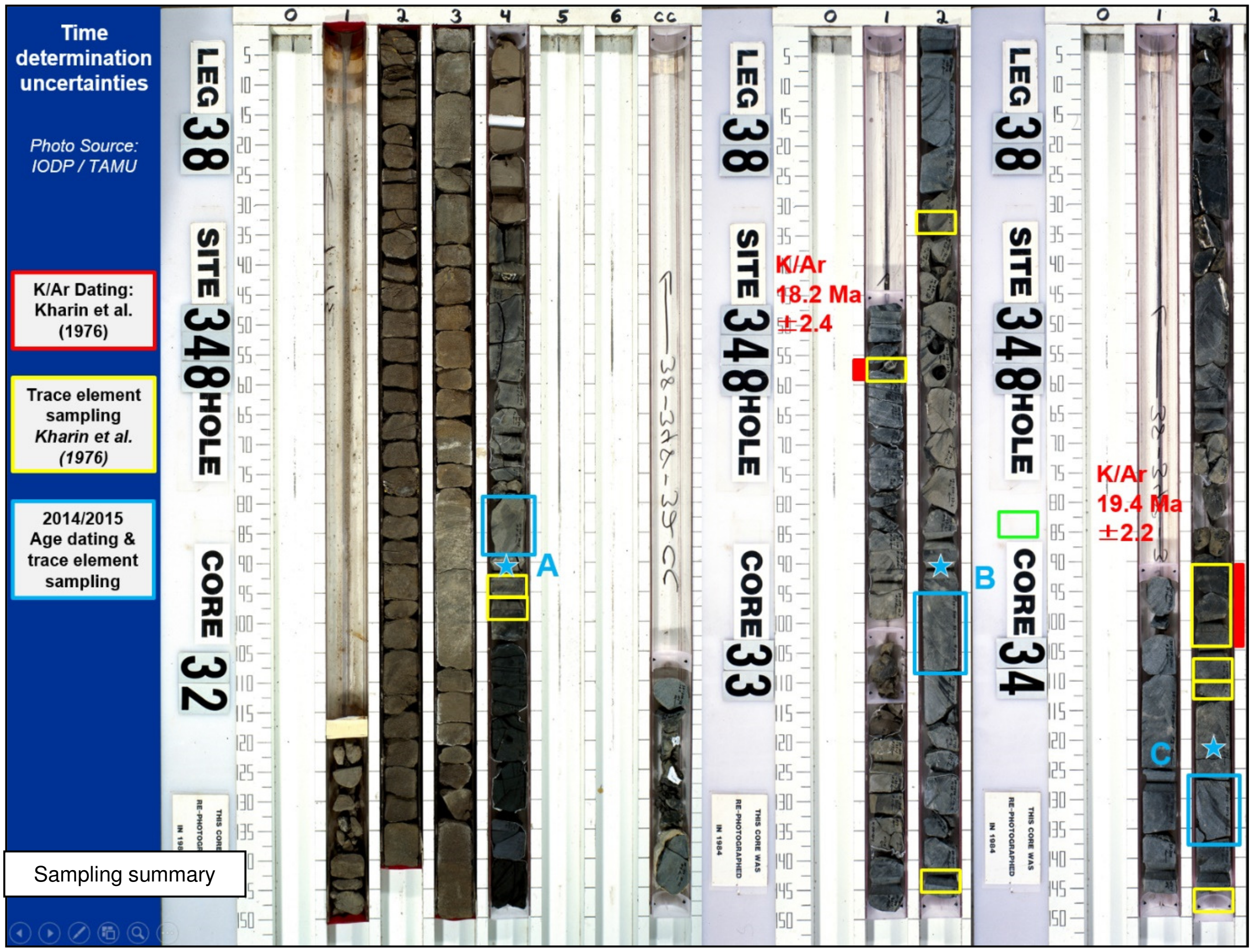
Supplement 3

DSDP Leg 38 sites 348 & 350 Thin-section sample descriptions.

The samples described here were used to selected samples for $^{40}Ar/^{39}Ar$ age analysis of unaltered plagioclase, which have been found in all 7 samples A-G, but are best seen in samples C, D, E, F and G.

The reviewed thin sections were analysed with 5x magnification in both plane polarized light (PPL) and with crossed polarized light (CP). A brief description of the selected thin sections follows with each sample.

(a) Icelandic Plateau thin-section analysis for 3 samples of borehole DSDP Leg 38 site 348



Site Summary

DSDP Leg 38 site 348 penetrated 17,4 m into fractured but homogenous basalt section at 526,6 m below the sea floor. The drilled interval is located within the assumed initial oceanic ridge basalt section of the Kolbeinsey ridge system and serves as a control site for comparison to Mid-oceanic ridge basalt (MORB) west of JMMC. The uppermost drilled basaltic section consisted primarily of finely-crystalline olivine-tholeiite with volcanic glass closer to the basalt/sediment contact, which has been replaced by smectite. In many cases, plagioclase crystals exhibit skeletal growth and 'swallow-tail'-morphology, which combined with the apparent glass content suggests that the basalt was rapidly cooled [e.g. *Lofgren, 1974*]. The basalt seems somewhat porphyritic, with micro-phenocrysts of plagioclase and olivine pseudomorphs that have fully altered to iddingsite. Plagioclase appears almost unaltered (~5-10% alteration), excluding some minor smectite fractures. Clinopyroxene and opaque minerals, such as augite, are unaltered but exhibit dentritic or feather-like morphology deeper in the cored section, which is common for ocean floor basalts [e.g. *Lofgren, 1983*]. The lowermost cored section consisted of fine- to medium-crystalline, aphyric olivine-tholeiite with rather large and well-formed, symmetrical vesicles with a porosity estimate of 5%. Considering the large vesicles, it is possible that the basalt may have reached close to the surface either as a sill or dyke intrusion, or as a subaerial lava flow; a conclusion also reached in the original analysis by *Kharin* [1976] and *White* [1978]. The absence of lava-flow characteristics, including pillow structure and glassy rims, does not support a submarine extrusion.

Thin section sample BCR004907294 – Thin section A

Fine grained basalt, perhaps olivine-tholeiite (olivine in matrix, Fe-oxides both anhedral and euhedral, therefore forming rather late in the crystallization) although the texture is not sub-ophitic but rather intergranular. Glass, which has been replaced by smectite, seems to have been rather common within the matrix. In many cases, plagioclase crystals exhibit skeletal growth, represented e.g. by their centre filled with smectite altered glass, and also exhibiting „swallow-tail“ morphology (Figure S 3-1). These plagioclase shapes combined with the apparent glass content suggests that the basalt was rapidly cooled [e.g. *Lofgren, 1974*]. It cannot be excluded, however, that some of the smectite filled areas may have been inter-crystalline porosity, which is common in olivine-tholeiites. The basalt seems somewhat porphyritic, with micro phenocrysts of plagioclase and olivine pseudomorphs (fully altered to iddingsite). An example of this is shown in Figure S 3-2. The largest plagioclase crystals have a length of around 500 µm.

It is highly likely that there was some glass content in this sample, but it has been completely replaced by smectite. Olivine is fully altered to iddingsite, but plagioclase seems almost completely fresh, excluding some minor smectite fractures (~5-10% alteration). Clinopyroxene and opaque minerals are unaltered. Hardly any vesicles are seen, but the few that are noted are filled with smectite and calcite.

Figure S 3-1. *Plagioclase exhibiting swallow-tail morphology and skeletal growth. View in PPL.*

Thin section sample BCR004907293 – Thin section B

Fine grained basalt, not fully holocrystalline. Clinopyroxene has crystallized fast in a cool environment exhibiting dentritic morphology or feather-like shape (Figure S 3-3). This is common for ocean floor basalts and has been described [e.g. *Lofgren, 1983*]. Plagioclase is rather finely crystallized, also showing signs of fast cooling such as skeletal growth and „swallow-tail“-morphology (Figure S 3-4). The sample is mostly aphyric, although some plagioclase crystals and olivine pseudomorphs (fully altered to iddingsite – Figure S 3-5) seem to be somewhat larger than the rest of the matrix (Figure S 3-6) indicating irregular crystallinity or micro-phenocrysts. There does not seem to be any fresh olivine left in the matrix of the basalt. The presence of olivine suggests that the basalt may be olivine-tholeiite, although sub-ophitic texture is not noted.

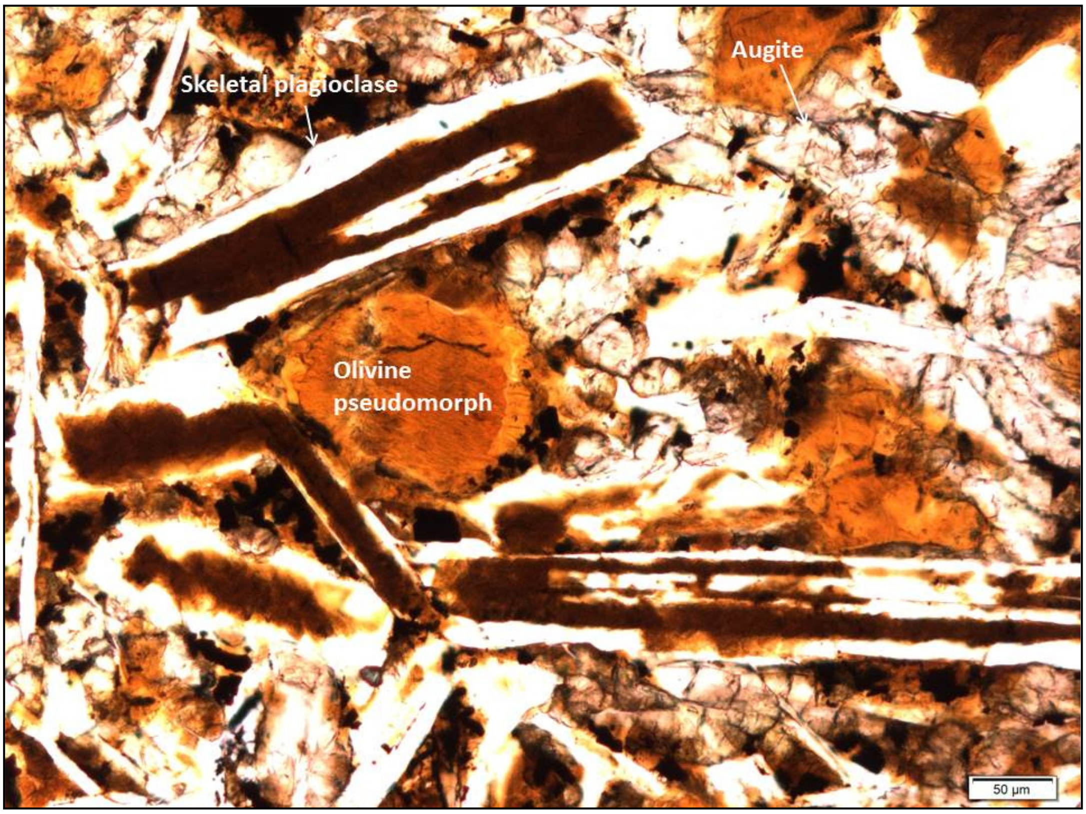


Figure S 3-2. *Plagioclase and olivine micro-phenocrysts. Olivine has been completely altered to iddingsite and plagioclase is skeletal, with glassy (smectite) centres. View in PPL.*

