LV-2014-063

Landsvirkjun

Alteration in the Þeistareykir Geothermal System

A Study of Drill Cuttings in Thin Sections

Report no: LV-2014-063

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ÍSOR
ÍSLENSKAR ORKURANNSÓKNIR

ÍSOR-2014/028

Project no.: 13-0147

August 2014

Key Page

LV report no:	LV-2014-063	**Date:**	August 2014
Number of pages:	107 **Copies:** 7	**Distribution:**	☒ **On www.lv.is** ☒ **Open** ☐ **Limited until**

Title: Alteration in the Þeistareykir Geothermal System. A Study of Drill Cuttings in Thin Sections.

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Prepared for: Prepared by Iceland GeoSurvey (ÍSOR) for Landsvirkjun.

Co operators:

Abstract: The Theistareykir geothermal field is located within the Theistareykir volcanic system in North Iceland. Since 2002 nine deep exploratory wells have been drilled in the area for a proposed electrical power plant. Thin sections have been prepared of drill cuttings from six of the wells and they have been inspected with a petrographic microscope and described in detail. The report summarizes the main results. The features described for each thin section include the rock composition, porosity, vein fillings, secondary minerals and their sequence of formation, as well as the alteration of primary minerals with special attention paid to the alteration of glass, olivine, plagioclase, pyroxene and Fe-Ti oxides. A list of secondary minerals for each well is presented, as well as the other features described. A relatively good correlation is observed between the logs of cuttings from the wells and the inspection of the thin sections, and they provide evidence of high temperatures close to the surface for all wells, except well ThG-8.

Keywords:

Þeistareykir, high-temperature field, drillholes, drill cuttings, thin sections, alteration, secondary minerals, vein fillings, porosity

ISBN no:

Approved by Landsvirkjun's project manager

Project manager's signature	Reviewed by
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Ágrip

Háhitasvæðið á Þeistareykjum er hluti af gosreininni sem liggur allt sunnan frá Mývatni og í sjó fram í Öxarfirði. Undanfarinn rúman áratug hefur verið unnið að rannsóknum á jarðhitasvæðinu með það að markmiði að reisa þar jarðgufuvirkjun. Frá árinu 2002 hafa í þessum tilgangi verið boraðar níu djúpar rannsóknarholur. Framgangi við borun holnanna og fyrstu úrvinnslu á t.d. svarfgreiningu hefur verið lýst í áfangaskýrslum fyrir hverja holu fyrir sig. Þar hefur ummyndun bergsins verið lýst og mat lagt á hita jarðhitakerfisins út frá ummyndunarsteindum. Í þeim tilgangi að afla enn frekari gagna um ummyndunarsögu bergsins og ýmsa eiginleika þess voru gerðar þunnsneiðar af völdum svarfsýnum úr sex af þeim níu holum sem hafa verið boraðar og er í skýrslunni lýst niðurstöðum smásjárskoðunar á þeim. Þeir þættir sem sérstaklega voru skoðaðir eru frumsteindasamsetning bergsins, póruhluti, sprungufyllingar, síðsteindir og myndunarröð þeirra og ummyndun frumsteinda. Þar var sérstök áhersla lögð á að skoða ummyndun glers, ólivíns, plagíóklass, pýroxens og Fe-Ti oxíða. Í stórum dráttum er ágætt samræmi á milli svarfgreininga sem gerðar voru meðan borun hverrar holu fór fram og þunnsneiðagreininganna.

Þunnsneiðagreiningarnar sýna merki um háan hita nærri yfirborði við allar holurnar, nema holu ÞG-8. í holum ÞG-3, ÞG-6 og ÞG-7, sem allar eru á borteig C, greinist bæði wairakít og kvars á innan við 100 m dýpi sem sýnir að hiti þar hefur á einhverjum tímapunkti verið a.m.k. 200°C. Prehnít greinist í holu ÞG-7 á 342 m dýpi og litlu dýpra í holum ÞG-3 og ÞG-6, og gefur vísbendingu um a.m.k. 240°C. Aktínólít finnst í þessum holum á um 750 m dýpi og þar hefur hitinn náð a.m.k. 280°C. Í holum ÞG-3 og ÞG-6 greinist hornblendi neðan 2300 m og þar hefur hitinn náð að lágmarki um 350°C. Greiningar á þunnsneiðum úr holum ÞG-4 og ÞG-5 á borteig A sýna að hiti hefur náð 240–250°C grunnt en þar greindust wairakít, kvars, klórít, epidót og prehnít á 310 m dýpi. Aktínólít fannst á 500–600 m dýpi og gefur það vísbendingu um a.m.k. 280°C hita. Ekkert kalsít greindist neðan við 800–900 m dýpi og því má telja líklegt að hiti í kerfinu þar geti verið a.m.k. 280–300°C. Hola ÞG-9 var boruð frá borteig N á vestursvæði Þeistareykja. Þar er mun dýpra niður á merki um háan hita og í þunnsneið af svarfi af 100 m dýpi er basaltið mjög ferskt og engin merki um ummyndun þess. Í þunnsneið af 390 m dýpi greinist sekúndert kvars og smektít og þar hefur hiti aldrei náð 200°C. Vegna mikils skoltaps við borun holunnar náðist ekkert svarf upp í 744–1495 m og því ekki vitað hvar t.d. epidót eða prehnít koma fyrst fram en báðar þessar steindir greinast í þunnsneið af 1532 m dýpi, ásamt wollastoníti. Þar hefur hitinn því á einhverjum tímapunkti náð 260°C. Lítið eitt dýpra greinist aktínólít sem samsvarar 280°C lágmarkshita og mikil ummyndun frumsteinda, plagíóklass, klínópyroxens og Fe-Ti steinda í neðsta hluta holunnar gefur sterka vísbendingu um að þar hafi hiti verið yfir 300°C. Tilvist kalsíts víðast hvar í holunni og laumontíts í þunnsneiðum af 2090 og 2300 m dýpi sýnir að svæðið hefur kólnað mikið þar sem hitinn er nú vel innan við 180°C.

Jarðhitasvæðið á Þeistareykjum er mjög sprungið og þar er fjöldi misgengja, mest normal misgengi með norðlæga stefnu. Tengingar milli leiðarlaga á 200 og 400 m dýpi u.s., sem gerðar voru á grundvelli þunnsneiðagreininga, sýna tiltölulega litla lóðrétta færslu á misgengjum milli borteiga A, C og N, þrátt fyrir verulega gliðnun á nútíma.

Við þunnsneiðagreininguna var lögð talsverð áhersla á að greina basaltið í sundur í annars vegar þóleiít og hins vegar ólivín-þóleiít. Basalthraun frá nútíma og síðjökultíma á Þeistareykjum eru að mestu leyti ólivín-þóleiít en þunnsneiðagreiningar sýna að á fyrri tímum hefur gosvirknin einkennst af basalthraunum þar sem þóleiít og ólivín-þóleiít hafa verið í nokkuð jöfnum hlutföllum.

