined by the distance between successive pulses of compression. **(c, d)** Two ways of picturing shear waves. These waves (S-waves) resemble the waves in a rope. Note that the back-and-forth motion occurs in a direction perpendicular to the direction the wave travels. The wavelength of S-waves is defined as the distance between successive peaks (or troughs).

https://en.wikipedia.org/wiki/P-wave#/media/File:Onde_compression_impulsion_1d_30_petit.gif

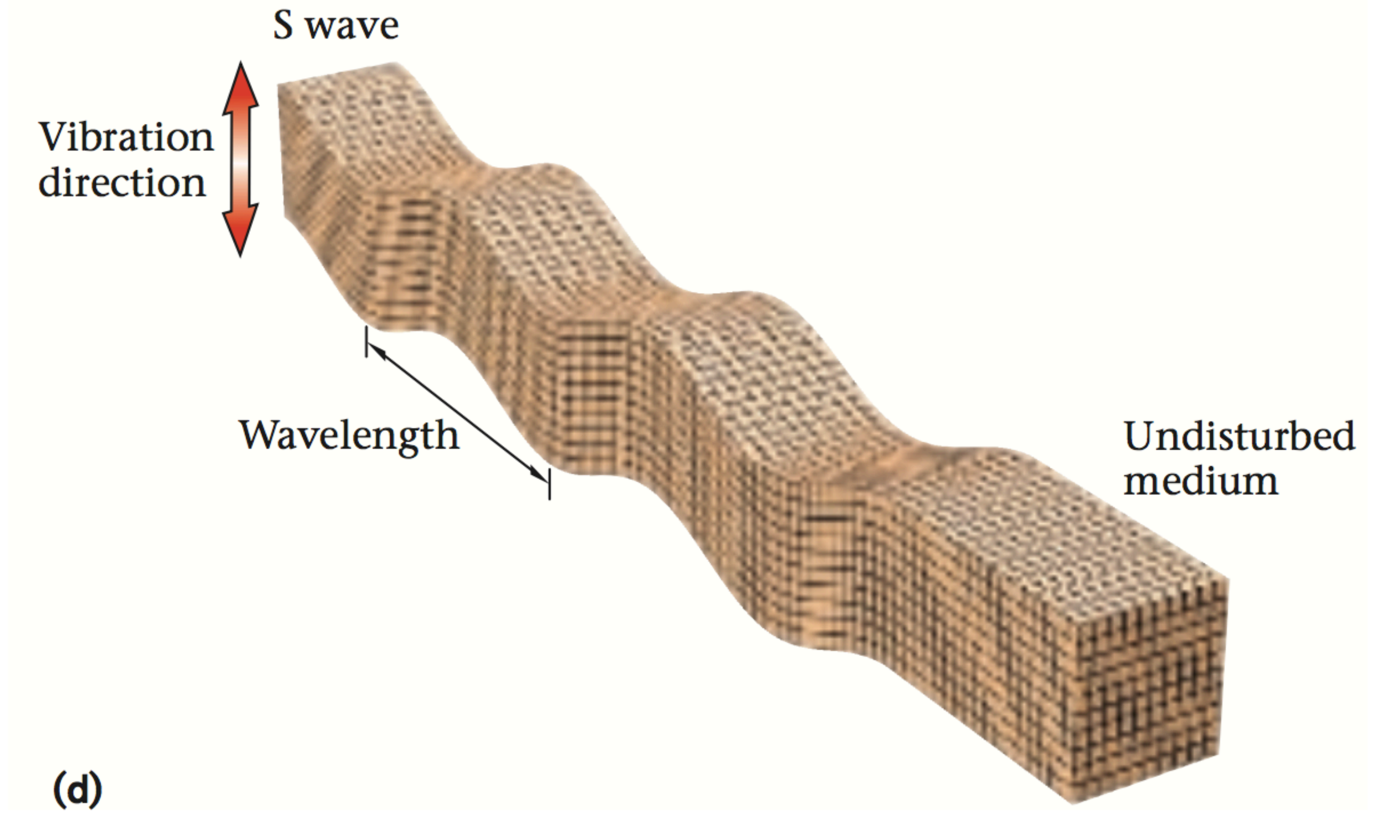
https://en.wikipedia.org/wiki/P-wave#/media/File:Ondes_compression_2d_20_petit.gif

Marshak.pdf (page 340 of 957)

S-bølge. “Sekondær”-bølge (tilfeldigvis også “Skjær”)



(c)



(d)

FIGURE 10.12 **(a, b)** Two ways of picturing compressional waves. These waves (P-waves) can be generated by pushing on the end of a spring. The pulse of energy compresses in sequence down the length of spring. Note that the back-and-forth motion of the coils occurs in the same direction the wave travels. The wavelength of P-waves is defined by the distance between successive pulses of compression. **(c, d)** Two ways of picturing shear waves. These waves (S-waves) resemble the waves in a rope. Note that the back-and-forth motion occurs in a direction perpendicular to the direction the wave travels. The wavelength of S-waves is defined as the distance between successive peaks (or troughs).

https://en.wikipedia.org/wiki/S-wave#/media/File:Onde_cisaillement_impulsion_1d_30_petit.gif

https://en.wikipedia.org/wiki/S-wave#/media/File:Ondes_cisaillement_2d_20_petit.gif

I tillegg til "P-bølger" og "S-bølger" finnes

"Overflatebølger"