Figure S 3-3. *Augite that has crystallized fast in a cool environment commonly becomes dendritic. Here exhibiting curved, branching dendrites. View in PPL.*

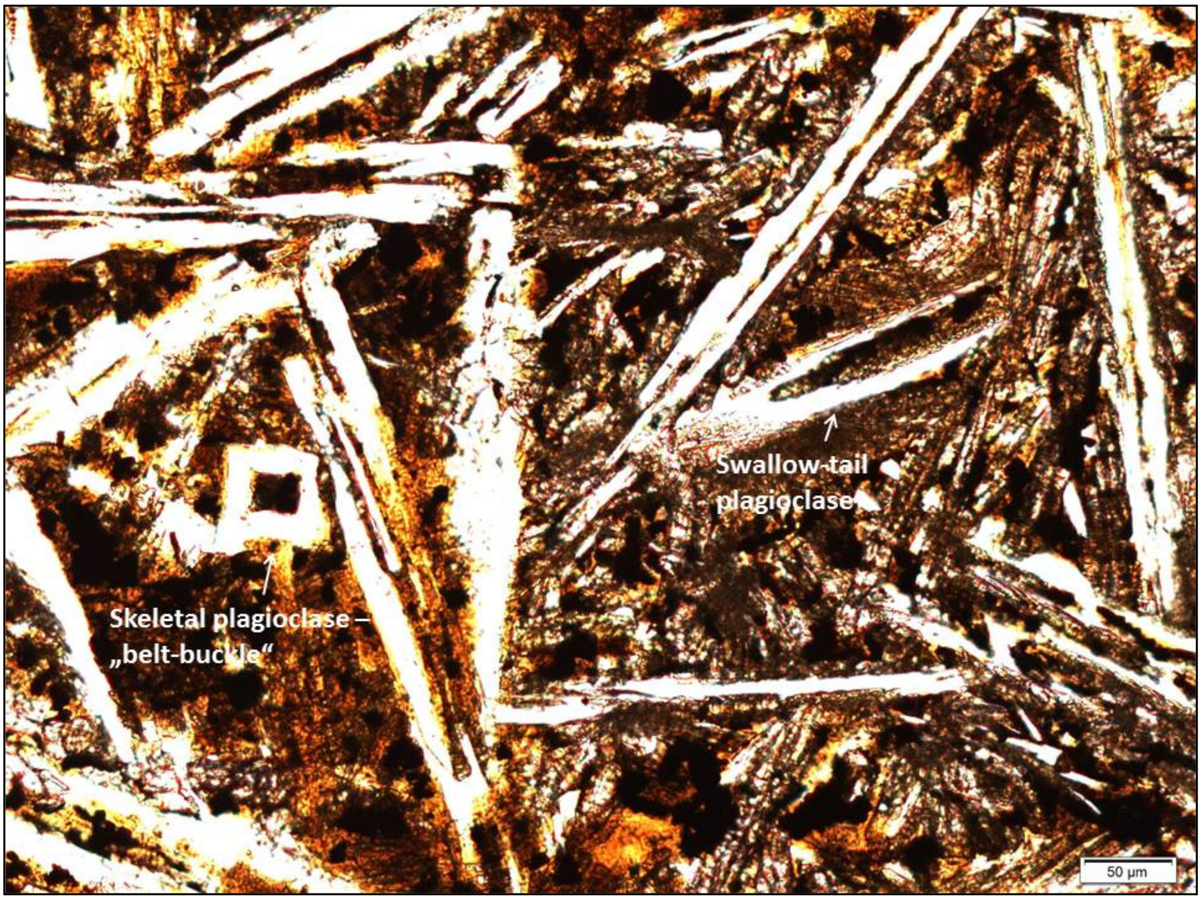


Figure S 3-4. *Skeletal plagioclase, suggesting fast cooling. View in PPL.*

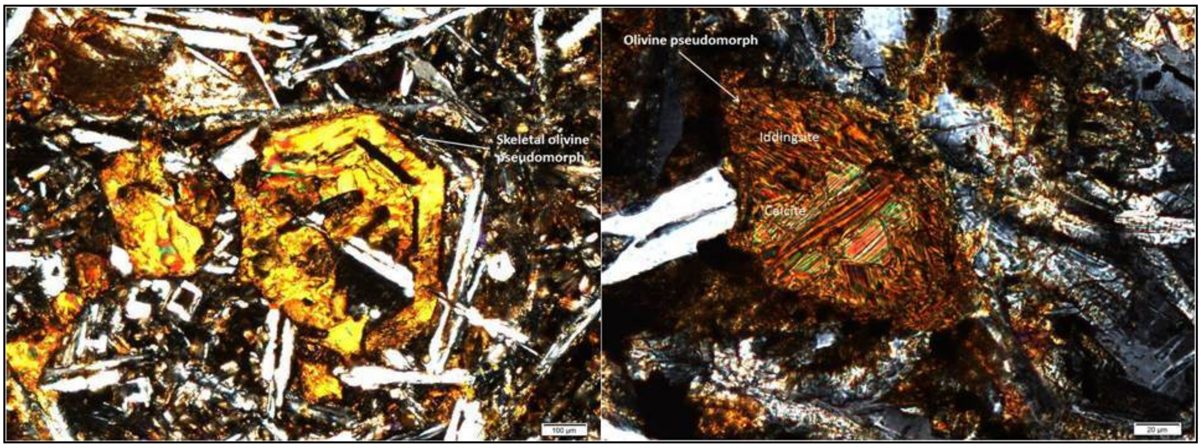


Figure S 3-5. *To the left: skeletal olivine pseudomorph – iddingsite. To the right: olivine pseudomorph – iddingsite and calcite. View in CP.*

