

How fast were my rocks? Modeling Seismic Velocities for Exhumed Rocks

Part 2: Isotropic Rocks

What are isotropic rocks?

Many rocks have randomly oriented minerals. These rocks are seismically *isotropic*, which means that a seismic wave passing through these rocks from any orientation will have the same velocity. This is the same as dealing with isotropic minerals under the microscope, which are opaque in cross-polarized light because the speed of light through the mineral is the same regardless of polarization. In latter sections, we'll look at *anisotropic* rocks, where the seismic wave speeds depend on which direction the waves pass through the rocks.

Picture an average granite. This consists of a suite of different minerals that are approximately randomly oriented (e.g., each feldspar crystal isn't oriented with their c-axes in the same direction as every other feldspar crystal). Each of these minerals contribute to the speed of a seismic wave passing through the bulk rock, but it doesn't matter which way the waves are passing through the rock, they're going to sample approximately the same proportion of minerals in random orientations.

Defining an 'effective media'

Different minerals have different seismic velocities, but we commonly care about what's happening on a much larger scale than the individual mineral scale. Passive-source seismic data (e.g., tomography) sample seismic velocities at the km-scale. If you're using active source seismic (e.g., reflection or refraction seismology), you can't 'see' as deep into the ground, but the resolution is higher. Even so, it's unlikely to be better than a few meters, which is still much bigger than the mineral scale and might even be bigger than the variations in lithology that you're looking at. This tutorial will walk you through calculating velocities for subduction zone interface shear zones, where your resolution will be on the km-scale. If you are working with a different type of seismic data, you can follow the same strategies, but you may need to be more detailed about your lithologic and mineral variations.

To calculate the average seismic velocities at the scale of seismic data, you need to figure out an 'effective media.' If you have interlayered quartz sandstones and limestones so that you have 50% of each within the area sampled by your seismic data (Figure 2.1a), those rocks will behave as if you have a single *effective medium* made up of homogeneously distributed 50% quartz and 50% calcite (Figure 2.1b). Because the resolution of the seismic data is commonly so much larger than the mineral or lithologic variations, they don't care if the quartz is in one layer and the calcite is in another - the velocities will behave as if everything is equally distributed!