Eitt af því sem einkennir megineldstöðvar á Íslandi er þróað berg, svo sem ríólít og dasít og myndun grunnstæðra kvikuhólfa. Á Þeistareykjum hefur eldvirknin einkennst af fremur frumstæðu bergi, og engin merki finnast um þróað berg frá nútíma og síðjökultíma og því litlar líkur á grunnstæðum kvikuhólfum. Bergfræði svæðisins einkennist því frekar af fremur óþroskuðu eldfjalli þar sem kvika berst tiltölulega beint upp frá möttlinum án viðkomu í kvikuhólfi.

Table of contents

List of tables

List of figures

1 Introduction

The Theistareykir geothermal field in North Iceland is in the process of being harnessed for power production. Since 2002, nine deep exploratory wells have been drilled, with more drilling being planned. A number of reports detail the drilling progress (Árnadóttir et al., 2009a, 2011c; Blischke et al., 2007; Gautason et al., 2007a, b, 2008; Guðfinnsson et al., 2011a; Guðmundsson et al., 2006, 2007; Ingimarsdóttir et al., 2009a; Mortensen et al., 2011a, b; Níelsson et al., 2011b, d; Richter et al., 2007; Sigurgeirsson et al., 2008a; Þórarinsson et al., 2006a, b) and describe the rock formations that were penetrated (Árnadóttir et al., 2009b, 2011a, b; Blischke et al., 2007; Gautason et al., 2008, 2007a, b; Guðfinnsson et al., 2011b; Guðmundsson et al., 2006, 2007; Ingimarsdóttir et al., 2009b; Mortensen et al., 2011c; Níelsson et al., 2011a, c; Richter et al., 2007; Sigurgeirsson et al., 2008b; Þórarinsson et al., 2006a, b).

The Theistareykir geothermal field is within the Theistareykir volcanic system which stretches southwards from the bay of Öxarfjörður towards Lake Mývatn. Volcanic activity was considerable at the beginning of the Holocene in the Theistareykir system, but the only eruption since then was the one that formed the Theistareykjahraun basaltic lava field just over 2500 years ago (Guðmundsson, 2008). The Theistareykir volcanic system also includes extensive hyaloclastite formations, which are indicative of subglacial eruptions from before the Holocene. Logs of cuttings from the exploratory wells also provide evidence for the emplacement of silicic and intermediate volcanic formations, in addition to basaltic lavas, intrusions and hyaloclastites (Árnadóttir et al., 2009b, 2011a, b; Blischke et al., 2007; Gautason et al., 2008, 2007a, b; Guðfinnsson et al., 2011b; Guðmundsson et al., 2006, 2007; Ingimarsdóttir et al., 2009b; Mortensen et al., 2011c; Níelsson et al., 2011a, c; Richter et al., 2007; Sigurgeirsson et al., 2008b; Þórarinsson et al., 2006a, b).

Thin sections have been prepared of drill cuttings from six of the wells that have been drilled in the Theistareykir geothermal field, wells ÞG-3, ÞG-4, ÞG-5, ÞG-6, ÞG-7 and ÞG-8. Subsequently, the thin sections have been inspected with a petrographic microscope and described in detail. This report summarizes the main results of this study.

2 Thin section descriptions

The features of the rocks as seen in the thin sections under the petrographic microscope and have been described include the rock composition, porosity, vein fillings, secondary minerals, sequences of secondary minerals when they can be deciphered, and alteration of primary minerals, with special attention paid to the alteration of glass, olivine, plagioclase, pyroxene and Fe-Ti oxides. The list of secondary minerals found in each well are listed in Tables 1–6, whereas all other aspects are listed in Tables 7–18, except the mineral sequences which are listed in Table 19. Each of the described features is discussed in more detail in the following section.

2.1 Features noted in thin sections

2.1.1 Secondary minerals

The lists of minerals seen in Tables 1–6 include all the secondary minerals noted in the thin sections via the petrographic microscope, with the exception that the listings of the opaque mineral pyrite is based on observations of drill cuttings under the binocular microscope (Guðmundsson et al., 2006; Þórarinsson et al., 2006b; Gautason et al., 2007b; Richter et al., 2007; Gautason et al., 2008; Blischke et al., 2007; Sigurgeirsson et al., 2008b; Árnadóttir et al., 2009b; Árnadóttir et al., 2011b; Mortensen et al., 2011c; Árnadóttir et al., 2011a; Níelsson et al., 2011c; Guðfinnsson et al., 2011b; Níelsson et al., 2011a). While it is relatively easy to identify pyrite under the binocular microscope, it does not lend itself to unambiguous identification by transmitted-light microscopy because it is opaque in thin sections of normal thickness, although its strong tendency to exhibit the characteristic cubic shape often suggests its presence (Figure 1).

2.1.2 Lithology

In thin sections of drill cuttings, one gets less complete view of the rock type than in sections of whole rock samples. Additionally, drill cuttings are commonly a mixture of fragments from different formations, in which case one needs to evaluate which formation is dominant and likely to having been penetrated at the time. The lithological classification scheme used in this report is the same as generally used at ÍSOR and has been developed over the years, first at Orkustofnun, the predecessor of ÍSOR, and is appropriate for the prevailing lithology encountered in Icelandic geothermal systems. The same scheme is also used for classifying drill cuttings in hand samples. The drill cuttings, as determined both in hand samples and in the thin sections, are dominated by formations of basaltic composition, which includes both basalts in the strict sense and basaltic hyaloclastites. There are also a few examples of andesites and rhyolitic formations. The following types of formations were identified in the thin sections.

Basaltic hyaloclastite. In the classification scheme used, basaltic hyaloclastites are classified as *basaltic tuff*, *basaltic breccia* and *glassy basalt*. The boundaries between these three different manifestations of basaltic hyaloclastites are gradational, which is to be expected considering the heterogeneous nature of hyaloclastite formations. The relative proportions of (crystallized) basalt fragments and basaltic glass fragments are most important in this classification, with basaltic tuff being dominated by glass fragments, usually with large amount of primary porosity (Figure 2), whereas glassy basalt is dominated by basalt fragments with lesser amount of glass present (Figure 3). Basaltic breccia falls in between. Glassy basalt is commonly from pillow lava formations and tends to have fairly variable grain size (size of the primary minerals), from cryptocrystalline particles, often with fair amount of glass, to medium-grained particles. Sometimes basalt lava formations and basalt intrusions are quite glassy and can be classified as glassy basalt. In general, the number of basaltic dike intrusions is likely to increase significantly with depth, and with large number of thin dikes, resembling sheeted dike intrusions of ophiolites, the cuttings could have the appearance of glassy basalt. In this case, the grains should be non-porous and often partly oxidized. Basaltic breccia can in some cases be difficult to distinguish from certain types of sedimentary formations, especially when the cuttings have become very fine-grained.