Marshak.pdf (page 340 of 957)

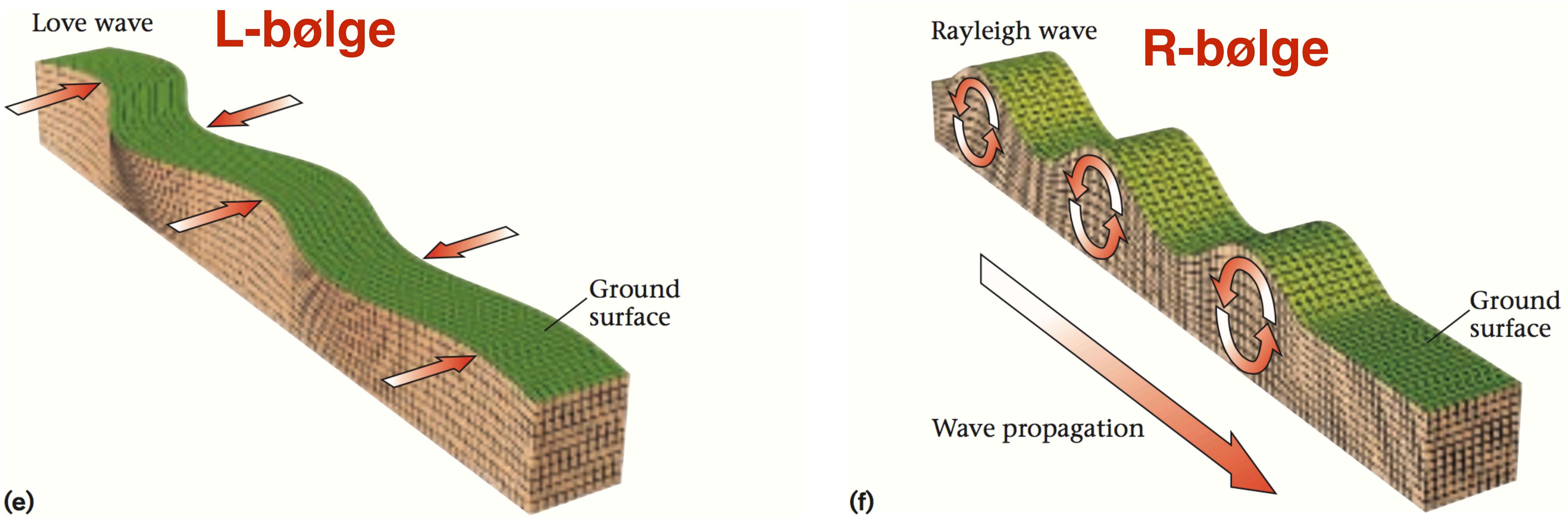


FIGURE 10.12 **(a, b)** Two ways of picturing compressional waves. These waves (P-waves) can be generated by pushing on the end of a spring. The pulse of energy compresses in sequence down the length of spring. Note that the back-and-forth motion of the coils occurs in the same direction the wave travels. The wavelength of P-waves is defined by the distance between successive pulses of compression. **(c, d)** Two ways of picturing shear waves. These waves (S-waves) resemble the waves in a rope. Note that the back-and-forth motion occurs in a direction perpendicular to the direction the wave travels. The wavelength of S-waves is defined as the distance between successive peaks (or troughs). **(e)** L-waves cause the surface of the ground to shear sideways, like a moving snake. **(f)** R-waves make the surface of the ground go up and down. They differ from water waves, whose particles follow a clockwise circular path as the wave passes (see Chapter 18). R-wave particles, instead, follow an elliptical counterclockwise orbit, as shown.

Nelson gir formler for P- og S-bølger
(det gjør ikke Marshak eller de fleste lærebøker i geologi)

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$$V_p = \sqrt{[(K+4/3\mu)/\rho]} \qquad V_S = \sqrt{\mu/\rho}$$

1,33μ

Where, V_p is the velocity (hastighet) of the P-wave, K is the incompressibility (inkompressibilitet) of the material, μ is the rigidity (stivhet) of the material, and ρ is the density (egenvekt) of the material.

Du trenger ikke pugge disse formlene.