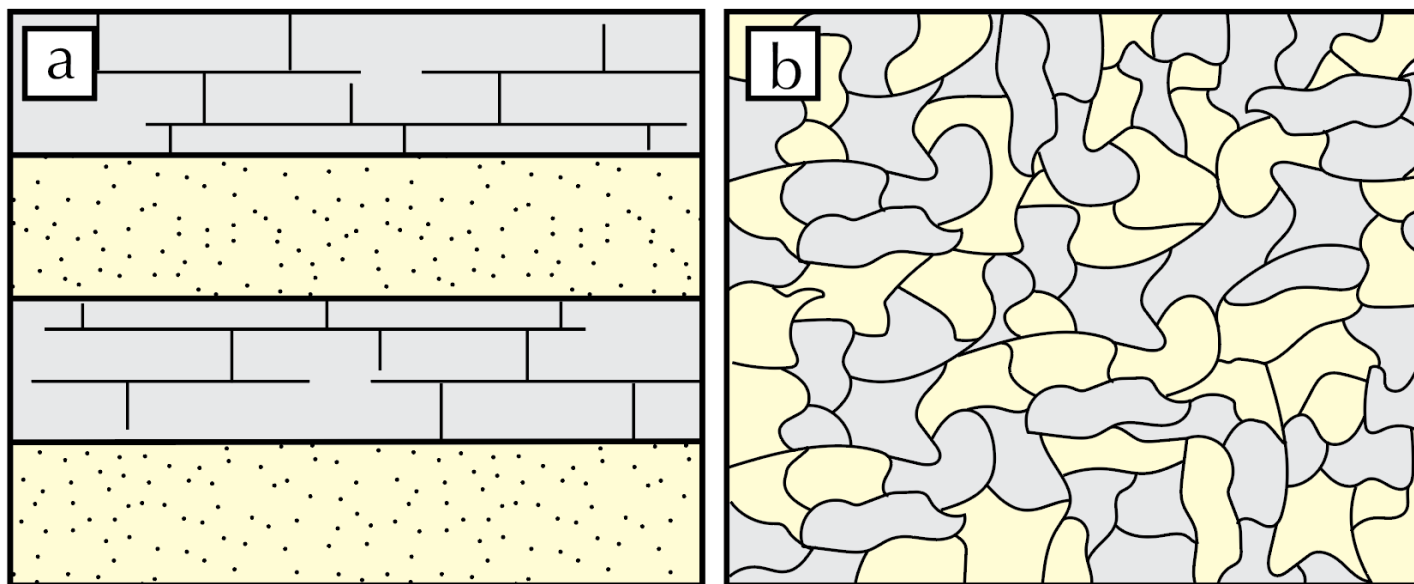


Figure 2.1. a) Distribution of lithologies in the actual rock. b) Seismically equivalent 'effective media' where quartz (yellow) and calcite (gray) are evenly distributed but the same proportion.

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We use this idea of effective media to figure out the seismic velocities of complex rocks, especially on scales larger than we could measure in the lab. To do this (Fig. 2.2), we:

1. Decide on the number of lithologies within the volume we want to model and measure or calculate their relative proportions.
2. Determine the minerals present and relative proportions for each lithology.
3. Calculate a weighted average of the mineral velocities at the relevant pressures and temperatures for each lithology.
4. Calculate a weighted average of the lithologic velocities to model the entire volume.

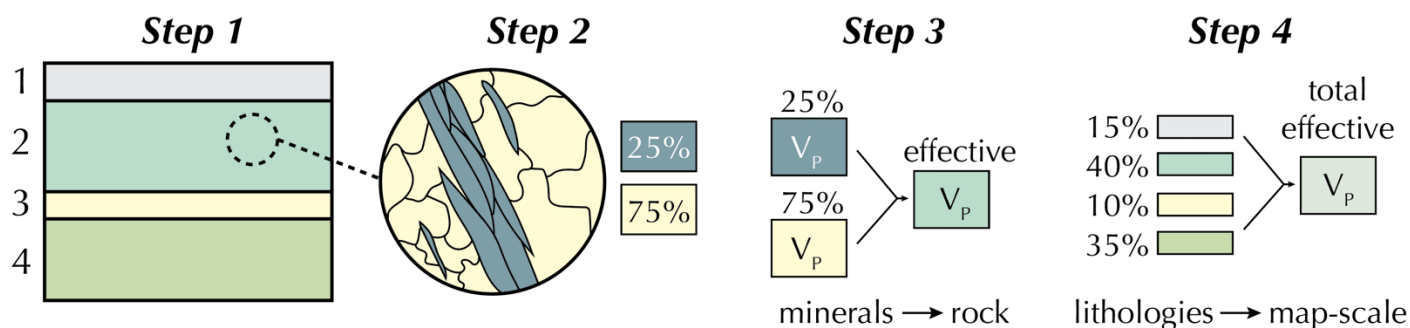


Figure 2.2. Illustrated steps to calculate effective isotropic seismic velocities for lithologically and mineralogically complex rocks.

The exercises below walk you through how to do this using the Abers & Hacker (2016) Matlab Toolbox with details on how to estimate the relative proportions.

Abers & Hacker (2016) Toolbox Overview

In this section, we're going to be working with modelling *isotropic* rocks, which is what this toolbox does. When you calculate an effective medium, it assumes that all minerals are distributed homogeneously and are randomly oriented. This toolbox has built-in scripts to average different minerals and different rocks.

The toolbox also corrects for variations with seismic wave speeds due to pressure and temperature (P-T) conditions. Seismic wave speeds are affected by the density of the material (denser materials will have faster wave speeds), so variations in both pressure and temperature can affect the density. Seismic wave velocities can be calculated using the bulk modulus (K), the shear modulus (G), and density (ρ). For all of these factors, they tend to **increase with increasing pressure** and **decrease with increasing temperature**, but the relative changes amongst these factors depend on different minerals, so the toolbox takes those details into account.

Note: the future parts of this tutorial using MSAT will not correct the minerals for P-T conditions. The variations for shallow rocks (<50 km) are very small, especially if you're comparing V_P/V_S ratios. This is something that you can, however, test by looking at variations from surface conditions to the P-T conditions that you're interested in using this toolbox.