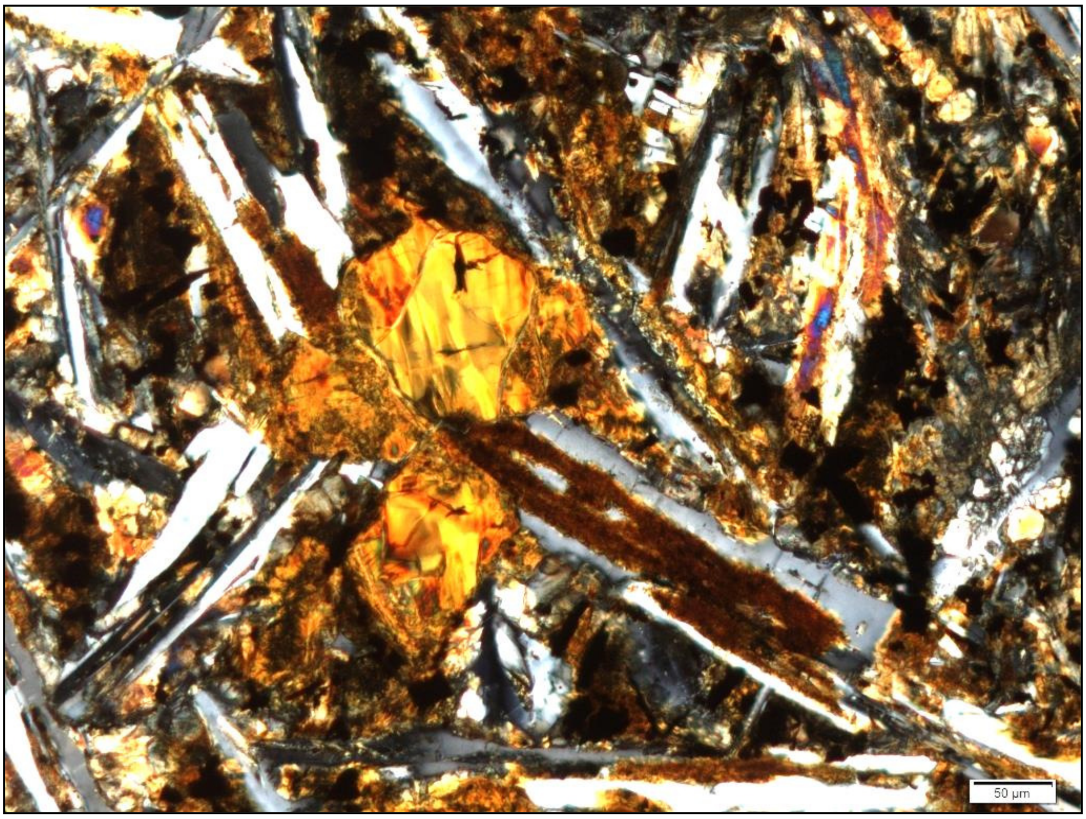


Figure S 3-6. *Olivine pseudomorphs and plagioclase crystals. View in CP.*

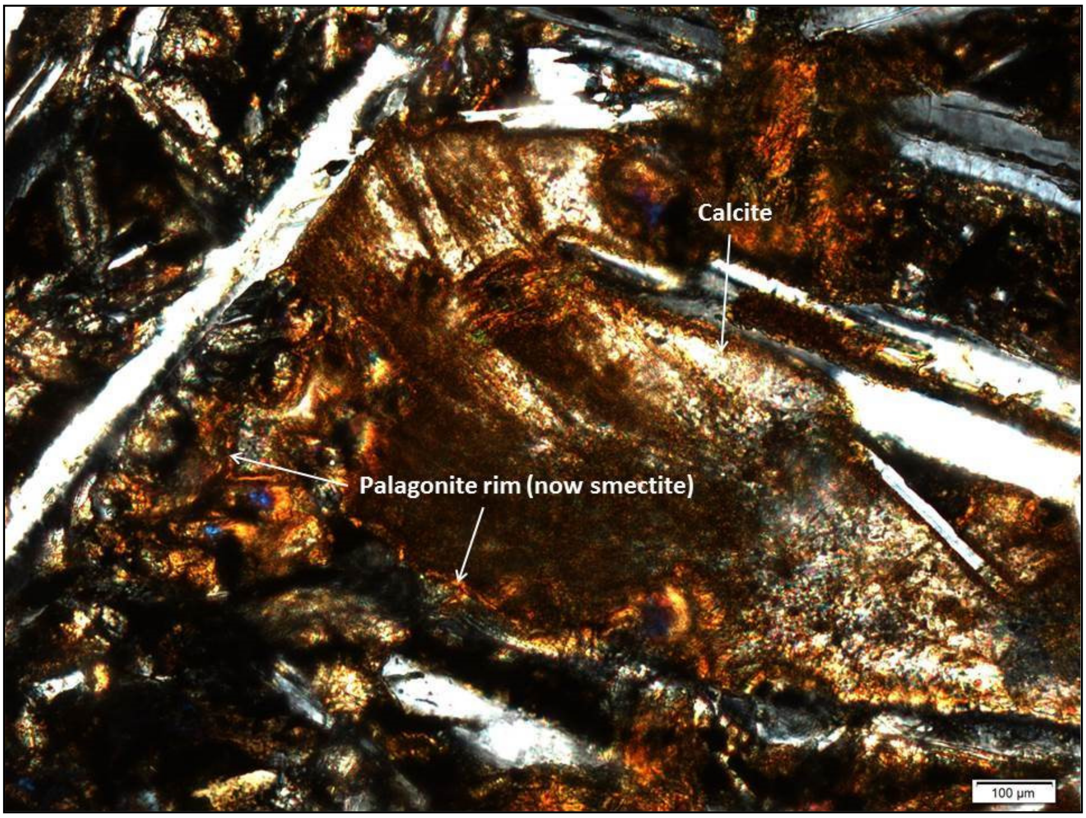


Figure S 3-7. *Altered glass in between plagioclase crystals. View in CP.*

Interstitial glass seems to be present, but it is fully altered to smectite and in some cases to calcite. The existence of glass within the sample is further proved by the signature of palagonite rims which are commonly exhibited on glass grains [e.g. *Jakobsson and Moore, 1986; Crovisier et al., 1992; Helgadóttir, 2006*]. Both can be seen in Figure S 3-7. Olivine is fully altered to iddingsite and in rare cases to calcite (Figure S 3-5). Some smectite alteration in tiny fractures is present in plagioclase (around 5% alteration). Clinopyroxene (augite) and opaque minerals are unaltered.

Thin section sample BCR004907296 – Thin section C

Fine- to medium grained, aphyric basalt with rather large and well formed (symmetrical) vesicles (Figure S 3-8). Porosity is estimated 5% (vesicular porosity). Considering the large vesicles, it is possible that the basalt may have reached surface and it may not have been erupted on the seafloor, but rather on land as a thick lava flow. It is however, also possible that this is an intrusive that may have intruded close to the surface, therefore releasing gas, forming vesicles. In any case, it seems likely that there was not much water involved, since the rock is well crystallized and if it were an intrusive the pressure would not have been substantial, allowing gas release.

The rock is holocrystalline, with some inter-crystalline porosity, that has been filled with smectite (Figure S 3-9). It seems rich in olivine pseudomorphs, especially in certain areas within the sample (Figure S 3-8) and is therefore likely to be rather primitive in composition. Although it is sometimes difficult to decide whether the supposed pseudomorphs are really olivine or if some of them could perhaps represent inter-crystalline porosity filled with smectite. The texture of the basalt is intergranular to sub-ophitic and opaque minerals are both anhedral and euhedral. This suggests that the basalt is olivine-tholeiite although. The largest plagioclase crystals are around 400 μm in length. No cross-cutting fractures were noted in this sample.

If glass was present it is fully altered to smectite. Olivine is also completely altered to iddingsite and plagioclase shows some minor alteration exhibiting smectite fractures or spots. The spots could perhaps show altered glass inclusions within the plagioclase. Vesicles are filled, or almost filled, with fine grained smectite.

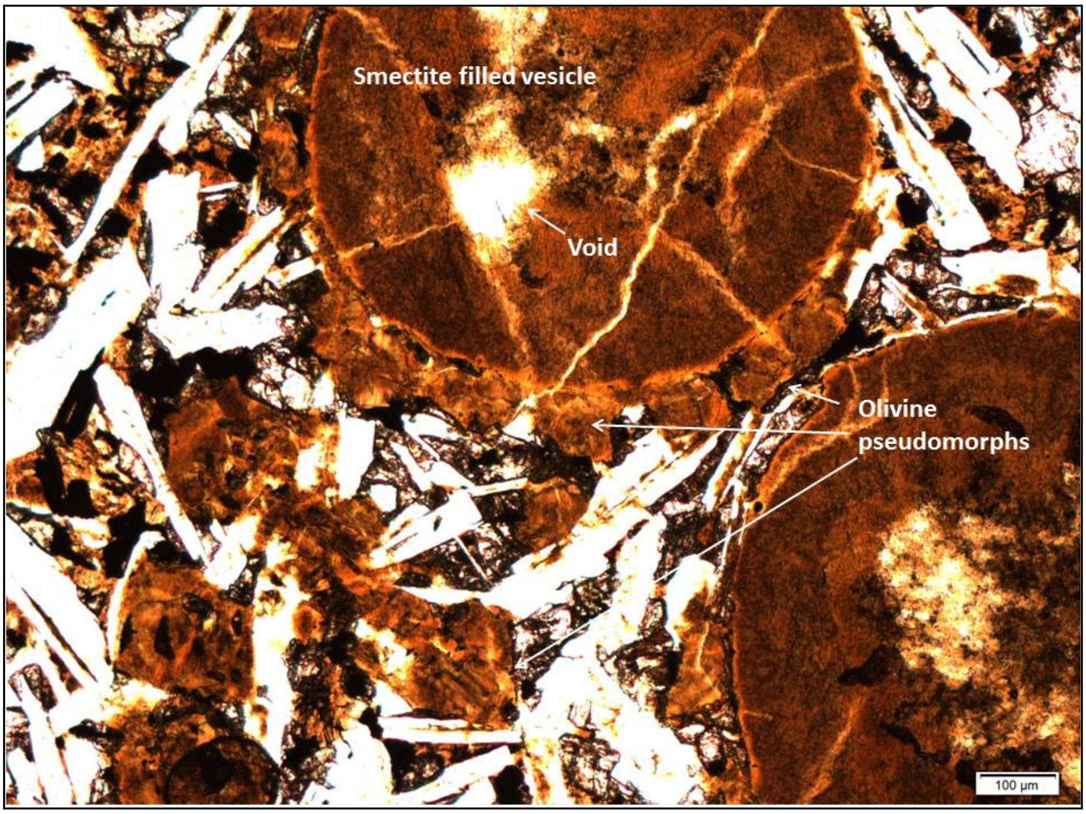


Figure S 3-8. *Vesicles in sample with olivine pseudomorphs. View in PPL.*

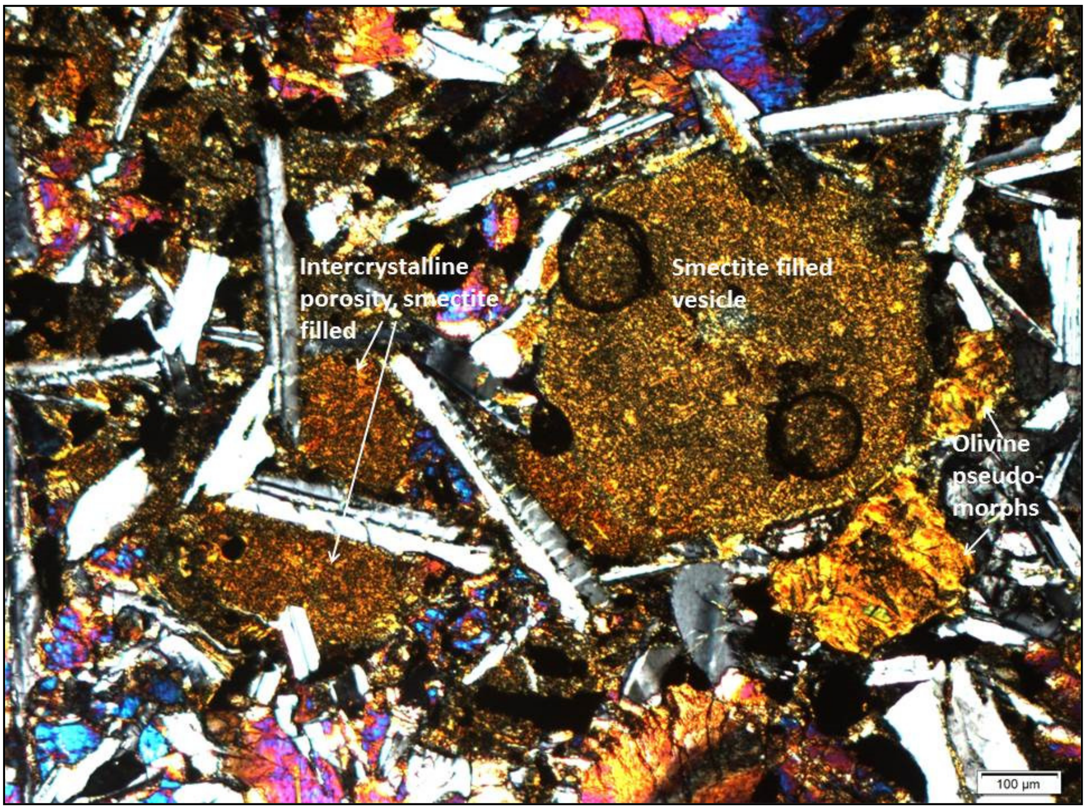
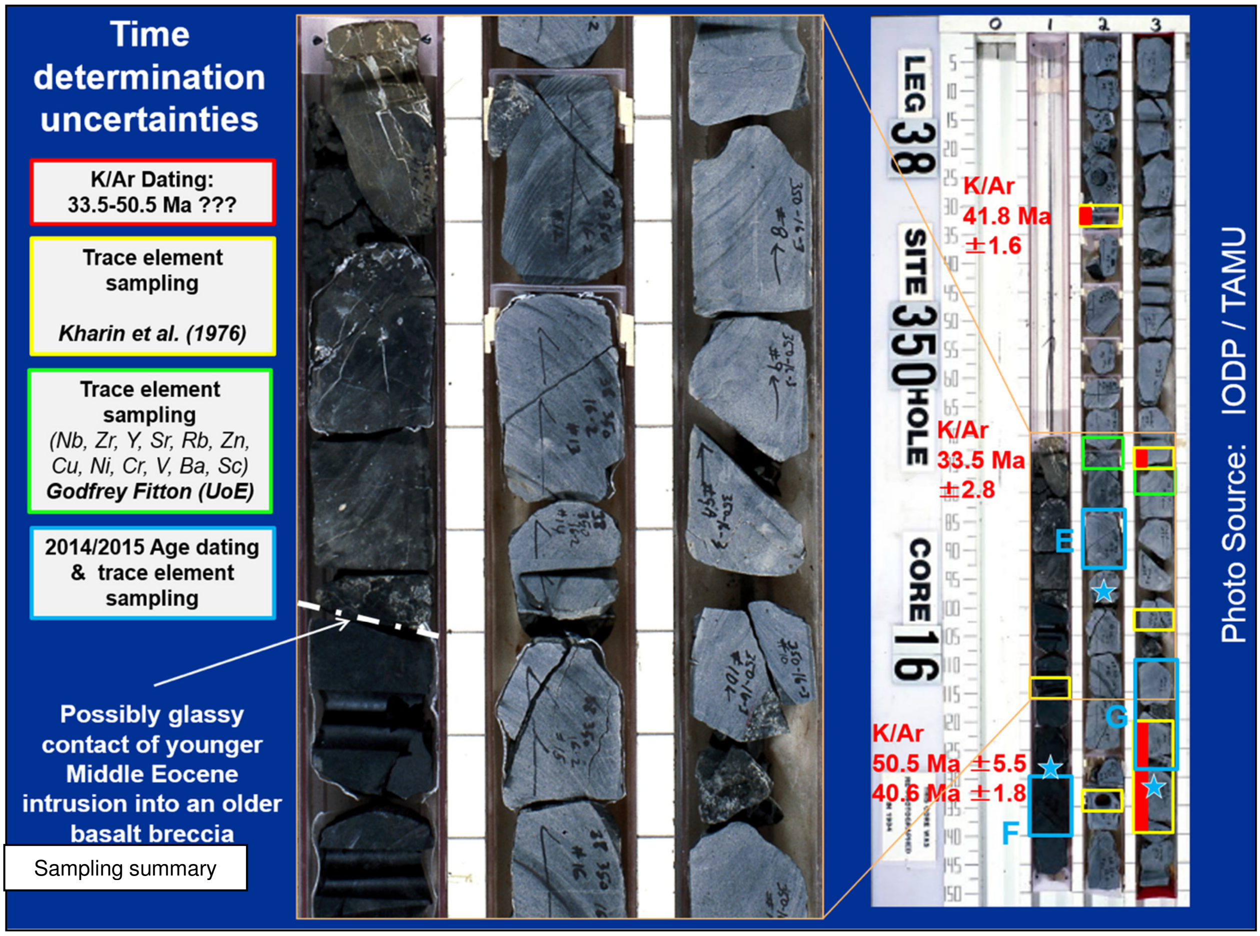