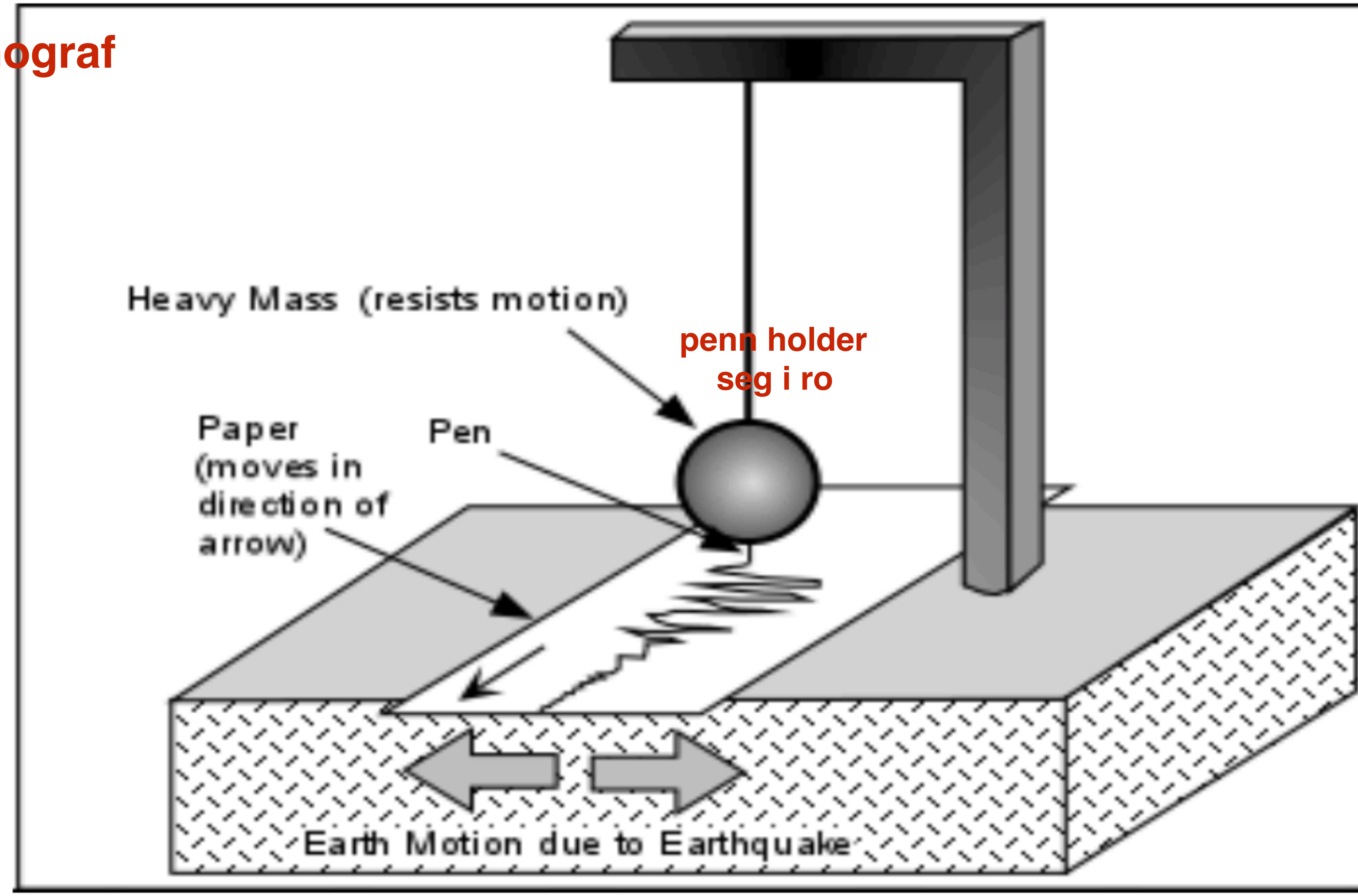
Men du ser fra formelene at V_p må ALLTID være større enn V_s på grunn av K og 1,33

Hele saken er komplisert,
fordi K, *μ*, og ρ øker på ulike måter med dybden i skorpen (vanligvis).

Seismometers

= **Seismometer** heter også **Seismograf**

Seismic waves travel through the earth as elastic vibrations. A ***seismometer*** is an instrument used to record these vibrations and the resulting graph that shows the vibrations is called a ***seismogram***.



denne seismometer måler kun horisontale rystelser

seism: vibrasjon
seismometer eller seismograf: verktøy
seismogram: utskrift
seismologi: vitenskap
seismolog: person
seismisk stasjon: der en seismolog og seismometer jobber

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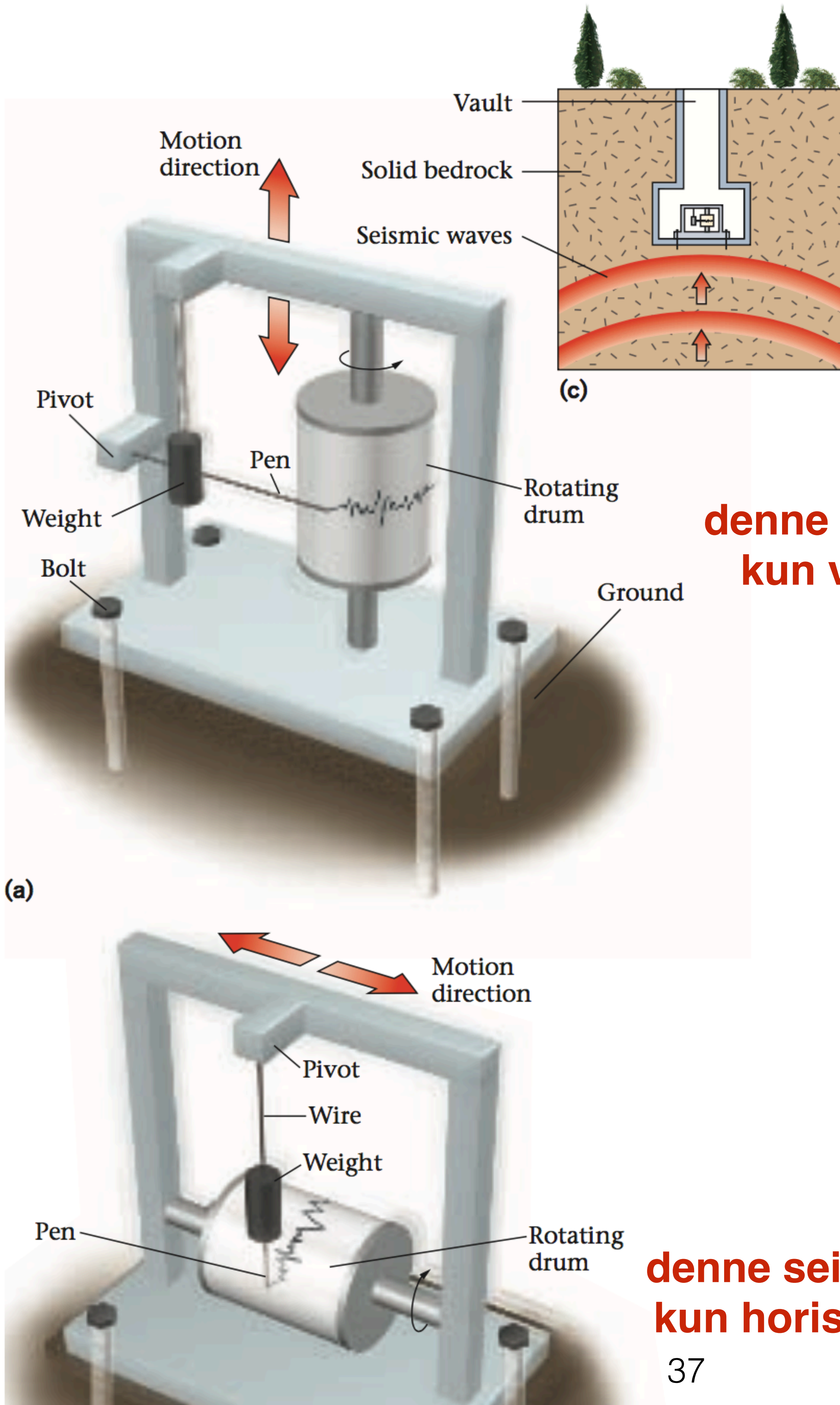