Exploring the toolbox

Before you get started:

- Download the [Abers & Hacker \(2016\) toolbox](#) from their Supporting Information (.zip files).
- Download the **SeismicIsotropicVelocities.m script** from this activity on Teach the Earth and put it in the same folder as the rest of the toolbox files.

The SeismicIsotropicVelocities script allows you to choose between several of the Abers & Hacker toolbox calculations in a single script. In the next few steps, you're going to try out these different options. Note: this assumes that you know how to open a script and call a function in Matlab. If you're not sure how to do this, see the resources in the Overview in this activity on Teach the Earth.

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Through the next few pages, you will learn how to calculate seismic velocities for:

1. A single mineral
2. A pre-defined rock
3. An effective media composed of multiple pre-defined rocks
4. A user-defined rock, where you specify the minerals and relative abundances
5. An effective media composed of multiple user-defined rocks

Calculating for a single mineral

Abers & Hacker provide a suite of pre-defined minerals (see the resources at the end of this document for a full list). Let's calculate the seismic velocities for **quartz at 100°C and 0.1 GPa**.

- Make sure that you're in the folder with the SeismicIsotropicVelocities script and the Abers & Hacker toolbox.
 - You can add a path if you want to be working in a different folder.
- For this script, it is expecting the P-T conditions in °C and GPa.
- In the command window, enter:
`[vp, vs, modu] = SeismicVelocityEstimates(100, 0.1, 'user_single', 'quartz')`
- You should get the following values printed out in the command window:

$$\begin{aligned}vp &= 6.048 \\vs &= 4.0991 \\modu &= 2.693e + 03\end{aligned}$$

These outputs are the p-wave (vp) and s-wave (vs) velocities in km/s, and the modu is the density in kg/m³.

Try it!

Run this same calculation for 2-3 different minerals (see list at the end of this handout). Remember that you need to write the mineral name exactly as it's listed, including spaces if needed and within the ''. Here are a couple of examples:

```
[vp, vs, modu] = SeismicVelocityEstimates(100, 0.1, 'user_single', 'ferroglaucophane')
[vp, vs, modu] = SeismicVelocityEstimates(100, 0.1, 'user_single', 'Mg tschermak')
```

After you have a few velocities:

- Which mineral of the ones that you tried has the fastest velocities? The slowest?
- Do the fastest minerals have the highest density?

Challenge

Experiment with changing the P-T conditions. What happens to the velocities as you increase pressure? Temperature? Both?

Tips & tricks. Every time you call the function as written in this tutorial, you will overwrite the vp, vs, and modu variables. You might want to be able to keep these so that you can compare them or plot them. To do that, change the variable names in the [] at the beginning of the function. For example:

```
[vp_mgt, vs_mgt, modu_mgt] = SeismicVelocityEstimates(100, 0.1, 'user_single', 'Mg tschermak')
```

This will store it as a new variable, which you'll be able to see in your Workspace and use for any future calculations! Remember that variables names can't have spaces and can't start with a number.

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Calculating for a pre-defined rock

Abers & Hacker provide a suite of pre-defined rocks (see the resources at the end of this document for a full list). Let's calculate the seismic velocities for *olivine clinopyroxenite at 100°C and 0.1 GPa*.

- In the command window, enter:

```
[vp, vs, modu] = SeismicVelocityEstimates(100, 0.1, 'predefined_rock', 'olivine clinopyroxenite (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)')
```

 - Yes, you do need to enter the full name if it's listed.
- You should get the following values printed out in the command window:

```
vp = 8.0686  
vs = 4.6683  
modu =  
k: 119.2508  
g: 72.1008  
r: 3.3084e + 03  
vp: 8.0686  
vs: 4.6683  
poi: 0.2484  
kt: 117.8465
```

These outputs are the p-wave (vp) and s-wave (vs) velocities in km/s, and the modu in this case is a structure with multiple different values. See key below. To use these in a later calculation, you would call modu.r, for example. The velocities are already pulled out for you.

k	Bulk Modulus (GPa)
g	Shear Modulus (GPa)
r	Density (kg/m ³)
vp	P-wave velocity (km/s)
vs	S-wave velocity (km/s)
poi	Poisson's Ratio
kt	Isothermal Bulk Modulus (GPa)

The different minerals and mineral abundances for each pre-defined rock are listed in the resources at the end of this document

Try it!