Figure S 3-9. *Inter-crystalline porosity. View in CP.*

(b) Icelandic Plateau thin-section analysis for 4 samples of borehole DSDP Leg 38 site 350



Site Summary

The sampled basalt section of DSDP Leg 38 site 350 at the southern tip of the easternmost SRC block was recovered from an acoustically opaque layer between 362 m and 388 m below seafloor. Samples from cores 14 and 16 were retrieved as the drilled section was heavily fractured and core 15 was not recovered. The samples revealed two different petrological units, a highly altered basaltic breccia and a basalt intrusion.

The younger intrusive basalt consists primarily of fine- to medium-grained holocrystalline olivine-tholeiitic basalt, with the deepest cored section consisting of a sub-ophitic to intergranular texture. Olivine is uneven in concentration and altered to iddingsite (75-80%), and in small amounts to mixed clay layers, accompanied by few but large unaltered plagioclase phenocrysts. Some inter-crystalline porosity can be seen in an otherwise dense rock that is filled with smectite, calcite, mixed layered clay, and quartz. Clinopyroxene, augite and secondary opaque minerals are unaltered in contrast to the inter-crystalline pores that also exhibit needle like or acicular crystals that may be zeolites secondary mineralization pore fills.

The breccia consists of dense, cryptocrystalline basalt with partially altered plagioclase, olivine pseudomorphs and large plagioclase phenocrysts. The basalt is rich in olivine and partially of picrite composition, which is also reflected by its geochemical composition for potassium, natrium and silicaoxids. A few notable fractures were observed, sometimes with increased smectite and calcite alteration to in the adjacent rock. The glassy sample portions appear fully altered, and olivine has been completely altered to iddingsite and calcite, and plagioclase partially altered (around 50%) to calcite, perhaps mixed layer clay and probably albite.

Thin section sample BCR004907313 from borehole 350 – Thin section D

Dense, cryptocrystalline basalt with partially altered plagioclase and olivine pseudomorph phenocrysts (Figure S 3-10). Some fresh plagioclase phenocrysts are noted, around 500 µm in size (Figure S 3-11). There are large plagioclase phenocrysts and then smaller micro phenocrysts of plagioclase and olivine. The basalt is rich in olivine and is probably of picrite composition (Figure S 3-12).

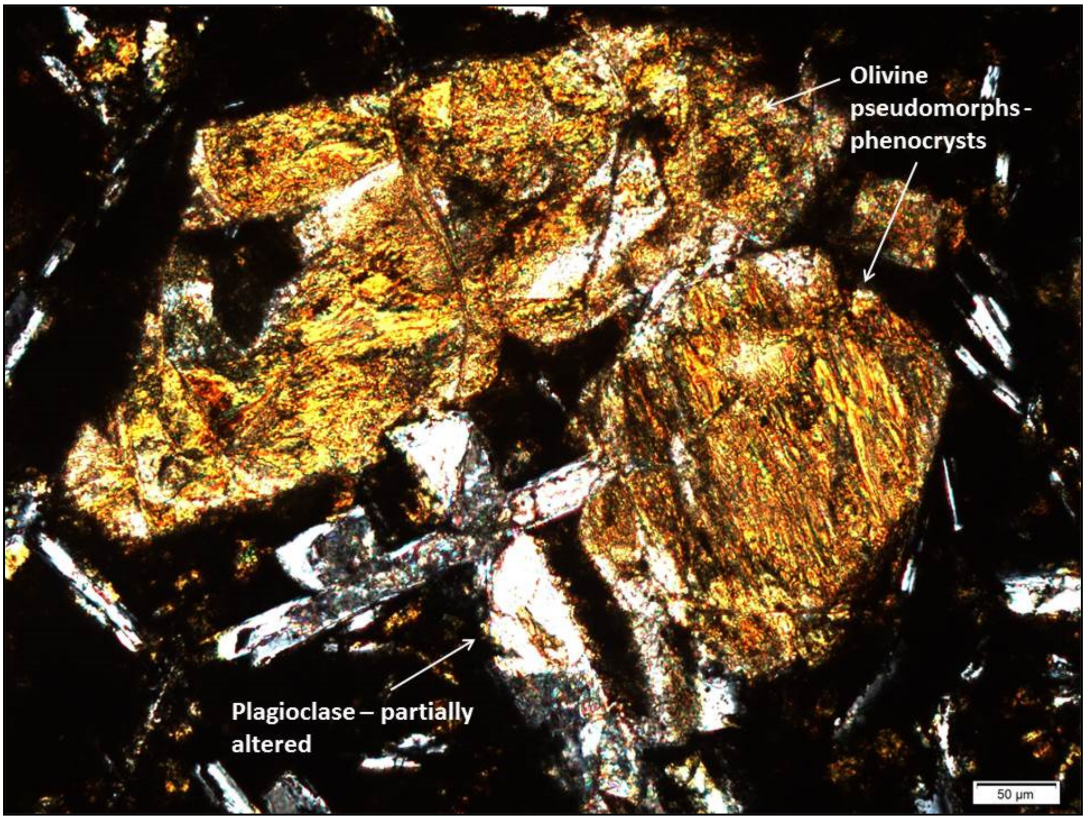


Figure S 3-10. *Olivine pseudomorphs and partially altered plagioclase in thin section D. View in CP.*