Basalt. Formations that are dominated by largely crystalline basalt fragments are termed basalts, and further classified according to the grain size of the primary minerals, from cryptocrystalline (Figure 4) to medium-grained (Figure 5). An attempt has also been made here to classify the basaltic rocks as either olivine tholeiites or tholeiites. Olivine tholeiite is generally relatively rich in olivine phenocrysts and has some olivine as a groundmass mineral as well (Figure 6), while tholeiite has only sporadic olivine phenocrysts or more often none (Figure 7). It is frequently difficult, however, to identify olivine once significant geothermal alteration has taken hold of the rock. In this case, identification can be made on the basis of the groundmass texture of the basalt in question; olivine tholeiite has a strong tendency to have either ophitic or sub-ophitic texture, where clinopyroxene wholly or partly encloses the plagioclase laths, and the Fe-Ti oxides are late-formed and interstitial between plagioclase and clinopyroxene. In tholeiites, which are more FeO- and TiO_2-rich, Fe-Ti oxides are more abundant and crystallize earlier, commonly forming euhedral crystals. The texture is then most often intergranular with smaller clinopyroxene crystals filling space between plagioclase laths along with the Fe-Ti oxides. Because this classification is not based on chemical analyses, it can only be considered as a rough estimation of the composition of the basaltic rocks.

Andesite (icelandite). The andesites seen in the thin sections are very fine-grained, making identification of primary minerals difficult (Figure 8). The distinguishing features of the andesites include strong flow texture, relatively large amount of titano-magnetite and small amount of phenocrysts. Illite, which is rare in the basalts, appears with increasing alteration.

Rhyolite. The rhyolites tend to have distinct flow texture but, unlike the andesites, they are poor in magnetite, and therefore appear lighter colored. Illite is a common alteration product along with quartz. It is also likely that an abundant, dull, brownish alteration product in the rhyolites is adularia (Figure 9).

Silicic tuff. This formation type, of which there is one case, comprises dominantly devitrified silicic glass, now mostly composed of quartz and illite (Figure 10).

Silicic breccia. This type of rock comprises both rhyolite and silicic glass fragments (Figure 11).

2.1.3 Porosity

Porosity refers to the primary porosity (vesicularity as igneous rocks predominate) of the formations, but the degree to which the primary pores are filled with secondary minerals is also noted. The amount of porosity is graded to be none, minor, fair, moderate or major. When porosity is minor, pores are rare and the sample has to be carefully examined to find them. Fair amount of porosity refers to when pores are in small amount but obvious; moderate when pores are widespread; and finally major when pores constitute about a third of the rock or more (Figure 12). The pores can then be empty, partly filled or filled when no open pore space is seen. As the size of the cuttings gets smaller, the amount of pore space seen becomes generally smaller, mainly because the size of individual particles is smaller than the primary pores in the formations. Another reason is that smaller cuttings are generally associated with deeper drilling, and hence more extensive alteration, which makes identification of primary porosity more difficult. Moreover, intrusions, whose abundance increases with depth, tend to be non-porous.

2.1.4 Vein fillings

The presence of vein fillings was noted (Figure 13), and as in the case of porosity, the abundance of veins is evaluated as being none, fair, moderate or major. This classification is obviously highly subjective, but serves as a rough guide to the amount of fracturing of the rock. Also listed are the types of secondary minerals seen filling veins. As is the case for porosity, and for the same reasons, the identification of the veins becomes less robust as the particle size of the cuttings becomes smaller.

2.1.5 Alteration of primary minerals

The primary minerals dominating in most cases are plagioclase, clinopyroxene and Fe-Ti oxides. In addition, olivine is seen in many of the basalts. Because volcanic glass, which can also be regarded as a mineral in the broad sense, is an important part of many of the formations and is highly susceptible to geothermal alteration, it is also included in this list of primary minerals. The terms used to describe the amount of alteration are unaltered and minor, fair, moderate, major, extensive and complete alteration. Minor alteration is not obvious at first sight, but when it is present small amount of clay is noted in some fractures or, in the case of Fe-Ti oxides, the beginnings of oxidation at some grain boundaries (Figure 14). Fair alteration indicates that the mineral is obviously starting to be affected, whereas the alteration is deemed moderate when significant secondary mineralization has occurred, and major when more than roughly half the mineral has been replaced. Glass and olivine are almost always completely altered, but plagioclase, clinopyroxene and Fe-Ti oxides are more likely to become extensively altered rather than completely. In a following section on the progression of mineral alteration, the nature of the alteration suffered by the primary minerals is described in more detail.

2.1.6 Secondary mineral sequences

In some cases, it is possible to decipher the sequence in which different secondary minerals precipitated in the formations (Figure 15), mostly in pores and fractures. In a few cases, it seems that a mineral precipitated both before and after another mineral. This need not be a contradiction, but simply a sign that the first mineral was forming over a significant period of time and changing conditions. In many cases, intense calcite veining and precipitation seems to be deceptive in the way it permeates formations, sometimes giving the wrong impression about the sequence of mineral precipitation. A cautious approach has been adopted in documenting the mineral sequences, which means that for many samples no information about sequences is given.

2.1.7 Comments

For each thin section, some general comments, mainly on lithology and alteration, are listed in Table 7, Table 9, Table 11, Table 13, Table 15 and Table 17.

2.2 Progression of mineral alteration

The formations seen in the cuttings from the Theistareykir wells mostly have basaltic composition, because they dominantly comprise basaltic hyaloclastites in addition to proper basalts. A few examples of rhyolitic and andesitic formations are also seen. The same applies to the samples inspected in the thin sections. The basalts have variable composition from olivine-rich olivine tholeiite to evolved tholeiite grading into andesite. Large part of the hyaloclastites was originally composed of volcanic glass, either sideromelane (Figure 12) or tachylite (Figure 16), that has subsequently been altered to form secondary minerals, but it is also common to see phenocrysts in the hyaloclastites, especially plagioclase. When crystallized, the basaltic igneous rocks invariably comprise plagioclase, clinopyroxene, mainly augite, and Fe-Ti oxides. Olivine is also common in the more primitive basalts (Figure 6). The andesites and rhyolites seen are highly altered and the andesites are very fine-grained to boot, making it hard to determine the original mineralogy of these rocks. However, it is likely that relatively sodic plagioclase, clinopyroxene and titanomagnetite are the principal minerals of the andesites, but rhyolites could also contain alkali feldspar and primary quartz as major constituents. The likely presence of adularia in the rhyolites seems to be associated with alteration of alkali feldspar.

2.2.1 Alteration of volcanic glass

In most of the thin sections, volcanic glass is completely altered. It is only in the uppermost part of one of the wells (ÞG-8) that the glass is either fresh or only partially altered. While the glass is replaced by a number of different minerals, phyllosilicates, smectite (Figure 17), mixed-layer clay (Figure 18), chlorite (Figure 1) and illite (Figure 19) or actinolite (Figure 20), dominate as alteration products. When the alteration of basaltic glass is of the lowest grade, smectite is the principal secondary mineral, but it changes to mixed-layer clay and then chlorite with increasing temperature. Several other minerals are seen to replace basaltic glass, including quartz and titanite (Figure 21, Figure 22), and prehnite precipitates are commonly seen in large amounts in altered hyaloclastites. Garnet is another, minor but notable, secondary mineral associated basaltic glass, commonly forming clusters of minute grains (Figure 22). At the highest alteration grade observed in the thin sections, actinolite is also seen in significant amounts. Silica-rich glass seems to alter to illite and quartz to a large extent, in addition to unidentified opaque minerals (Figure 19).