Run this same calculation for 2-3 different rocks (see list at the end of this handout). Remember that you need to write the rock name exactly as it's listed, including spaces if needed and within the '. Here's an example:

```
[vp, vs, modu] = SeismicVelocityEstimates(100, 0.1, 'predefined_rock', 'zeolite facies')
```

After you have a few velocities:

- Which rock of the ones that you tried has the fastest velocities? The slowest?
- Do the fastest rocks have the highest density?

You should see that the denser rocks have faster velocities.

Challenge

Plot density (modu.r) vs. vp for 3-4 rocks. Does it follow what you expect from your answers above?

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Calculating for multiple pre-defined rocks

Most map areas include multiple different lithologies that we might want to model. This section walks you through how to calculate the velocities of an effective media that includes different lithologies of different proportions. ***This function only works with predefined rocks***, but we will see how to calculate for any type of rock in the next couple of sections. Let's calculate the seismic velocities for a map area consisting of **75% epidote blueschist and 25% eclogite at 500°C and 1.5 GPa**.

- In the command window, enter:

```
[vp, vs, modu] = SeismicVelocityEstimates(500, 1.5, 'multirock', {'epidote blueschist', 'eclogite'}, [75 25])
```

 - You must list all rock types within the {}
 - You must list your abundances with the []
 - Relative abundances should add up to 100 and should be listed in the same order as your rocks.

This function will assume the 75% goes with the first rock, 25% goes with the second, etc.
- You should get the following values printed out in the command window:

```
vp = 7.3206  
vs = 4.2141  
modu =  
    k: 96.704  
    g: 57.4142  
    r: 3.2330e + 03  
    vp: 7.3206  
    vs: 4.2141  
    poi: 0.2522  
    kt: 94.8715
```

These outputs at the p-wave (vp) and s-wave (vs) velocities in km/s, and the modu in this case is a structure with multiple different values.

Try it!

Run this same calculation for 2-3 different sets of rocks (see list at the end of this handout) or varying the proportion of the rocks. Remember that you need to write the rock name exactly as it's listed, including spaces if needed and within the ''. Here is an example with more than two rocks:

```
[vp, vs, modu] = SeismicVelocityEstimates(500, 1.5, 'multirock', {'epidote blueschist', 'eclogite', 'dunite'}, [60 20 20])
```

After you have a few velocities:

- Calculate vp/vs for each of the rocks. You can do this by typing vp/vs in the command line.
- How does the ratio of p-wave to s-wave velocity vary with different lithologies?

Challenge

Plot vp/vs for 3-4 rocks vs. the lithology name for 3-4 rocks.

Hint: make a multi cell string using {} with the name of each rock, like you have in the function. Remember that text needs to be within ''.

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Calculating for a user-defined rock

We commonly have specific rocks that we're interested in modelling that may not be available in the predefined list in the toolbox. Marble is a common input to subduction zones, for example, but isn't an option from this toolbox. Let's calculate the seismic velocities for *a quartz-mica schist at 500°C and 1.5 GPa that is 75% quartz and 25% mica*.

- In the command window, enter:

```
[vp, vs, modu] = SeismicVelocityEstimates(500, 1.5, 'user_rock', {'quartz',  
'muscovite'}, [75 25])
```

 - Just like with the last example, you must list both rock types within the {}
 - You must list your abundances with the []
- You should get the following values printed out in the command window:

```
vp = 6.1168  
vs = 3.9294  
modu =  
k: 46.1427  
g: 42.3339  
r: 2.7419e + 03  
vp: 6.1168  
vs: 3.9294  
poi: 0.1487  
kt: 45.3414
```

These are the same outputs as previous functions (see lists in the previous sections). You might notice that the velocities for this rock are much lower than the last rock we looked at. This is because quartz is generally a pretty slow mineral!

Try it!

Run this same calculation for 2-3 different rocks that you define. Feel free to make wild combinations of minerals and modal abundances! This is just to learn about how this function works. Here is an example with only one mineral where we're modelling a marble, but you can have as many different minerals as you like!

```
[vp, vs, modu] = SeismicVelocityEstimates(500, 1.5, 'user_rock', {'calcite'}, [100])
```

After you have a few velocities:

- Calculate vp/vs for each of the rocks. You can do this by typing vp/vs in the command line.
- How does the ration of p-wave to s-wave velocity vary with different lithologies?