denne seismometer måler
kun vertikale rystelser

denne seismometer måler
kun horisontale rystelser

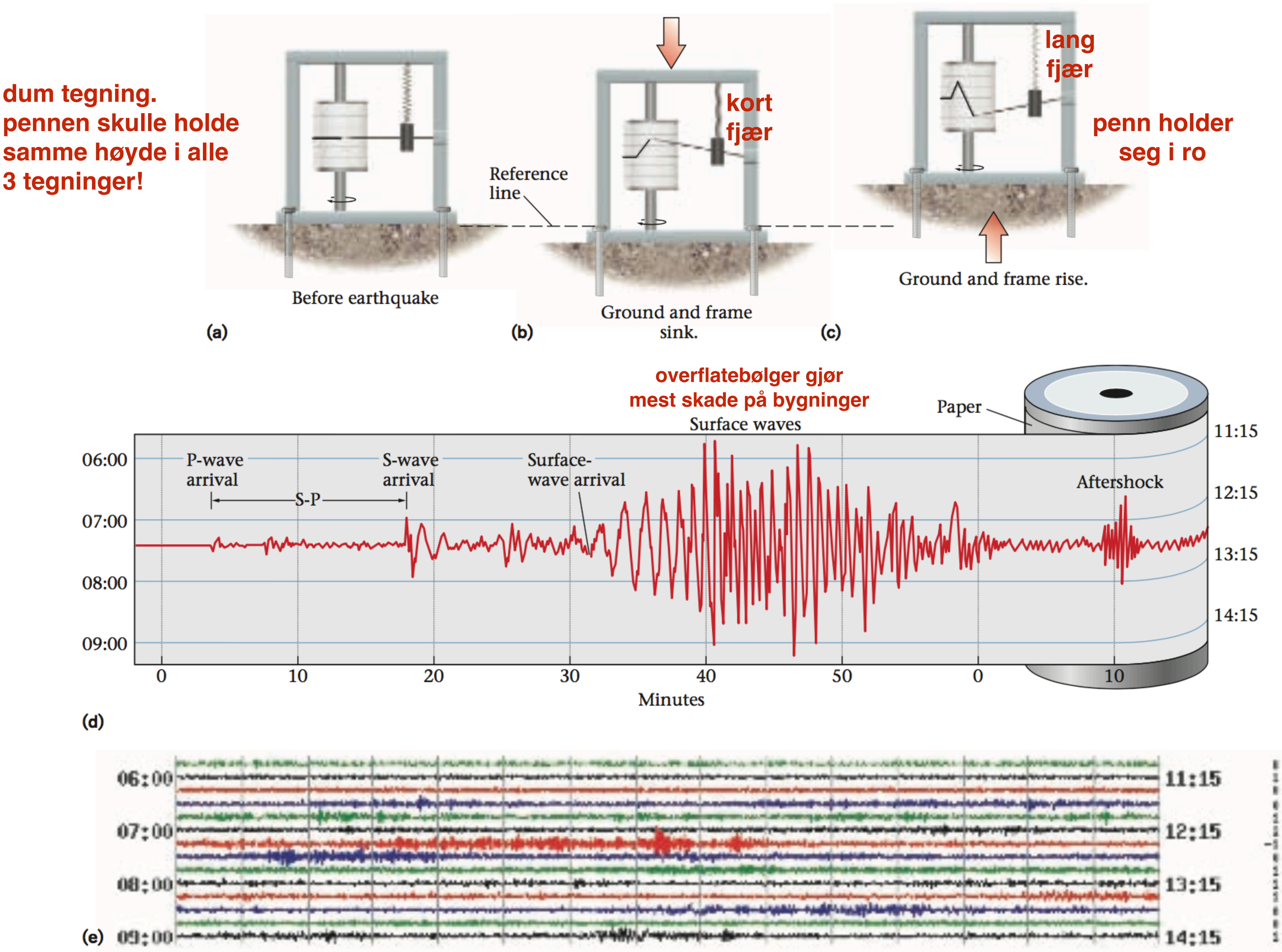


FIGURE 10.14 How a seismograph works (here, a vertical-motion seismograph). **(a)** Before an earthquake, the pen traces a straight line. **(b)** During an earthquake, when the ground and the frame of a seismograph go down, the weight stays in place because of inertia, so the pen rises relative to the paper roll. **(c)** When the ground and the seismograph frame rise, the pen goes down. **(d)** This closeup of the record (seismogram) for a single earthquake shows