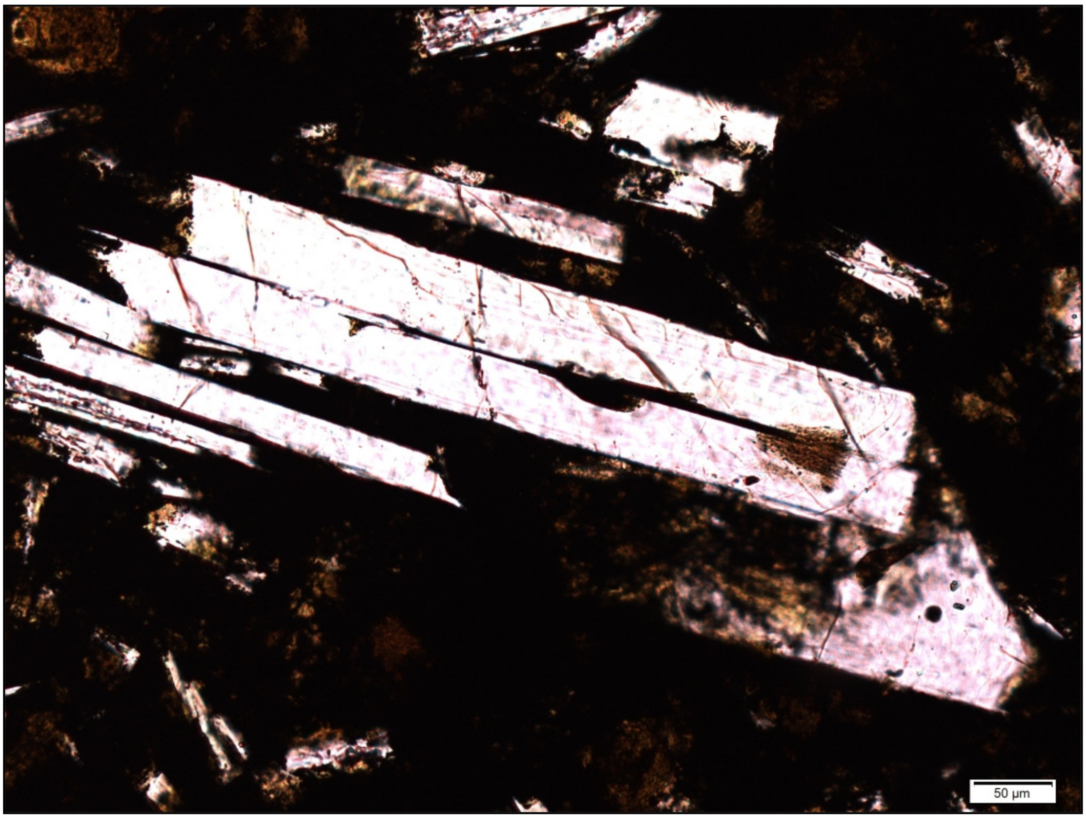


Figure S 3-11. *Unaltered plagioclase phenocryst. View in PPL.*

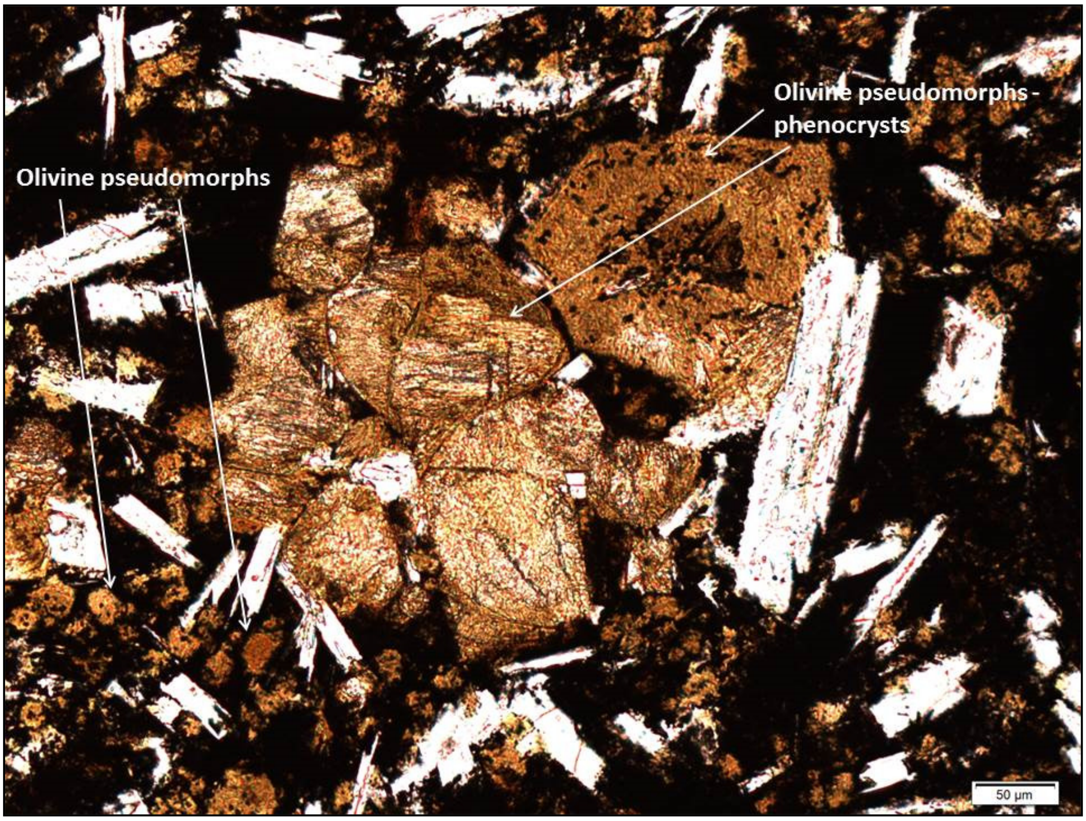


Figure S 3-12. *Olivine rich basalt with olivine pseudomorphs (iddingsite and calcite), both as phenocrysts and as part of the matrix. View in PPL.*

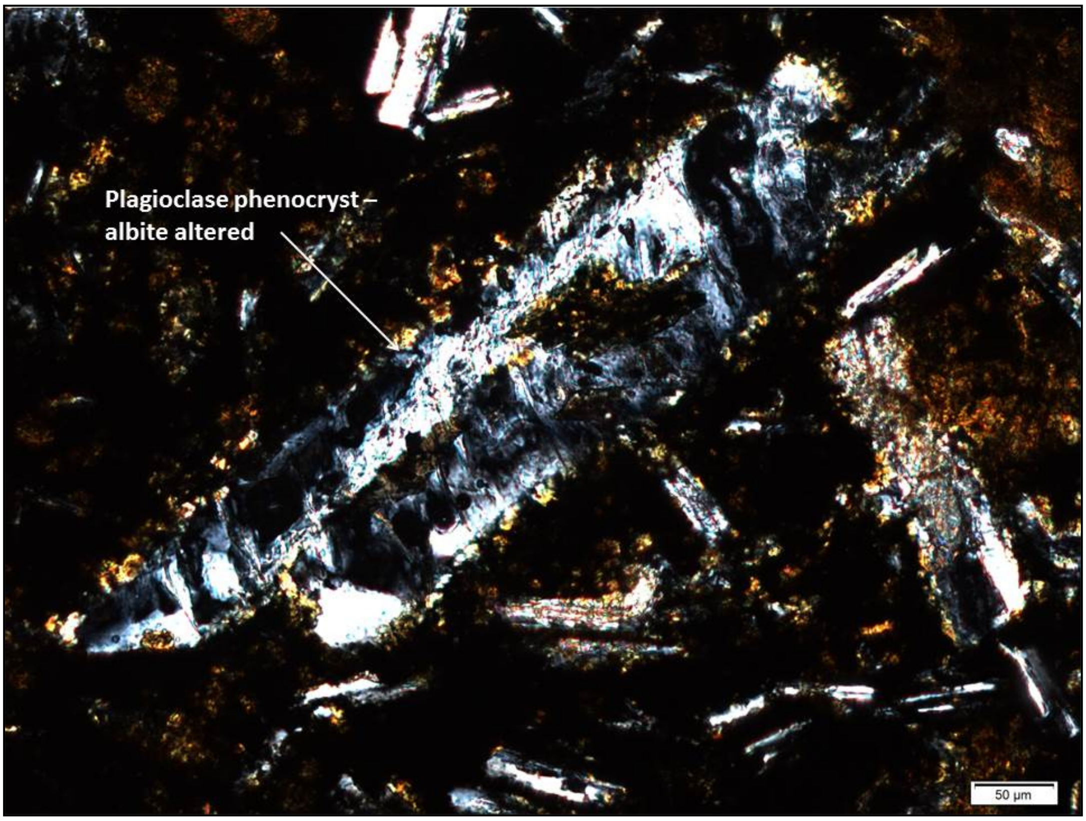


Figure S 3-13. *Albite altered plagioclase phenocryst in thin section D. View in CP.*

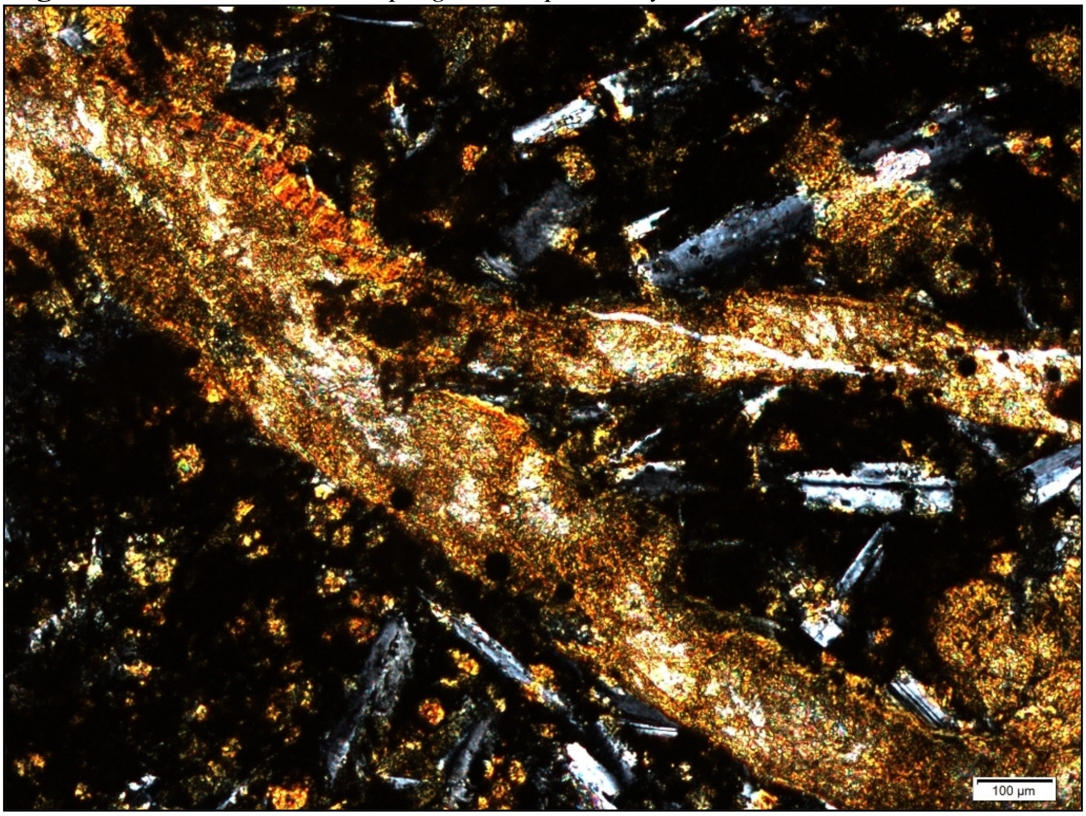


Figure S 3-14. *Fracture with smectite and calcite filling. View in CP.*

A few notable fractures are seen, sometimes exhibiting increased alteration in the adjacent rock. Plagioclase and olivine are the most prominent primary crystals but clinopyroxene is very poorly crystallized and can therefore hardly be seen. The same applies to opaque minerals.

It is hard to tell anything about the glass in the basalt since the glassy part is mostly black but when the overall alteration of the sample is considered it is likely that all glass in the sample is fully altered. Olivine is completely altered to iddingsite and calcite, and plagioclase partially altered (around 50%) to calcite, perhaps mixed layer clay and probably albite (Figure S 3-13). Alteration minerals in fractures (precipitation) are smectite and calcite (sequence in that order) (Figure S 3-14).