2.2.2 Alteration of olivine

Olivine is highly susceptible to geothermal alteration, becoming completely altered at relatively low temperatures, and in only two of the thin sections (ÞG-8, 100 and 330–340 m MD; Figure 6, Figure 16) is nearly fresh olivine with some deuteric alteration seen. In all other cases, it is completely replaced by secondary minerals. Iddingsite seems to replace olivine at relatively low temperatures, iddingsite being not a single mineral but a hydrous mixture of minerals, mainly of clay minerals (Figure 23), ferric iron oxides and silicates. At higher temperature, the clay becomes better developed and can be identified in most cases as either mixed-layer clay (Figure 14) or chlorite (Figure 24), or the amphibole actinolite has formed. Ferric iron oxides are also seen (here loosely termed hematite, but probably also include goethite and other hydrous iron oxides), quartz (Figure 25) and calcite (Figure 24). As the extent of alteration increases, it becomes increasingly difficult to identify olivine among the primary minerals, and it is highly likely that olivine-bearing rocks are more common than shown in Table 8, Table 10, Table 12, Table 14, Table 16 and Table 18.

2.2.3 Alteration of plagioclase

Alteration of plagioclase seems to start at temperatures less than 200°C and gradual alteration continues to temperatures well in excess of 300°C in all likelihood. Initial alteration noted includes minor clay (Figure 23) and calcite in fractures, and hint of albitization (Figure 26). In a few samples, intense calcite alteration of plagioclase is noted

(Figure 27, Figure 28), apparently mainly occurring along fractures. As the temperature approaches 300°C, the amount of calcite decreases, but the amount of albitization and chlorite (Figure 29) and, at higher temperatures actinolite (Figure 30, Figure 31), increases. Epidote also becomes increasingly more common replacement and small amounts of titanite are also seen (Figure 31).

2.2.4 Alteration of pyroxene

Alteration of clinopyroxene seems to start at a higher temperature than that of plagioclase, probably well in excess of 200°C, but once it takes hold is seems to occur rapidly. Initially, some mixed-layer clay or chlorite is seen in fractures (Figure 7) and then, at a higher degree of alteration, actinolite (Figure 32), but the alteration seems to progress slowly with increasing temperature until at over about 300°C when uralitization appears to occur quite rapidly (Figure 33, Figure 34, Figure 35). Other alteration products include some epidote and titanite and possibly garnet.

2.2.5 Alteration of Fe-Ti oxides

Like pyroxene, the Fe-Ti oxides, likely mainly titanomagnetite with some ilmenite, are more resistant to the beginning of alteration than plagioclase (Figure 32, Figure 36), but, again similar to pyroxene, the alteration seems to progress quickly once it gets going, with complete replacement probably occurring before plagioclase becomes extensively altered. It should be noted, though, that alteration of oxides can easily be underestimated because they are opaque. Initial alteration is mostly seen as ferric iron oxide rims around the oxide grains (Figure 3, Figure 14), but then titanite is the main alteration product noted (Figure 37), but it is likely that ferric iron oxides and pyrite are also involved. At high degree of alteration, the titanite replacement seems to form irregular patches of smaller grains (Figure 35).

2.2.6 Alteration of other primary minerals

The rhyolites probably had alkali feldspar as a primary mineral, but it seems likely that it has been largely replaced by adularia (Figure 9), although this is not beyond doubt. Because of the small size of the secondary mineral, the optical properties cannot be ascertained with a petrographic microscope. It is possible that the rhyolites also contain primary quartz, but it could be difficult to tell primary and secondary quartz apart in these rocks. Deep in wells ÞG-3 (Figure 38) and ÞG-6 (Figure 39) secondary hornblende appears to have formed, possibly replacing actinolite. Both are amphiboles but hornblende tends form tabular grains as opposed to the fibrous habit of actinolite. It is thought that the development of hornblende requires temperature of about 350°C at minimum. Biotite is seen in one case in a sample of rhyolite, but it is not clear if it is primary or secondary in origin (Figure 40).

2.2.7 Types of precipitates

Many of the samples contain large amount of precipitates of secondary minerals, both filling veins and pores and as fragments entirely comprising secondary minerals. At the low-temperature end, calcite, clay and quartz dominate (Figure 41, Figure 42), but with increasing temperature, wairakite (Figure 43), prehnite and epidote (Figure 44) become more visible.

2.3 Descriptions of wells

Unlike the cuttings from the wells, which were collected at 2 meter interval, the thin sections do not provide a continuous representation of the rock formations that are penetrated by the wells, being only from relatively widely spaced depth intervals. However, thin section inspection enables more comprehensive determination of rock types and alteration mineralogy at the selected depths than possible by viewing cuttings under a binocular microscope. In some cases, for instance, temperature index minerals are noted at considerably shallower depths under the petrographic microscope than with the binocular microscope, because small mineral grains which are hard to detect in hand samples are often obvious in thin sections.

As might be expected, considering how mixed the cuttings can be, there are some discrepancies between rock types as determined during logging of the cuttings and in thin sections with the petrographic microscope. In general, the agreement is good, though, as can be seen in Figure 45, Figure 46 and Figure 47, where lithology as determined in thin sections is shown next to the stratigraphic columns for the wells as determined with the help of a binocular microscope. It should be noted that in these figures, the formation boundaries use are the same as determined with the help of the binocular microscope. In most cases, discrepancies relate to hyaloclastite formations, whether they are termed basaltic tuff, basaltic breccia or glassy basalt. But, as mentioned previously, the demarcation between these formation types is gradational and the distinction consequently somewhat subjective.

2.3.1 Distribution of key minerals

The distribution of the temperature index minerals quartz, chlorite, epidote, prehnite, actinolite and calcite is shown in the diagrams in Figure 48, Figure 49, Figure 50, Figure 51, Figure 52 and Figure 53, respectively, next to stratigraphic columns for the wells derived from cuttings logs. As the mineral distribution in these diagrams is based on interpolations between relatively widely spaced thin section samples, and in some cases starting at a few hundred meters depth or with long circulation loss intervals, the figures need to be interpreted with caution. In some cases, therefore, the minerals could also occur at shallower depths than shown, and in other cases, their occurance could be not as continous as indicated or the absence intervals shorter.