Challenge

Plot vp/vs for 3-4 rocks vs. the lithology name for 3-4 rocks.

Hint: make a multi cell string using {} with the name of each rock, like you have in the functin. Remember that text needs to be within ''.

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Calculating for a user-defined set of lithologies

We also commonly don't have a single type of rock that we're interested in – it's usually a bunch of different rocks. Let's calculate the seismic velocities for *a section of rock that is 30% quartz-mica schist (75% quartz and 25% mica) and 60% marble (calcite) at 500°C and 1.5 GPa.*

- In the command window, enter:

```
[vp, vs, modu] = SeismicVelocityEstimates(500, 1.5, 'user_multirock', {'quartz', 'muscovite'}, [75 25], 'calcite', [100], [30 60])
```

 - In this case, you define each of the lithologies first with {minerals} and [modal abundances].
 - Then you define the modal abundances of the lithologies in the final [].
 - Spend some time with the lines above to make sure that you know where each of the numbers and minerals winds up and *why* they are in that order.
- You should get the following values printed out in the command window:

```
vp = 6.3570
vs = 3.5574
modu =
    k: 64.4745
    g: 34.6635
    r: 2.7391e + 03
vp: 6.3570
vs: 3.5574
poi: 0.2720
kt: 63.5020
```

Try it!

Let's try this with a set of three different lithologies at 500°C and 1.5 GPa. Imagine you have a set of rocks that are listed below with lithologic and mineral abundances. These are simplified for the purposes of learning the toolbox, but you're welcome to make them more complicated!

Lithologic Modal Abundances	Lithology	Mineral Modal Abundances
15%	Epidote blueschist	50% glaucophane 50% epidote
50%	Marble	100% calcite
35%	Chlorite schist	5% quartz 22% low albite 30% ferroactinolite 32% epidote 11% clinocllore

Try to set up the velocity calculations using the user_multirock option. The values you should get are below so that you can check your work.

```
vp = 6.8493
vs = 3.7682
k: 82.8654
g: 42.0523
r: 2.9615e + 03
```

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Modelling your own area

You can go from here to model your own rocks! You will need to know the P-T conditions for your rocks, and then remember to follow the steps from Fig. 2.2: decide on the lithologies, calculate or estimate the mineral modal abundances, and then use the `user_multirock` option that you just learned about to calculate the net velocities.

As you get started on this part, you might be asking the questions:

- How many lithologies?
- How detailed do I need to be with my minerals?

These are tough questions, but you can determine how detailed you need to be using a *sensitivity analysis*. This is a strategy where you change your assumptions and see how much of a difference it makes in the overall calculations. Examples:

- You have a range of P-T conditions. Calculate the velocities for your lithologies at the maximum and minimum P-T (or for a range of P-T) and see how much the velocity varies.
- You have some lenses of a different lithology that make up a small proportion of the overall rocks. Calculate velocities with or without these lithologies to see if including them significantly changes the results.
- Similarly, you have a small proportion of a mineral in a given lithology. Calculate the velocities with and without that mineral accounted for to determine if including it significantly changes the results.

Sensitivity analyses are a great way to determine what simplifying assumptions you can or can't make!

Tips & tricks – estimating modal abundances. You can estimate modal abundances in a couple of different ways, depending on whether you're thinking about map, outcrop, or thin section scale. We recommend different strategies for each:

- Use a point counting software (<https://jmicrovision.github.io/>) to get good quantitative estimates of your mineral abundances. You can also estimate by eye, depending on how much variation you see and how much it affects your results. This is a good time to use sensitivity analyses to determine what is needed for your rocks and your data.
- Outcrops can be either traced in a graphics software (e.g., Adobe Illustrator) and then analyzed using something like Matlab or ImageJ. This works best if you set one lithology to black and figure out the percentage of pixels that lithology takes up out of the total image.
- Outcrops and geologic maps can also be estimated by calculating or measuring the structural thickness (e.g., using a cross section) and calculating the percent of the total structural thickness. This assumes that structural thicknesses don't vary laterally, so sensitivity analyses may be appropriate to evaluate whether that is a reasonable assumption for your rocks and conditions.