the signals generated by different kinds of seismic waves. **(e)** Digital seismic record from a seismograph station in Arkansas. The vertical lines represent minutes. Colors have no meaning, they just make the figure more readable. All of the earthquakes shown are small.

Du kan telle sekunder mellom lyn og torden for å bestemme hvor langt vekk lynet er.

Lyn (lys) tar ca. 0 sekunder å reise til deg.
Torden (lyd) tar ca. 3 sekunder å reise hver km.
(Lydhastighet er 343 meter per sekund.)

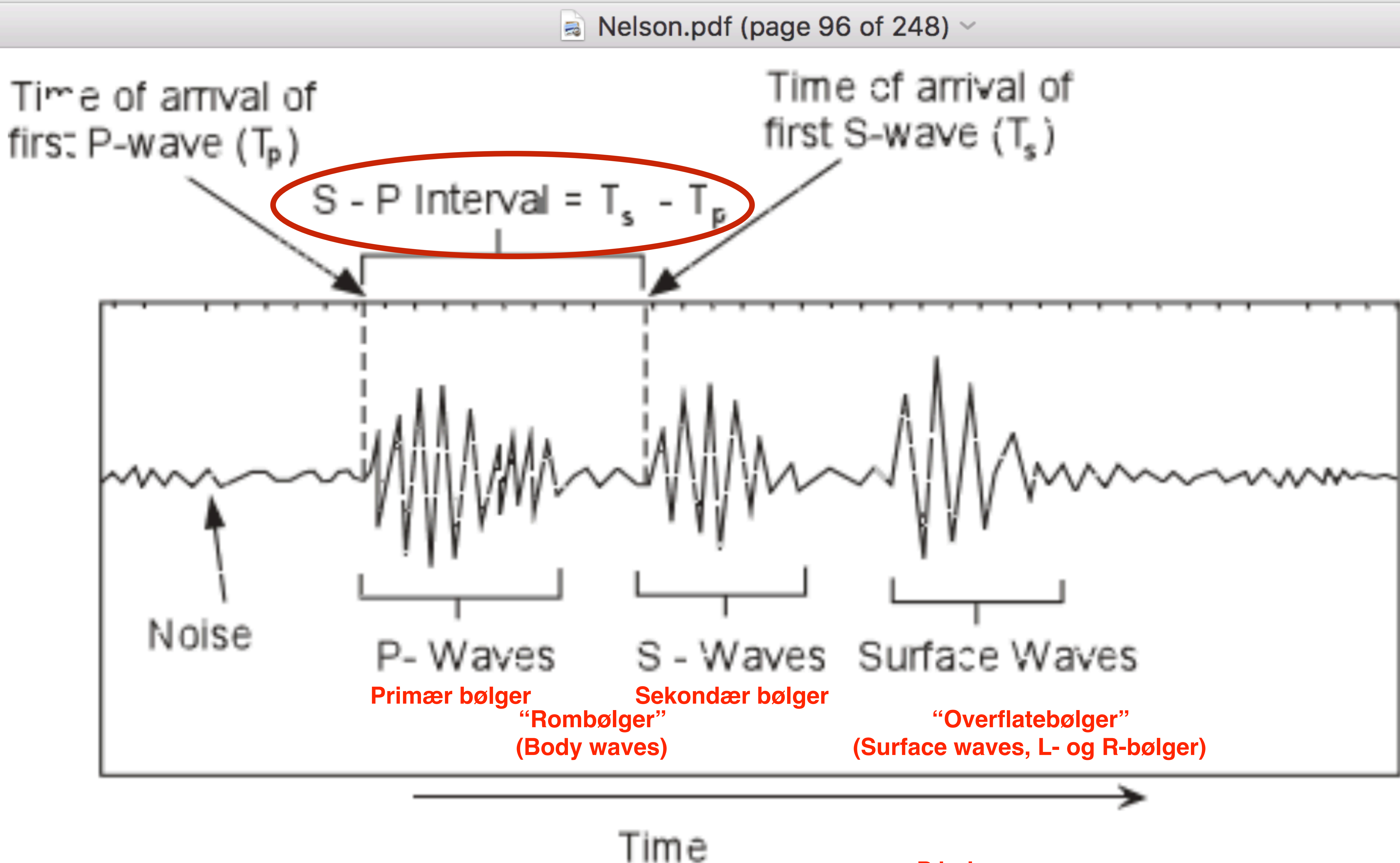

Liahtnina-Prone States. ...


Superbolts' of liahtnina strike when ...