Figure 50 shows that epidote becomes common at about 800–1000 m TVD near pad C, where wells ÞG-3, ÞG-4 and ÞG-5 are located. In wells ÞG-4 and ÞG-5, which were drilled from pad A, epidote appears shallower and it can be seen in the first thin sections from these wells. Prehnite starts precipitating even shallower in wells at pad C than epidote, closer to 400–500 m depth, but, like epidote, can be seen in the shallowest samples from ÞG-4 and ÞG-5 (Figure 51). In well ÞG-8, neither prehnite nor epidote has appeared at about 700 m TVD, but from that depth down to about 1400 m TVD, no samples are available because of circulation losses. Both prehnite and epidote can be found in samples from just below the gap. It is worth noting that crystalline basalt appears to favor the early growth of epidote, while early and abundant prehnite seems to be associated with rock formations rich in basaltic glass. This could be the reason for the apparent delayed development of epidote compared to prehnite in the wells at pad C. In all wells, actinolite is first seen in minor amounts a little deeper than the first prehnite and epidote (Figure 52). With the exception of well ÞG-8, calcite is seen in the shallowest samples (Figure 53). In well ÞG-8, calcite is not seen at 100 m, but in the next sample from 330–340 m, it can be found. From there, calcite can be seen down to the bottom of the well. In contrast, calcite is present only over a short interval in wells ÞG-4, ÞG-5 and ÞG-6, down to about 800 m TVD in wells ÞG-4 and ÞG-6 and even shallower in well ÞG-5, although one calcite grain was seen in one sample from a little deeper than 800 m TVD, possibly an accidental grain from higher in the well. Calcite is present down to the bottom of wells ÞG-3 and ÞG-7, almost continuously in well ÞG-3, but with a nearly continuous gap from about 1250 m TVD down to over 1500 m TVD in well ÞG-7. This could be a sign of temperature reversal in the lowermost part of well ÞG-7.

2.3.2 Well ÞG-3

The lithologies seen in the thin sections from ÞG-3 are predominantly basaltic, both basalt layers and hyaloclastite formations. Otherwise, only one fine-grained intermediate igneous formation was noted (Table 7). In the lowest part of the well, several basaltic intrusions were seen, mostly from 2410 m and below, which indicates that below this depth significant part of the basement is composed of intrusions.

Clinopyroxene and plagioclase alteration is mostly minor or moderate down to less than 1300 m MD, but it becomes common to see these minerals with major alteration in the lower half of the well (Table 8). Extensive alteration of primary minerals is also seen in the lowest part.

The shallowest thin section sample from well ÞG-3 comes from 500 m MD. At that depth, fair amount of alteration has already taken hold (Table 1, Table 8). The presence of epidote and prehnite suggests that the temperature has at some point reached about 250°C. Actinolite is first noted at 750 m MD, but calcite is still present in some amount. This indicates that the temperature of the geothermal system has reached at least 280°C at this depth at some point in time. The amount of calcite decreases significantly below about 1100 m depth, and yet it persists in small amounts, generally as poorly developed grains, until the bottom of the well (deepest sample 2658 m MD) (Figure 54). It is interesting that simultaneously a likely secondary hornblende (Figure 38) is observed at 2542 m, suggesting temperatures having reached at least about 350°C. As experience from Icelandic high-temperature systems indicates that calcite is not stable at temperatures above 300°C, this suggests that one of these minerals is metastable at the present conditions. Moreover, measurements that have been conducted in well ÞG-3 indicate formation temperatures over 350°C in the lowermost part of the well. This and the ragged looks of calcite suggests that it is calcite that is beyond its stability field in the lower part of well ÞG-3. A possible explanation is that there has been recent warming in this part of the geothermal reservoir, with calcite persisting from cooler conditions in the past.

2.3.3 Well ÞG-4

All the formations seen in the thin sections from well ÞG-4 have basaltic composition. Hyaloclastic formations are common down to about 1100 m MD, but basalt layers are more abundant below this depth (Table 9).

In the first thin section of a sample from 310 m, basaltic glass is already completely altered, and the same is true for olivine when first seen slightly deeper at 380 m (Table 10). The alteration of plagioclase and clinopyroxene is mostly moderate or minor, respectively, down to 970 m MD, below which it is mostly deemed major.

In the uppermost thin section sample from 310 m depth, several minerals indicative of moderately high temperatures, have already precipitated (Table 2), suggesting that the temperature has already reached about 240–250°C at this shallow depth at some point. Wollastonite appears slightly deeper at 462 m and minute actinolite is seen at 750 m, indicating temperature of at least 280°C. When calcite disappears below 860 m MD, it is likely that the temperature has reached close to 300°C at some point. Hence, the evidence points to very shallow depth down to the top of the high-temperature system in this part of the reservoir beneath Bæjarfjall mountain, and temperature probably in excess of 300°C in the lowermost part of the well, which reaches down to more than 1150 m below sea level.

2.3.4 Well ÞG-5

All the formations seen in the thin sections from well ÞG-5, which cover the range 480 to 1500 m MD have basaltic composition, and are either proper basalts or basaltic hyaloclastites (Table 11). However, some silicic volcanic rock fragments were noted mixed with the basalt at 480 m. One formation, at 1280 m, was identified as basalt intrusion.

All glass and olivine observed in the thin sections have been completely altered (Table 12). Alteration of plagioclase and clinopyroxene is variable, but mostly either moderate or major, with major alteration of plagioclase and clinopyroxene starting at 600 and 764 m depth, respectively.

Like in the neighbouring well ÞG-4, the evidence indicates shallow depth down to the high-temperature system in well ÞG-5. In the uppermost thin section sample from 480 m MD, quartz, chlorite, epidote and prehnite are already present, indicating that the temperature has reached at least 240–250°C at this depth. Small amount of actinolite is seen at 600 m, suggesting temperature of about 280°C (Table 3), and increasing amounts of actinolite are seen below this depth. This is consistent with no calcite being seen below 600 m, with the exception of one grain in the sample from 892 m. It is therefore likely that the temperature in this part of the reservoir has at some point reached close to 300°C or more. No clear signs of hornblende formation were seen in the samples from well ÞG-5.

2.3.5 Well ÞG-6

Well ÞG-6 is located at pad C like well ÞG-3, but the thin sections cover the range 130 to 2700 m MD. Likely basaltic hyaloclastite formations seem to dominate the thin section samples, with only a few basalt layers noted. The only formation that is not basaltic in composition is the lowest one at 2700 m, which is a rhyolite formation with abundant quartz (Table 13). A grain of biotite found in this sample could be primary. Some silicic fragments were also seen in a sample of basaltic breccia at 558 m.

All basaltic glass and olivine seen in the thin sections are completely altered (Table 14). In the shallowest samples, the alteration of plagioclase, clinopyroxene and Fe-Ti oxides is either fair or minor, but major alteration is seen in all minerals at 760 m, and from about 1000 m, all these minerals have suffered major alteration in most samples, and in the lowest part of the well the alteration is judged extensive.