Thin section sample BCR004907320 – Thin section E

Fine to medium grained holocrystalline basalt. Probably olivine-tholeiite (opaque minerals have crystallized late and fill up in between plagioclases and clinopyroxenes). There is not much olivine, however, the ones that are seen are pseudomorphs (fully altered to iddingsite). In some areas the olivine seems a little bit more concentrated (Figure S 3-15). Large but few plagioclase phenocrysts are present (1-3 mm) (Figure S 3-16). Plagioclase in the matrix is also rather large (up to 400 µm). Some inter-crystalline porosity is noted (filled with smectite – Figure S 3-17) and very few vesicles (1-2).

Olivine is almost completely altered (80%) to iddingsite (where a hint of mixed layer clay (MLC) can be seen (Figure S 3-15). Some parts of olivine are still fresh, and plagioclase seems unaltered. Clinopyroxene and opaque minerals are unaltered.

Smectite fills up inter-crystalline porosity but MLC seems to be associated with olivine alteration (only a hint of MLC). The inter-crystalline pores also exhibit needle like or acicular crystals that may be zeolites of some sort (Figure S 3-18). It is not clear if some of the inter-crystalline pores show opal precipitation or if there are remains of fresh glass in between crystals in some cases.

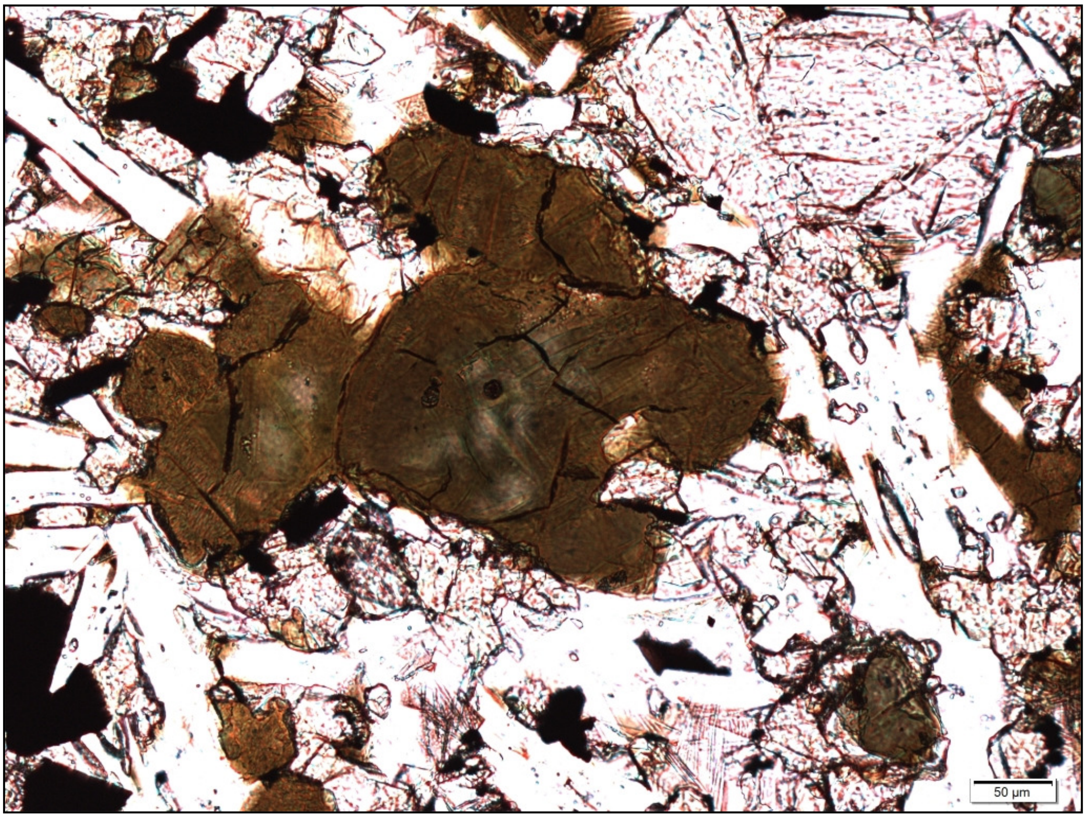


Figure S 3-15. *A few olivine pseudomorphs. View in PPL.*

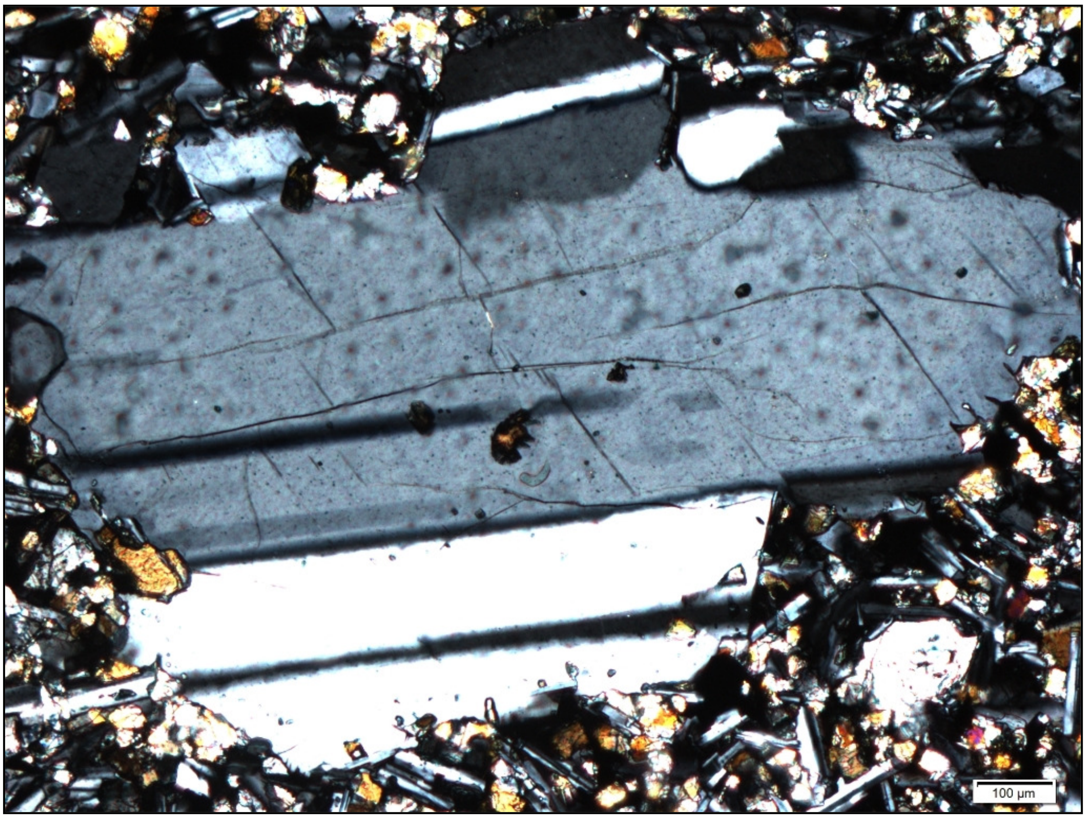


Figure S 3-16. *Plagioclase phenocryst around 1 mm in length. View in CP.*

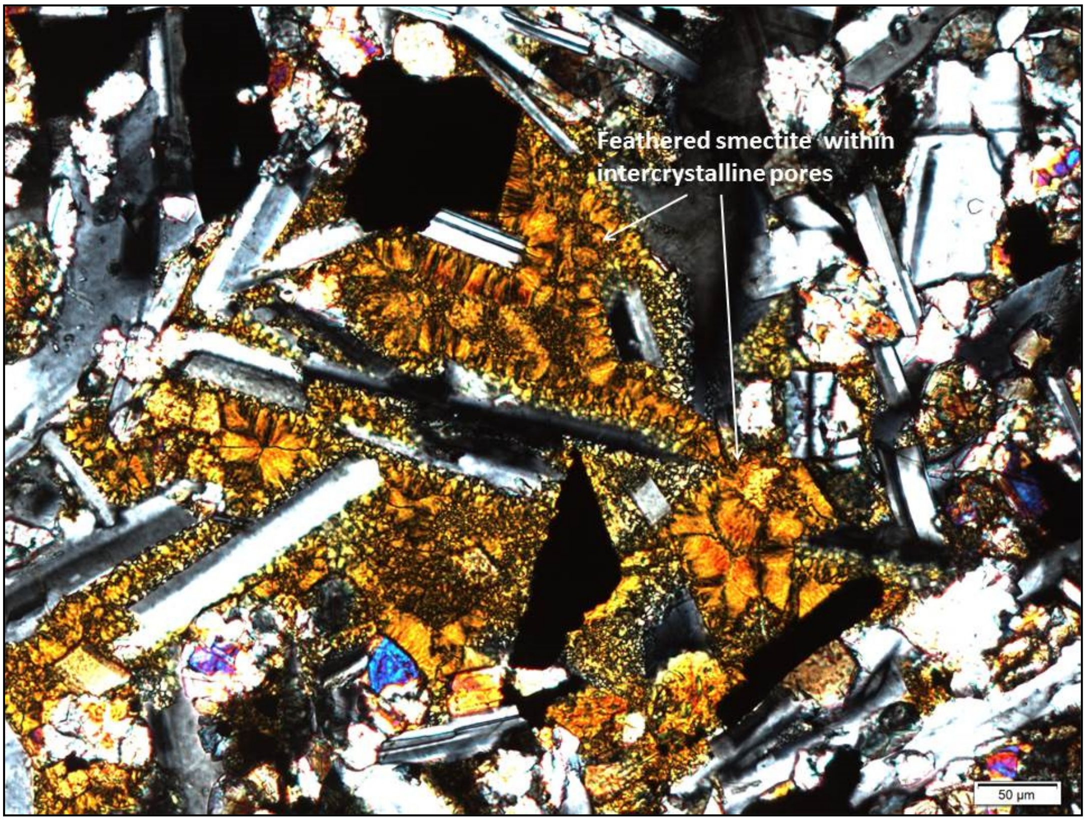


Figure S 3-17. *Inter-crystalline pores filled with feathered smectite, precipitating from the walls of the pores. View in CP.*