Hvis du teller til 9, er lynet 3 km vekk.

Vi kan kalle denne tid for "*torden-minus-lyn interval*"

Dette er det samme som med jordskjelv:
"*S-minus-P interval*"



P bølger
S bølger
etterpå kommer L-bølger og R-bølger

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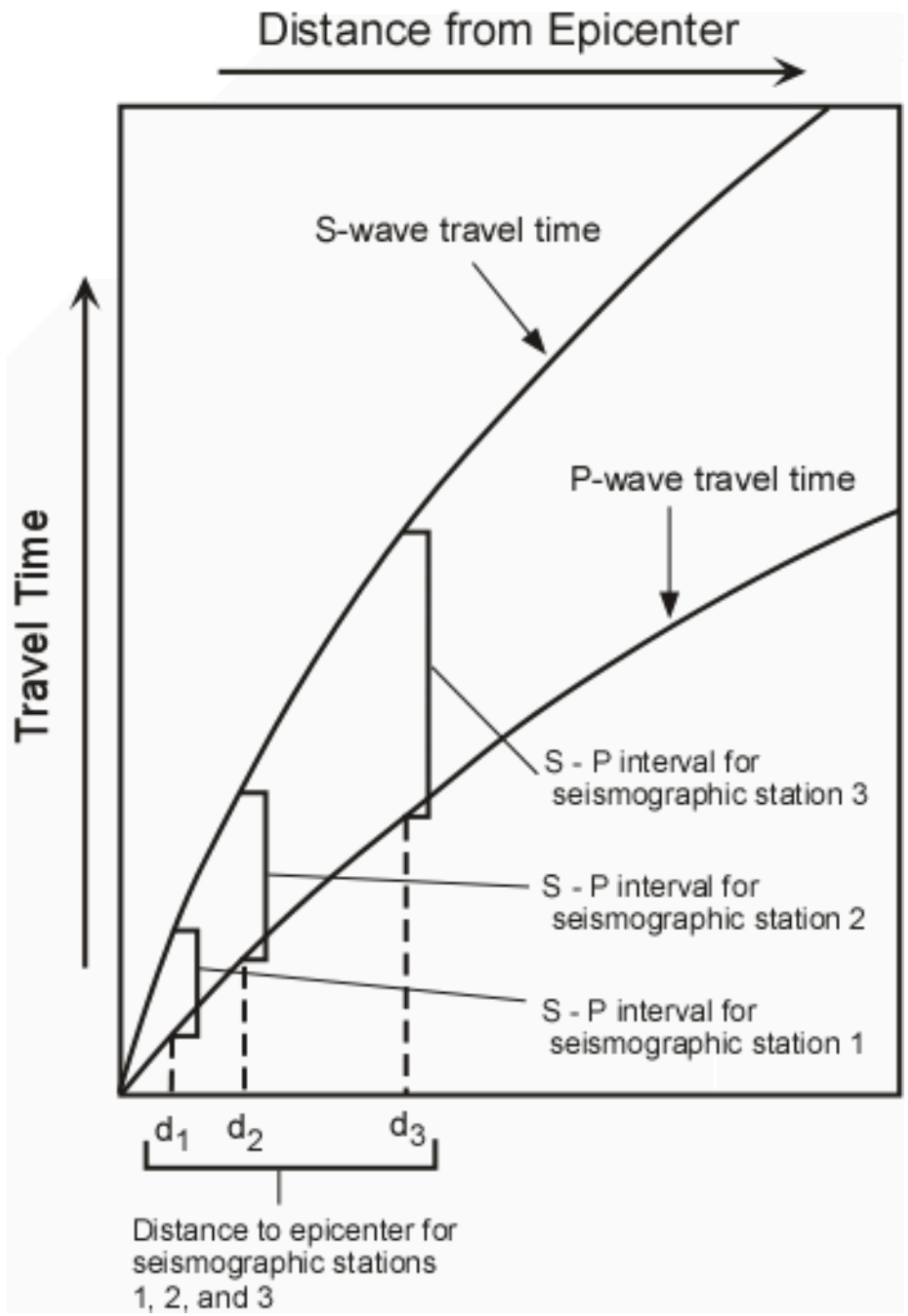

"S minus P" tidsinterval gir avstand. Hvis du kjenner avstand fra 3 steder, har du unik plassering.