Quartz and wairakite are already seen in the top sample from 130 m, as well as smectite and mixed-layer clay (Table 4). Thus, there is evidence for for the temperature having been about 200°C already at 130 m depth. In the next sample from 350 m, chlorite has appeared alongside mixed-layer clay. Then in a sample from 428 m, epidote and prehnite are both found and wollastonite at 490 m, suggesting temperature in excess of 250°C. Actinolite is seen from 760 m down to the bottom of the well. Meanwhile, calcite is present from the uppermost sample at 130 m down to 840 m, and then again at 1990 m and in three more samples below, in minor amounts in all cases. Hornblende was found in a sample at 2350 m (Figure 1) and possibly in the rhyolite layer at 2700 m, suggesting temperature close to 350°C. Interestingly, the same was observed in well ÞG-3 that hornblende and calcite were found in the same sample, as was noted earlier. The same explanation might apply that calcite persists from cooler conditions and that the presence of hornblende is indicative of a later warming event.

2.3.6 Well ÞG-7

Well ÞG-7 is located at the same pad as wells ÞG-3 and ÞG-6. The thin sections cover the range 54–2490 m MD. As observed in the thin sections, this well has more silica-rich volcanic formations than any of the other wells, or one silicic tuff formation (Figure 10) and two silicic breccia formations (Figure 11) at 880, 1730 and 1790 m, respectively (Table 15). In addition, a breccia formation at 1864 m also contains fragments of rhyolite (Figure 9) and devitrified silicic glass. Abundant secondary quartz, illite and likely adularia are associated with the silica-rich rocks. Illite is widely present in the well, not only in the silicic formations. An andesitic breccia was also seen at 248 m (Figure 8). Otherwise, basaltic rocks dominate, with hyaloclastite formations clearly in majority, especially in the upper 2000 meters of the well.

No unaltered glass or olivine was observed in the thin sections, not even of the sample from 54 m depth, and in all cases, these phases were completely altered (Table 16). In contrast, alteration of plagioclase, clinopyroxene and titanomagnetite is in most cases minor or they are apparently completely unaltered at 342 m and above. At 382 m, however, plagioclase has suffered major alteration and clinopyroxene and titanomagnetite are moderately altered. Below about 1000 m, all minerals are highly altered, with extensive alteration in the lowest sample from 2490 m.

Quartz is already seen in the uppermost sample from 54 m depth, along with smectite, but the next sample from 94 m also contains wairakite and mixed-layer clay (Table 5), indicating that the temperature has at some point been up to at least 200°C. Chlorite is seen at 134 m, and prehnite and wollastonite at 342 m, which indicates alteration temperature over 250°C at the latter depth. The first indication of actinolite was seen at 742 m, but from 1020 m, it is continuously seen. Calcite is seen continuously from 54 m down to 1410 m, although only in minor amounts from below 1200 m, and is intermittently present down to 1730 m, from where it is continuously seen down to the bottom of the well (Figure 55), albeit never in a large amount. Unlike in samples from the neighboring wells ÞG-3 and ÞG-6, no hornblende is found in the thin sections from ÞG-7, possibly indicating lower temperature conditions than in the former wells.

2.3.7 Well ÞG-8

Well ÞG-8 is located in an area some distance to the west from the other wells studied in this report. There are indications that this part of the geothermal system is somewhat cooler than the parts penetrated by the other wells. It should be noted, though, that because of a total loss of circulation, no cuttings were retrieved between 744 and 1495 m MD. As seen in the thin sections, the formations penetrated by the hole are basaltic in composition, either basalt layers or basaltic hyaloclastites (Table 17). However, in a few places there are silicic fragments that could indicate the proximity of silica-rich formations, or the fragments could be sedimentary particles or airborne volcanic tephra fragments. Samples from 524 and 582 m could be from a fault zone breccia formation. Two of the basalt formations at 1834 and 2090 m are likely to be intrusions and three more basalt formations between these two could also be intrusions.

The uppermost thin section sample from ÞG-8 is from 100 m, which is the location of a fresh olivine tholeiite basalt formation (Figure 6). This is also the only observed example of fresh glass and olivine in all the wells (Table 18). However, in a sample from 330–340 m, both the basaltic glass and olivine are affected by major alteration, and both phases are completely altered at 470 m (Figure 24). At 524 m, both clinopyroxene and Fe-Ti oxides have minor alteration, whereas plagioclase has been moderately altered. Below the circulation loss zone, starting at 1532 m, plagioclase, clinopyroxene and Fe-Ti oxides have mostly suffered major alteration, and from 2350 m down to the bottom of the well the alteration is extensive (Figure 35), suggesting high-temperature conditions, probably over 300°C.

As mentioned earlier, the sample from 100 m contains fresh basalt, free of secondary minerals. In contrast, the next sample from 330–340 m contains smectite, zeolites and chalcedony, indicating low-temperature hydrothermal conditions below 180°C (Table 6). At 390 m, quartz has appeared, suggesting that the temperature has reached at least 180°C at some point. Then at 470 m, the presence of both chlorite and wairakite indicates that the temperature was over 200°C. Neither epidote nor prehnite was seen before the circulation loss began at 744 m, but both can be found in the next thin section from 1532 m. In a sample of coarse cuttings brought up with a junk basket, probably sampling the 1130–1152 m depth interval, inspection with a binocular microscope showed no evidence for the precipitation of epidote or prehnite. Actinolite is seen in a thin section of a sample from slightly greater depth, 1580 m, suggesting temperature of at least 280°C. Calcite is found in all samples, except the uppermost from 100 m. Its abundance fluctuates somewhat, but it can be found both as distinct grains and in the groundmass all the way to the bottom of the well (Figure 34). The junk basket sample from 1130–1152 m also had laumonite, which is also seen in thin sections from 2090 and 2300 m MD (Figure 56). This is strong evidence for cooling of the geothermal system from temperature of at least 280°C to less than 180°C. This and the fact that the basalt at 100 m is fresh and free of secondary minerals raises the question whether high-temperature geothermal activity precedes the emplacement of this basalt and what can been seen today is a fossil high-temperature system.

2.4 Secondary mineral sequences

Secondary mineral sequences, as observed in the thin sections, are listed in Table 19. There are a few apparent contradictions where a mineral forms both earlier and after another mineral, but this need not be incorrect, as explained earlier.

Quartz and epidote are the secondary minerals which order of precipitation can most often be deduced. It is noticable that above roughly 1000 m depth quartz tends to precipitate earlier than epidote, but the converse tends to be true below this depth. Wairakite and especially prehnite tend to precipitate after quartz and epidote. The order of calcite, chlorite and actinolite is more irregular. A possible cause is that these minerals are forming over longer period of time with changing conditions or alternatively that their formation is episodic. The latter might be true especially for calcite.

3 Connections between different wells

In connecting between different wells, the thin section inspection will only supplement the cuttings logs because of the sparse thin section sampling. Nevertheless, the more in-depth examination permitted by the petrographic microscope can provide more robust connections between wells.