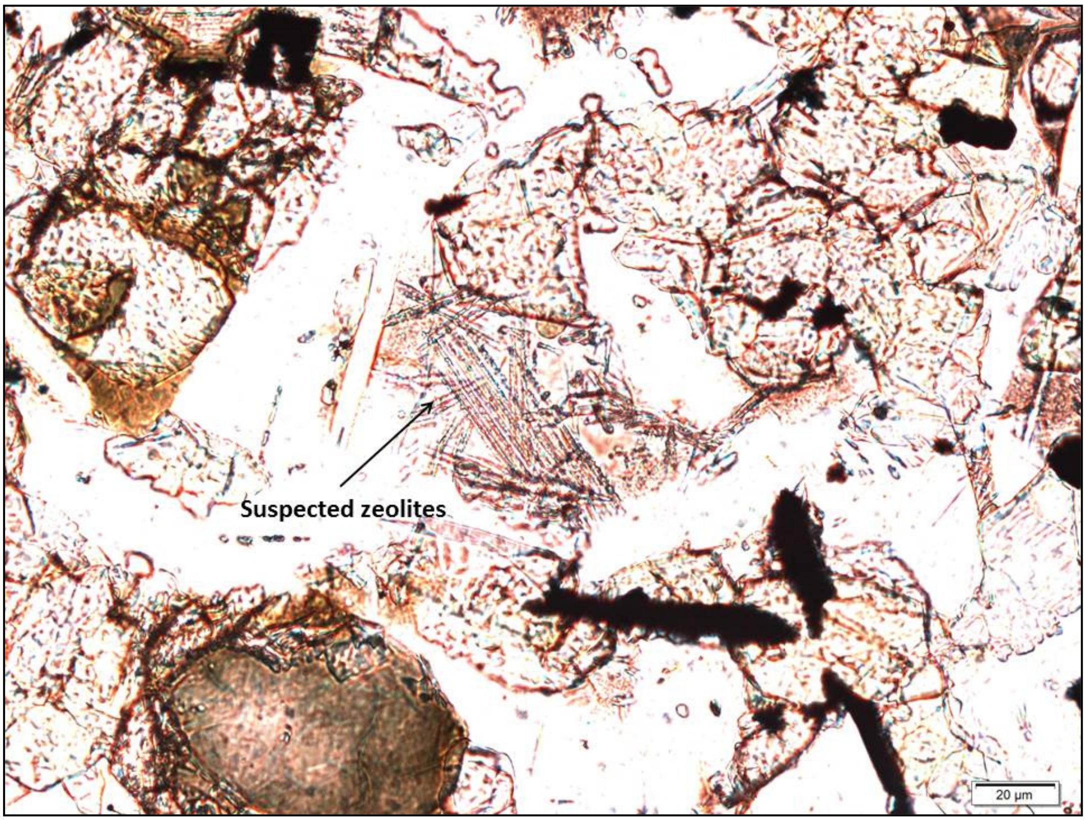


Figure S 3-18. *Suspected zeolites within inter-crystalline pores. View in PPL.*

Thin section sample BCR004907311 – Thin section F

Fine grained, holocrystalline basalt with plagioclase and clinopyroxene micro phenocrysts (or just irregular crystallisation – perhaps seriate texture) and some plagioclase macro phenocrysts (~700 µm, less than 5%). Opaque minerals are mostly euheudral but have probably crystallised later than plagioclase. There is substantial inter-crystalline porosity in some areas, filled with smectite. It is possible that some glass may have been present within the sample, now altered to smectite and calcite (a hint of palagonite rim turned to smectite is noted in one area within the sample – Figure S 3-19). Hardly any vesicles are seen, only 1-2 filled with calcite and smectite. Within the sample there is one large fracture with precipitations of smectite followed by calcite (Figure S 3-20).

If glass was present in between the primary crystals, then it is fully altered to smectite and in some cases to calcite. Olivine is also fully altered to smectite but other primary minerals (plagioclase, clinopyroxene and opaque minerals) remain unaltered.

Alteration minerals (precipitations) can be seen in one large fracture: smectite followed by calcite (including dogtooth calcite) and in the few vesicles.

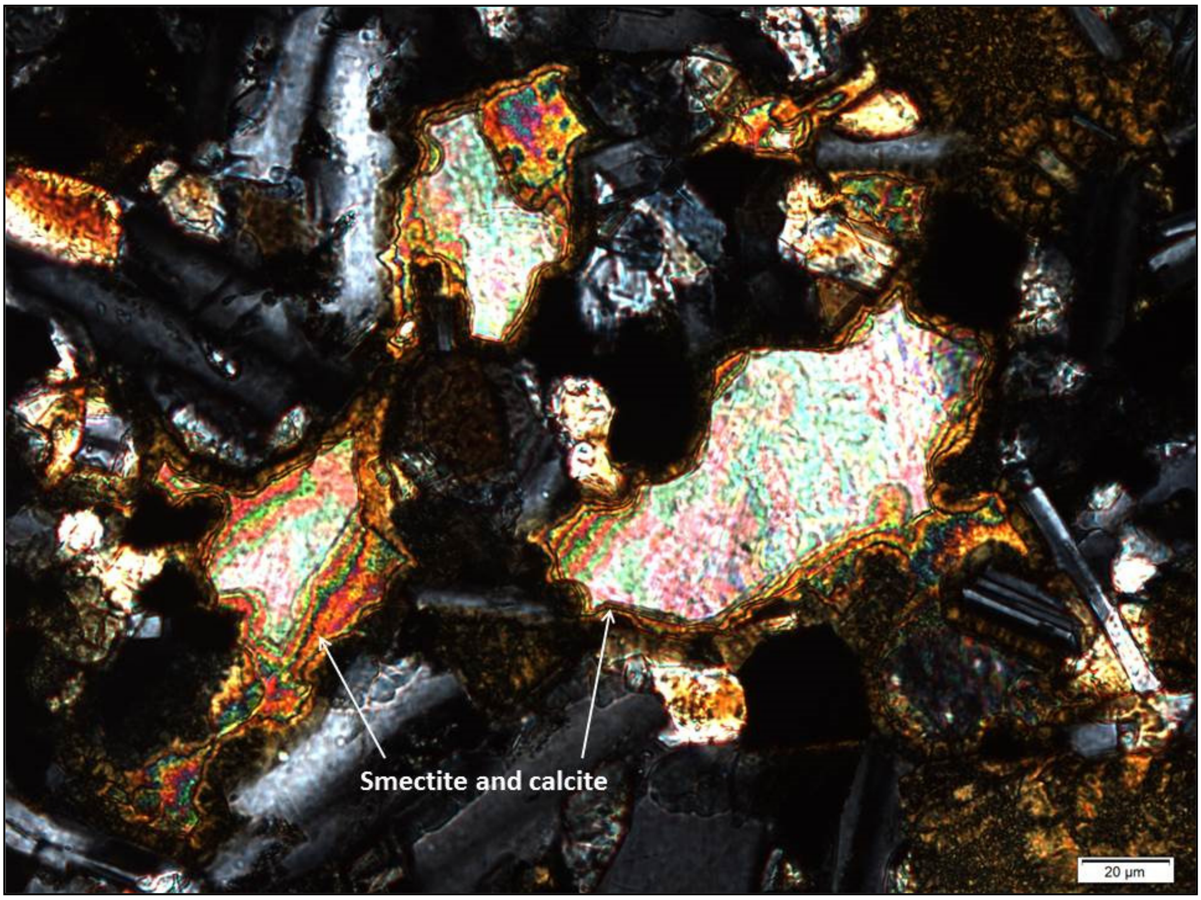


Figure S 3-19. *Either inter-crystalline pores filled with precipitations or glass that has altered to smectite and calcite. View in CP.*

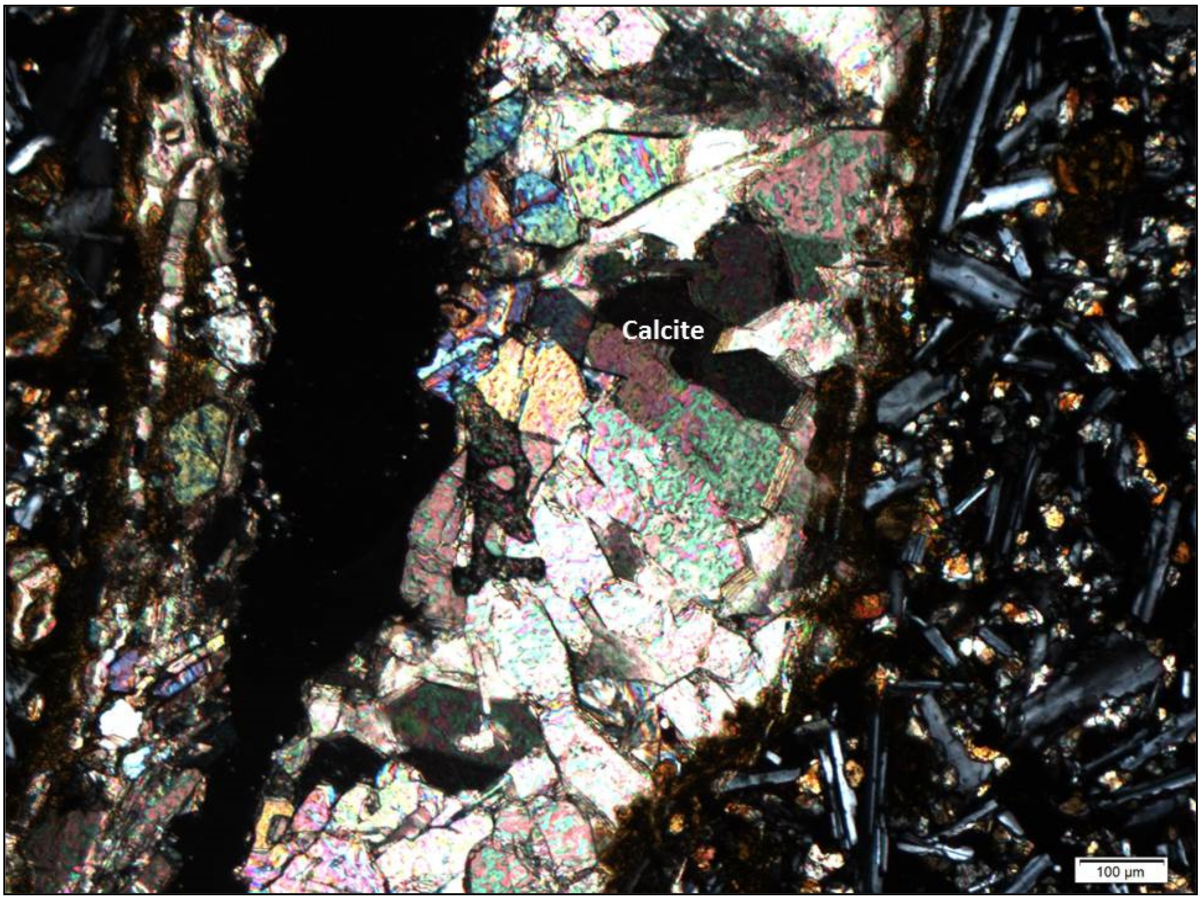


Figure S 3-20. *Fracture filling of smectite and calcite. View in CP.*

Thin section sample BCR004907321 from borehole 350 – Thin section G

Sparsely plagioclase porphyritic basalt, one phenocryst exhibits skeletal growth with both augite and opaque minerals crystallised in the gaps (Figure S 3-21). Plagioclase phenocrysts are up to ~400 µm in size. In between plagioclase crystals there are small clinopyroxene crystals, but some larger ones are seen in between. The texture of the basalt could therefore be described as sub-ophitic in some areas but in most cases, it is intergranular. Opaque minerals form late and are mostly irregular in form (anhedral or subhedral). Olivine (pseudomorphs mostly) is seen in the matrix and there are even some unaltered sections of olivine present. This combined suggests that the basalt may be of olivine-tholeiite composition. The rock is dense, no vesicles are seen but it does have some inter-crystalline porosity. A fracture filling is seen on one edge of the sample (Figure S 3-22).