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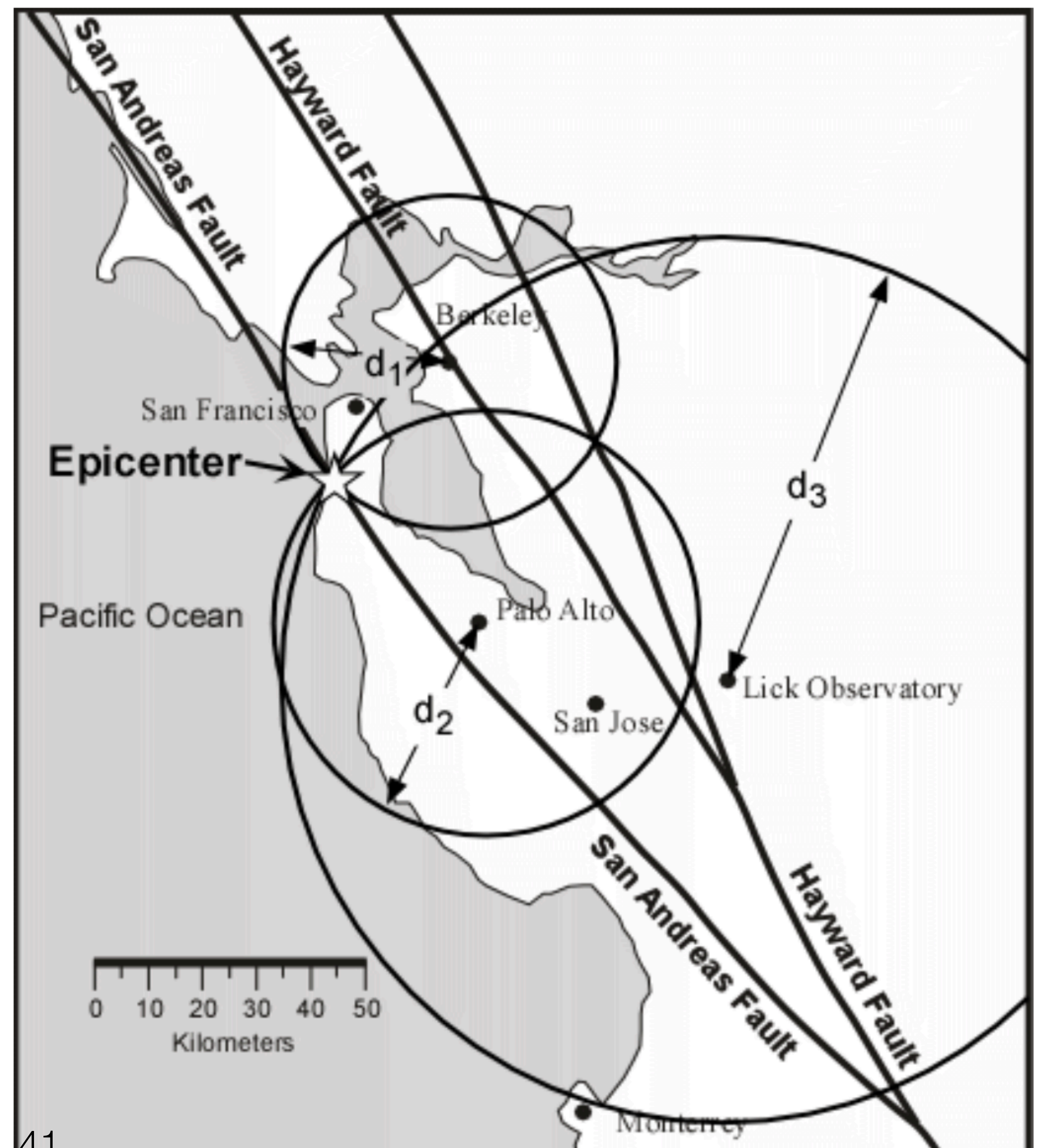
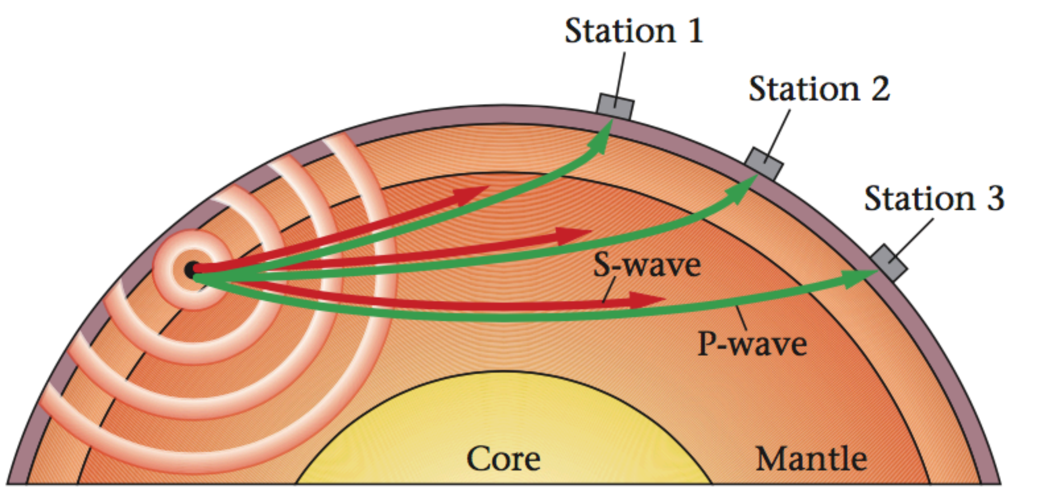