References

Abers, G.A. and Hacker, B.R., 2016. A MATLAB toolbox and Excel workbook for calculating the densities, seismic wave speeds, and major element composition of minerals and rocks at pressure and temperature: *Geochemistry, Geophysics, Geosystems*, no. 17(2), p. 616-624.

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Predefined Minerals available in the Abers & Hacker (2016) Toolbox

Type the **full name** in the function call to use

quartz	forsterite	glaucophane	muscovite	prehnite
coesite	fayalite	ferroglaucophane	celadonite	pumpellyite
high albite	enstatite	tremolite	talc	laumontite
low albite	ferrosilite	ferroactinolite	clinochlore	wairakite
anorthite	Mg tschermak	tschermakite	daphnite	brucite
orthoclase	diopside	pargasite	antigorite	clinohumite
sanidine	hedenbergite	hornblende	zoisite	phase A
almandine	jadeite	anthophyllite	clinozoisite	sillimanite
grossular	acmite	phlogopite	epidote	kyanite
pyrope	Ca tschermak	annite	lawsonite	spinel
hercynite	magnetite	ilmenite	rutile	titanite
cordierite	scapolite	calcite	aragonite	magnesite

Predefined Rocks available in the Abers & Hacker (2016) Toolbox

Type the **full name** in the function call to use

"diabase 504B (Alt, J.C., H. Kinoshita, L.B. Stokking, et al., Proceedings of the Ocean Drilling Program, Initial Reports, 148, 1993)"	16.5% Low Albite 38.5% Anorthite 1% Forsterite 32.25% Diopside 10.75% Hedenbergite 1% Magnetite	epidote amphibolite facies	2.0% Quartz 20.0% Low Albite 9.0% Temolite 16.0% Ferroactinolite 15.0% Tschermakite 10.0% Pargasite 2.0% Muscovite 2.0% Clinocllore 3.0% Daphnite 18.0% Epidote 3.0% Spinel
"gabbonorite Oman (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)"	9.6% Low Albite 38.4% Anorthite 7.5% Forsterite 2.5% Fayalite 4.5% Enstatite 5.5% Ferrosilite 25.6% Diopside 6.4% Hedenbergite	garnet amphibolite facies	2.0% Quartz 11.0% Low Albite 6.0% Anorthite 11.0% Almandine 8.0% Grossular 3.0% Pyrope 17.0% Ferroglaucophane 18.0% Tremolite 5.0% Ferroactinolite 14.0% Tschermakite 4.0% Zoisite 1.0% Spinel
"olivine gabbro Oman (Browning, P., Cryptic variation within the cumulate sequence of the Oman ophiolite: magma chamber depth and petrological implications, in Ophiolites and oceanic lithosphere, Geological Society Special Publications, edited by I.G. Gass, S.J. Lippard, and A.W. Shelton, pp. 71-82, Geological Society of London, London, 1984)"	13.75% Low Albite 41.25% Anorthite 7.5% Forsterite 2.5% Fayalite 28.0% Diopside 7.0% Hedenbergite	amphibolite facies	1.0% Quartz 18.0% Low Albite 18.0% Anorthite 13.0% Tremolite 25.0% Ferroactinolite 12.0% Tschermakite 12.0% Paragasite 1.0% Magnetite
"wehrlite Oman (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)"	3.25% Low Albite 9.75% Anorthite 31.5% Forsterite 3.5% Fayalite 4.0% Enstatite 1.0% Ferrosilite	granulite facies	21% High Albite 21% Anorthite 9% Enstatite 9% Ferrosilite 5% Diopside 9% Hedenbergite