Olivine is almost fully altered (~75%), but some of the olivine crystals are only partially altered to iddingsite. Plagioclase, clinopyroxene and opaque minerals are unaltered.

The fracture in the sample shows smectite, calcite, mixed layer clay and quartz (in that sequence). A part of the fracture filling can be seen in Figure S 3-22. Inter-crystalline pores seem to contain similar minerals as in thin section E, i.e. needle shaped suspected zeolites along with smectite (Figure S 3-23).

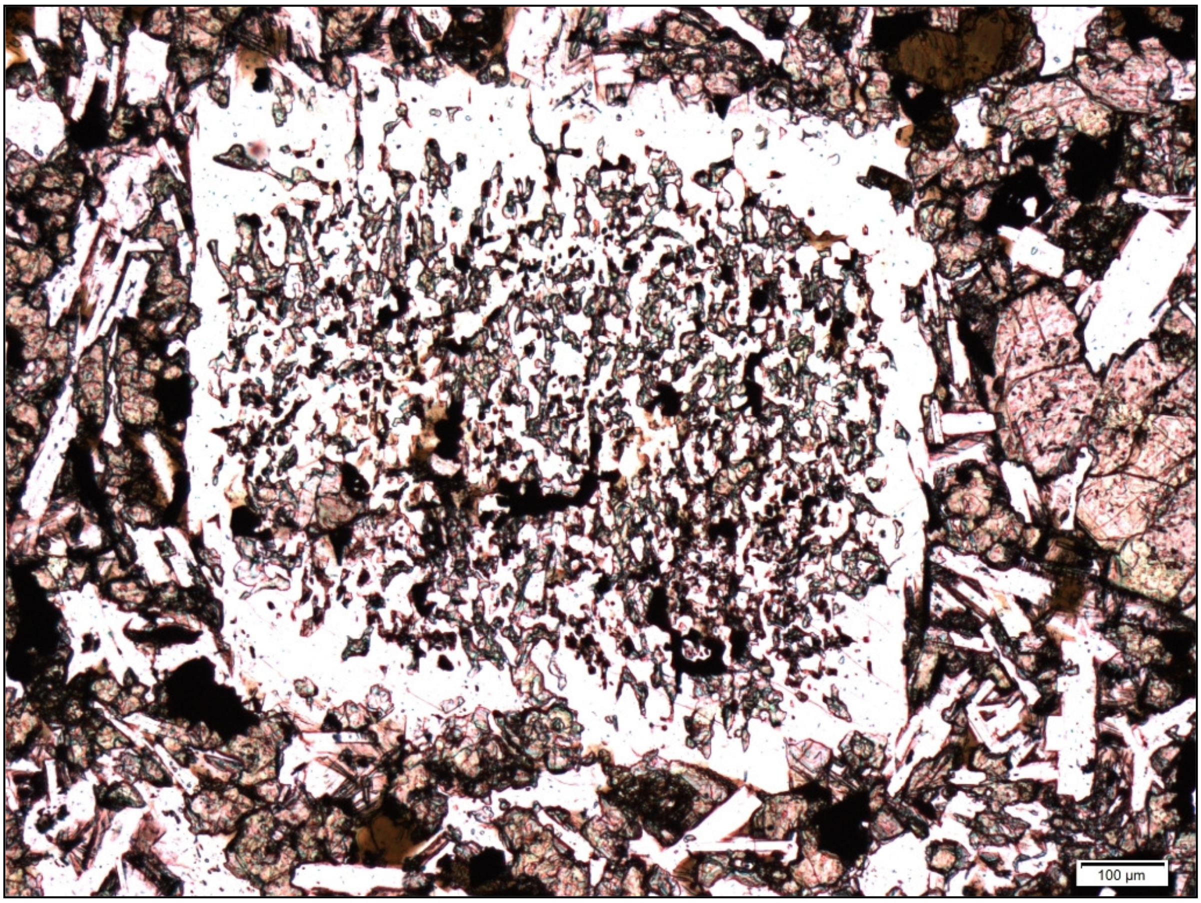


Figure S 3-21. *Skeletal plagioclase phenocryst. View in PPL.*

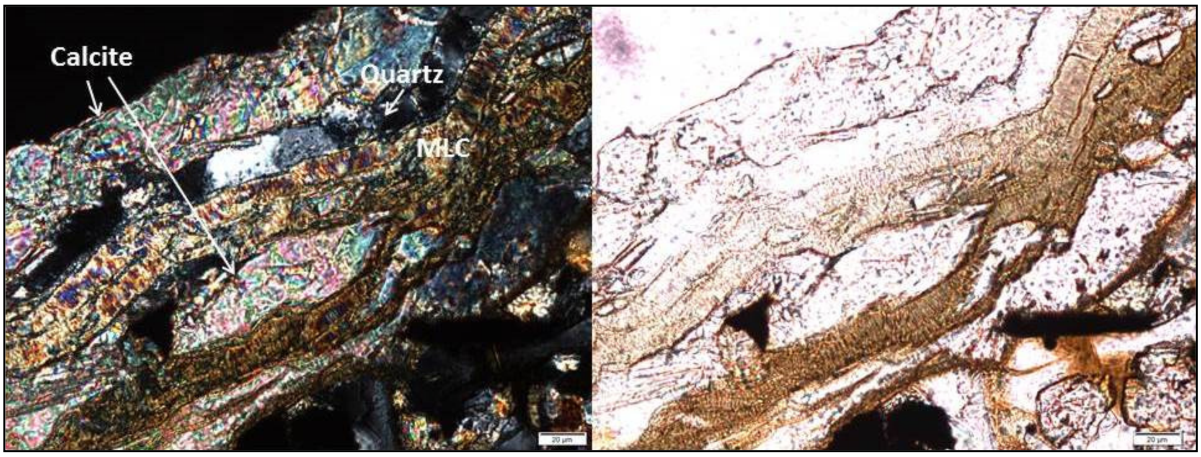


Figure S 3-22. *Fracture filling from one edge of the sample. To the left: view in PPL. To the right: view in CP.*

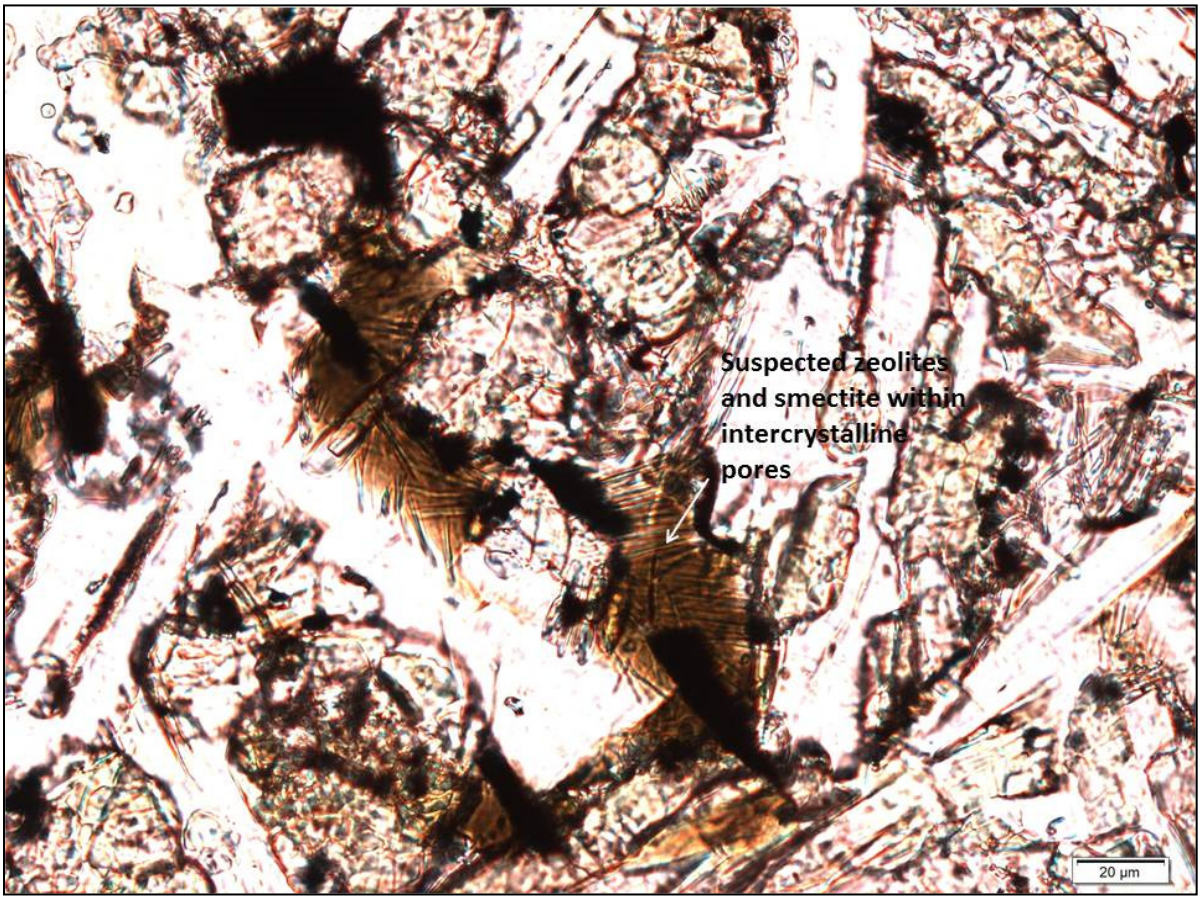


Figure S 3-23. *Inter-crystalline pores with smectite and suspected zeolites. View in PPL.*

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