3.1 Connections based on rock composition

As was discussed earlier in section 2.1.2, an attempt was made to classify basaltic rocks as either olivine tholeiites or tholeiites. The results are shown in Figure 61. According to this figure, tholeiitic and olivine tholeiitic magmas have been erupting alternately during the time covered by the strata, without any obvious trends. Nor are there many clearcut connections between wells. The latter can probably be explained partly by the abundance of hyaloclastites, which tend to have limited horizontal extent and change rapidly, both laterally and vertically. Furthermore, it is likely that dike intrusions are common in the deeper parts of the wells and in most cases these are either only found in one well or at very different depths in two or more wells. Generally, the basalts are not distinctive enough to identify them in different locations, the marker layer or layers mentioned in the next section being an exception. Andesitic or rhyolitic formations are potentially an exception, but none of them can be used to connect between wells. Even a sequence of silicic rocks in well ÞG-7 that could be over 100 meter thick cannot be found in any of the other wells.

3.2 Marker layers

In all the wells, with the possible exception of well ÞG-3, likely marker layer or layers can be found between 200 and 400 m below sea level, with the upper boundary close to 200 m (Figure 57). In wells ÞG-6, ÞG-7 and ÞG-8, the layers look more brecciated than in ÞG-4 and ÞG-5, possibly because they have been weathered. The marker layers are unusually plagioclase-rich and relatively coarse grained (Figure 58). They also carry relatively coarse pyroxene and often olivine crystals (Figure 59). The layers tend to be considerably altered, containing abundant chlorite, and also actinolite in well ÞG-5, and often pervasive calcite precipitates (Figure 58, Figure 60). The thickness of this unit or units could greater in well ÞG-5 than the other wells, and it is possibly absent in well ÞG-3, but considering the proximity to wells ÞG-6 and ÞG-7, the apparent absence could also be caused by the spacing of the thin section samples. The fact that the depth relative to sea level of the marker layers is not drastically different in the wells suggests that there have not been great vertical fault movements in this area after the emplacement of the layers.

4 Discussion and conclusions

With mostly 50–100 meter spacing, the thin section samples from the Theistareykir wells are very widely spaced compared to the 2 meter interval of the cuttings samples. This means that the thin section examination is not ideally suited to reveal the lithostratigraphy of the Theistareykir area, but it supports the cuttings logs and can be used to check their accuracy. However, when it comes to determining the mineralogy and alteration of the rock formations, the thin section inspections offer significant advantages. Thin section observations with a petrographic microscope allow indentification of minute amounts of both primary and secondary minerals that would be nearly impossible to detect with binocular microscope observations of cuttings, and provide textural evidence that cannot be obtained with the binocular microscope. This means that better information can be obtained in the thin sections about temperatures and potential changes in temperatures with time.

The thin section inspections provide evidence for high temperatures close to the surface in all the wells, except ÞG-8. Well ÞG-7, which is located at pad C like wells ÞG-3 and ÞG-6, has both quartz (Figure 48) and wairakite at less than 100 m depth, suggesting that the temperature was at least 200°C at some point at this depth. Then at 342 m, prehnite is seen in ÞG-7 and a little deeper in ÞG-3 and ÞG-6 (Figure 51), indicating temperature of at least 240°C. Actinolite appears at about 750 m MD in all three wells (Figure 52), at which point, the temperature should have reached at least 280°C. The traces of hornblende that were found in ÞG-3 and ÞG-6 below 2300 m MD (Table 1 and Table 4) suggest that the maximum temperature has reached about 350°C at least in this part of the geothermal reservoir. At the same time, traces of calcite can be found at almost all depths in well ÞG-3 down to the bottom (Figure 53). In contrast, calcite distribution is sporadic in the lower part of ÞG-6. Studies of fluid inclusions in the lower part of ÞG-3 show a range of temperatures, exceeding 350°C at the high end. Results of downhole logging after the drilling of the well indicate formation temperature over 350°C in the lowest part. The likely explanation, therefore, for the contradiction of the presence of hornblende and calcite in ÞG-3 is that hornblende precipitates represent the current conditions in the well. Meanwhile, calcite appears to persist beyond its stability range. This suggests that there has been a recent warming event in this part of the geothermal reservoir from temperature of about 300°C or less to about 350°C or more. This is likely to apply to the portion penetrated by well ÞG-6 also. In well ÞG-7, however, no hornblende was seen. Calcite mostly disappears in the 1400–1700 m MD range, where the temperature could then exceed 280–300°C, and then reappears in the lower part of the well. A possible explanation is a temperature inversion with temperatures lower than 280–300°C in the bottom of the well, perhaps because the well reaches into a downflow branch of the geothermal system.

Wells ÞG-4 and ÞG-5 are located at pad A close to Bæjarfjall mountain. Like in the wells at pad C, which is located over 1 km to ENE relative to pad A, the depth down to the high-temperature system is very shallow, with quartz, wairakite, chlorite, epidote and prehnite all present in the shallowest sample from 310 m MD in well ÞG-4 (Table 2), indicating temperature having reached at least 240–250°C at some point. Actinolite first appears in both wells between 500 and 600 m MD (Figure 52) and calcite is not seen below 800–900 m MD in either of the two wells (Figure 53). Thus, it is likely that the temperature in the part of the reservoir penetrated by ÞG-4 and ÞG-5 exceeds 280–300°C. Hornblende was not seen in the thin sections from these wells and therefore it seems unlikely that the temperature reaches 350°C, although it should be noted that the true vertical depth of ÞG-4 and ÞG-5 is hundreds of meters shallower than any of the wells at pad C.

Well ÞG-8 is the first and so far the only well drilled from pad N. The well is located in the 2500 years old Theistareykjahraun lava field, near the crater Stórihver, about 2–3 km to the west from pads A and C, and some distance from the main surface manifestations of geothermal activity in the Theistareykir area. The depth down to high-temperature conditions is greater in ÞG-8 than the other wells studied. The first sample from 100 m contains fresh basalt formation where no alteration can be detected, and in a sample from 390 m, secondary quartz (Figure 48) and smectite can be found, but neither wairakite nor mixed-layer clay, indicating temperature less than 200°C. Because of the large gap in sampling caused by circulation losses between 744 and 1495 m MD, the depth range where epidote (Figure 50) and prehnite first appear is not well constrained, but these minerals are found in the first sample from below the gap at 1532 m MD along with wollastonite. At this depth, the temperature must then have exceeded 250°C at some point in time. The presence of actinolite (Figure 52) slightly deeper indicates temperature reaching at least 280°C. The great extent of alteration of the primary minerals, plagioclase, clinopyroxene and Fe-Ti oxides (e.g. see Figure 34, Figure 35), in the lowermost part of the well strongly suggests that the temperature was over 300°C sometime in the past. However, the fact that calcite (Figure 53) is found in all samples, except the first one from 100 m, indicates that this is unlikely to be the case any more. Furthermore, the well developed laumontite (Figure 56) that was found in samples from 2090 and 2300 m MD (Table 6) implies that there has been drastic cooling in the portion of the reservoir penetrated by the lower part of well ÞG-8, with present day temperatures likely to be lower than 180°C. Resistivity measurements provide strong evidence for a geothermal reservoir under the Theistareykir lava field, with a low-resistivity cap and a high-resitivity core (Guðmundsson et al., 2008). The center is not far from the crater Stórihver, in which direction well ÞG-8 was drilled (Níelsson et al., 2011b). The evidence indicating that the rocks in lowest part of the well are at a temperature less than 180°C gives reason to suggest that the geothermal reservoir dectected could be fossil.