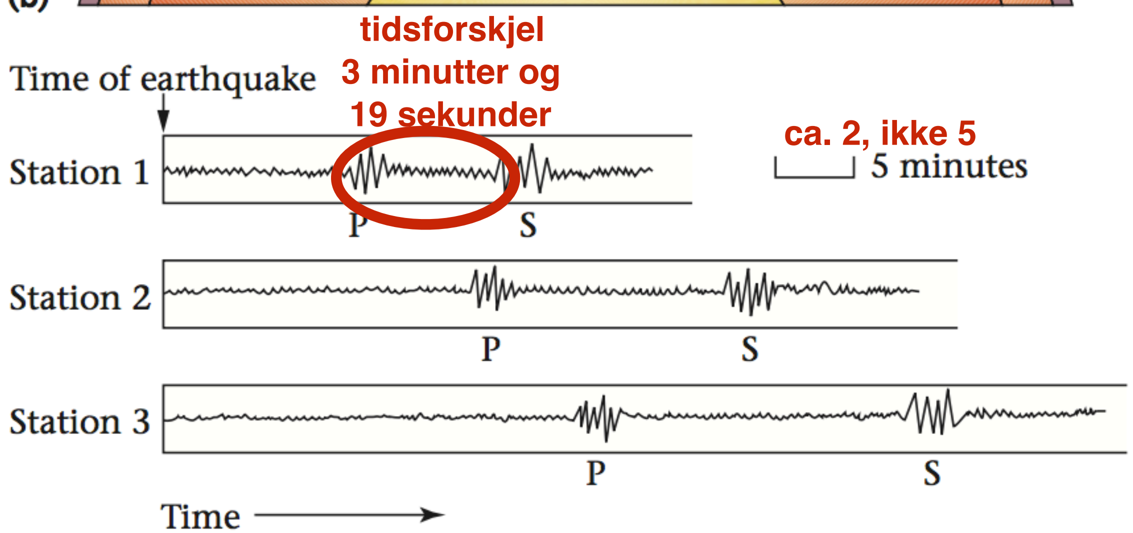
Marshaks forklaring

termine the map position of the epicenter, we use a method called triangulation, by plotting the distance between the epi-

(a)



(b)



(c)

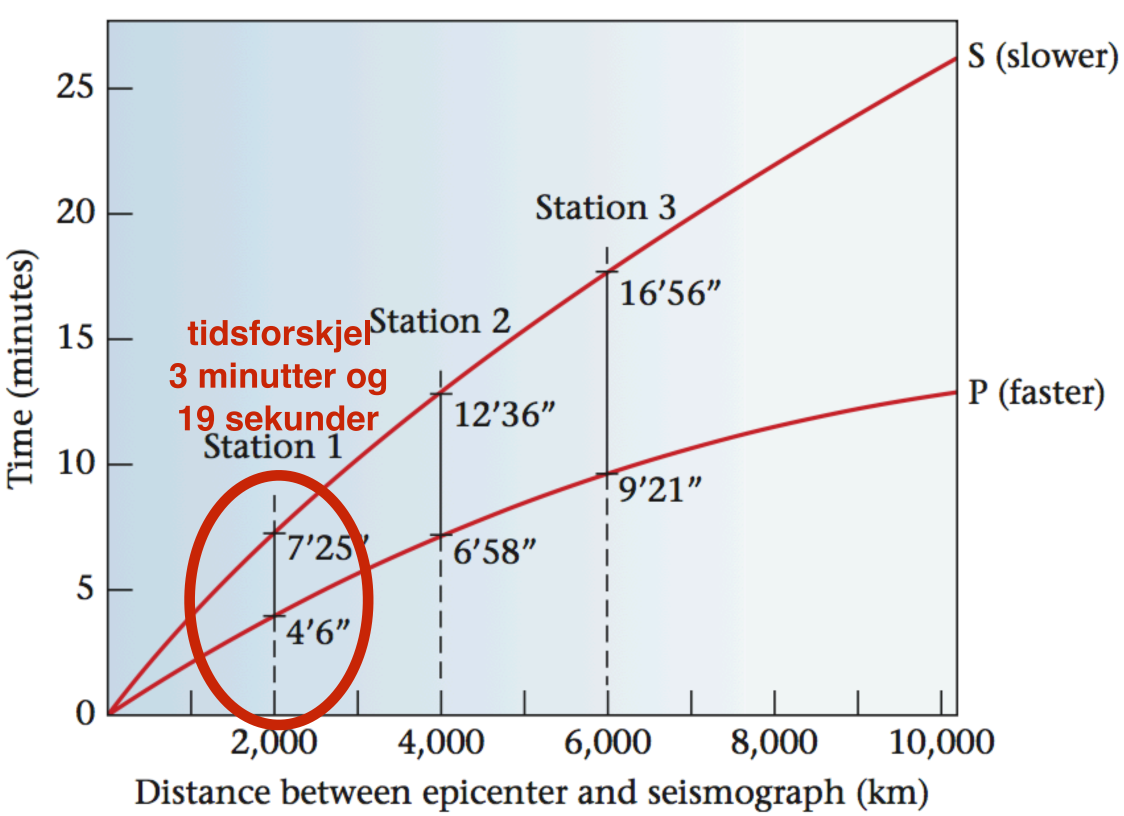


FIGURE 10.16 **(a)** Different seismic waves travel at different velocities, like cars racing at different speeds. **(b)** Thus, different waves arrive at different times at seismograph stations. P-waves arrive first, then S-waves. **(c)** The greater the distance between the epicenter and the seismograph station, the greater the time delay between the P-wave and S-wave arrival times. In this example, station 1 is closest to the epicenter, and station 3 is farthest away from it. Note that the P-wave arrives later at station 3 than at station 1, and that the time interval between P- and S-wave arrivals is greater at station 3 than at station 1. Arrivals at station 2 are in between. **(d)** We can represent the contrasting arrival times of P-waves and S-waves on a travel-time curve. **(e)** If an earthquake epicenter lies 2,000 km from station 1, we draw a circle with a radius of 2,000 km around the station. Following the same procedure for stations 2 and 3, we can locate the epicenter: it lies at the intersection point of the three circles.

metoden fungerer halvveis rundt jordkloden