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	37.6% Diopside 9.4% Hedenbergite		2% Tremolite 7% Ferroactinolite 9% Tschermakite 7% Pargasite 1% Magnetite
"olivine clinopyroxenite (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)"	13.2% Forsterite 1.8% Fayalite 77.35% Diopside 7.65% Hedenbergite	garnet granulite facies	20% Low Albite 15% Anorthite 5% Almandine 13% Grossular 10% Pyrope 9% Enstatite 9% Ferrosilite 5% Diopside 11% Hedenbergite 2% Jadeite 1% Magnetite
"pyrolite (Gubbins, D., A. Barnicoat, and J. Cann, Seismological constraints on the gabbro-eclogite transition in subducted oceanic crust, Earth and Planetary Science Letters, 122, 89-101, 1994)"	2.1% Almandine 1.1% Grossular 10.8% Pyrope 54.5% Forsterite 6.7% Fayalite 14.7% Enstatite 1.5% Ferrosilite 7.4% Diopside 1.2% Hedenbergite	lawsonite blueschist facies	2% Quartz 8% Low Albite 11% Glaucophane 6% Ferroglaucophane 12% Tremolite 17% Ferroactinolite 2% Muscovite 6% Clinocllore 3% Daphnite 30% Lawsonite 3% Rutile
"lherzolite (Ernst, W.G., Petrochemical study of lherzolitc rocks from the Western Alps, J. Petrol., 19, 341-392, 1978)"	45.4056% Forsterite 5.0682% Fayalite 22.4838% Enstatite 2.4982% Ferrosilite 20.0287% Diopside 4.5% Spinel	jadeite lawsonite blueschist facies	2% Quartz 8% Jadeite 11% Glaucophane 6% Ferroglaucophane 14% Temolite 17% Ferroactinolite 2% Muscovite 5% Clinocllore 4% Daphnite 28% Lawsonite 3% Rutile
"lherzolite, basal (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)"	67.0440% Forsterite 6.9560% Fayalite 19.152% Enstatite 1.848% Ferrosilite 2.88% Diopside 0.12% Hedenbergite 1.0% Spinel 1.0% Magnetite	epidote blueschist	5% Quartz 18% Low Albite 4% Glaucophane 4% Ferroglaucophane 15% Tremolite 5% Ferroactinolite 2% Muscovite 8% Clinocllore 8% Daphnite 5% Clinozoisite 23% Epidote 3% Rutile
"harzburgite (Lippard, S.J., A.W. Shelton, and I.G. Gass, The Ophiolite of Northern Oman, 178 pp., Geological Society of London, London, 1986)"	72.48% Forsterite 7.52% Fayalite 18.24% Enstatite 1.76% Ferrosilite	amphibole eclogite	3% Quartz 17% Almandine 15% Grossular 7% Pyrope 15% Diopside 3% Hedenbergite 12% Jadeite 10% Ferroglaucophane 4% Tremolite 2% Ferroactinolite 8% Pargasite 2% Muscovite 2% Rutile
dunite	90.0% Forsterite	zoisite eclogite	6.0% Quartz

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	10.0% Fayalite		18.054% Almandine 8.0% Grossular 8.0% Pyrope 4.0% Enstatite 2.0% Ferrosilite 19.5% Diopside 5.401% Hedenbergite 17.0% Jadeite 2.0% Muscovite 8.0% Zoisite 2.0% Rutile
zeolite facies	8.0% Quartz 19.0% Low Albite 2.0% Muscovite 18.0% Clinocllore 10.0% Daphnite 25.0% Laumontite 2.0% Spinel 4.0% Magnetite 12.0% Calcite	lawsonite amphibole eclogite	2.5% Quartz 8.0% Almandine 7.5% Grossular 3.7289% Pyrope 7.5% Diopside 1.3583% Hedenbergite 10.0% Jadeite 5.5% Glaucophane 8.0% Ferroglaucophane 9.1122% Tremolite 9.5% Ferroactinolite 3.8333% Pargasite 2.0% Muscovite 2.667% Clinocllore 2.0% Daphnite 14.0% Lawsonite 2.8% Rutile
prehnite-pumpellyite facies	13.0% Quartz 20.0% Low Albite 2.0% Muscovite 16.0% Clinocllore 8.0% Daphnite 14.0% Prehnite 13.0% Pumpellyite 3.0% Spinel 6.0% Magnetite 5.0% Calcite	Eclogite	6% Quartz 18% Almandine 13% Grossular 11% Pyrope 4% Ferrosilite 24% Diopside 2% Hedenbergite 18% Jadeite 2% Muscovite 2% Rutile
greenschist facies	5.0% Quartz 22.0% Low Albite 12.0% Temolite 5.0% Ferroactinolite 2.0% Muscovite 11.0% Clinocllore 8.0% Daphnite 32.0% Epidote 3.0% Spinel		