The Theistareykir area is highly dissected with faults, mostly normal faults with roughly northerly strike direction (Guðmundsson et al., 2008). Connections between the marker layer or layers between 200 and 400 m below sea level (Figure 57) indicate that although there has undoubtedly been considerable extension in the area in the Holocene (Guðmundsson et al., 2008), the vertical movements of the faults that lie between drill pads A, C and N probably do not exceed a few tens of meters. Other connections between wells are difficult because of the sparse thin section samples and the chaotic nature of hyaloclastite formations.

In this study, an attempt was made to classify the basalts as either tholeiites (Figure 7) or olivine tholeiites (Figure 6). The Holocene and Late Glacial basaltic lavas of the Theistareykir volcanic system are dominated by olivine tholeiites (Guðmundsson et al., 2008), but the classification of basaltic rocks found in the wells indicates that tholeiites and olivine tholeiites were erupted and intruded in comparable amounts in the more distant past, without any distinct pattern emerging with time (Figure 61). The few evolved, intermediate and silicic, igneous formations noticed in the thin section cannot be traced between wells.

Silicic volcanic formation in Iceland, mostly rhyolites and dacites, tend to be associated with central volcanoes and the development of shallow magma reservoirs. The preponderance of eruptions of relatively primitive volcanic rocks and the lack of tholeiites and more silicic volcanics in Theistareykir in the Late Glacial and Holocene period does not support the existence of a shallow magma reservoir under the area. Rather it is more reminiscent of an immature volcano where the magma comes from the mantle without much fractionation or interaction in the crust. This can perhaps be explained by shorter residence time of magma in the crust because of much higher magma productivity during the deglaciation. This would not explain the lack of more evolved volcanics in the Holocene, however. So this begs the question whether Theistareykir is a young volcano or a mature volcano that has undergone rejuvenation. If the former is true then the base of the volcano could be quite shallow, maybe no more than a few hundred meters below the surface or less. There are no unambiguous signs of a hiatus that could be associated with the extinction of one volcano and the beginning activity of a new one. However, the interval between about 600 and 800 m below sea level is conspicuously rich in basaltic breccias in the wells at pads A and C (Figure 45, Figure 46, Figure 47), and the question is if these formations are sedimentary and that this interval represents a hiatus in volcanic activity.

Table 1. *Secondary minerals noted in samples from well ÞG-3. Smc = smectite, mlc = mixed-layer clay, chl = chlorite, ill = illite, cc = calcite, py = pyrite, zeol = zeolite, lau = laumontite, cd = chalcedony, qz = quartz, wai = wairakite, ttn = titanite, ep = epidote, pre = prehnite, wo = wollastonite, gt = garnet, act = actinolite, alb = albite, hm = hematite, idd = iddingsite, xon = xonotlite, hbl = hornblende, bt =biotite, mt = magnetite, adl = adularia.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
500	Basalt - fine-grained			X		X	X				X	X	X	X	X					X						
544	Basalt - fine- to medium-grained			X		X	X				X	X	X							X						
604	Basalt - fine-grained			X		X	X				X	X	X													
674	Basaltic tuff			X	X	X	X				X		X													
750	Basaltic breccia			X	X	X	X				X	X	X		X			X								
820	Basaltic tuff			X	X	X	X				X	X	X	X	X			X								
890	Basaltic tuff			X		X	X				X		X	X	X			X								
950	Basalt - fine- to medium-grained			X	X	X	X				X	X	X			X		X								
1020	Basaltic breccia			X		X	X				X	X	X	X	X	X		X								
1100	Basaltic breccia			X		X	X				X		X	X	X			X								
1170	Glassy basalt			X		X	X				X		X	X	X			X								
1270	Basaltic breccia			X		X	X				X	X	X	X	X	X		X								
1366	Glassy basalt			X		X	X				X		X		X	X		X								
1426	Basalt - fine-grained			X		X	X				X	X	X	X	X			X								
1470	Basalt - medium-grained			X		X	X				X		X		X	X		X								
1530	Glassy basalt			X		X	X				X	X	X	X				X								
1610	Basalt - fine- to medium-grained			X		X	X				X	X	X	X	X			X		X						
1678	Glassy basalt			X		X	X				X	X	X	X	X		X	X		X						
1740	Intermediate volcanic rock			X	X	X	X				X	X	X	X	X	X		X								
1786	Glassy basalt			X	X	X	X				X	X	X	X	X	X		X								
1880	Basaltic breccia			X		X	X				X		X	X	X			X								
1940	Basalt - fine- to medium-grained			X		X	X				X		X	X	X			X								
2000	Basalt (intrusion) - fine- to medium-grained			X		X					X		X	X	X	X	X	X		X						
2086	Glassy basalt			X		X	X				X		X	X	X			X								
2142	Glassy basalt			X							X		X	X	X	X		X								
2210	Basaltic breccia			X		X	X				X		X	X	X			X								
2256	Glassy basalt			X		X	X				X	X	X	X	X	X		X								
2350	Basalt - fine-grained			X		X	X				X		X	X	X	X		X								
2410	Basalt - fine- to medium-grained			X		X	X				X		X	X	X			X								
2482	Basalt - fine- to medium-grained			X		X	X				X		X	X	X	X		X								
2542	Basalt (intrusion) - fine- to medium-grained			X		X	X				X		X	X	X		X	X					X			
2568	Basalt (intrusion) - fine- to medium-grained			X		X	X				X		X	X	X			X								
2604	Basalt - fine-grained			X		X	X				X		X	X	X		X	X				X				
2658	Basaltic breccia			X		X	X				X	X	X	X	X	X	X	X								

Table 2. *Secondary minerals noted in samples from well ÞG-4. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
310	Basaltic tuff			X		X	X				X	X		X	X											
380	Basaltic tuff			X		X	X				X	X	X	X	X		X									
462	Basalt - cryptocrystalline to medium-grained			X		X	X				X	X	X	X		X					X					
532	Basaltic tuff			X	X	X	X				X	X	X	X	X	X		X		X						
604	Basalt - medium-grained			X		X	X				X			X				X								
672	Basaltic tuff			X		X	X				X	X	X	X	X											
736	Basaltic tuff			X		X	X				X	X	X	X	X		X	X								
794	Basalt - fine-grained			X		X	X				X	X	X	X	X	X	X									
860	Basaltic tuff			X		X	X				X		X	X	X	X			X							
930	Basaltic breccia			X			X				X		X	X	X	X		X								
970	Basaltic breccia			X			X				X		X	X	X			X								
1010	Glassy basalt			X							X		X	X	X	X	X	X								
1078	Basaltic breccia			X							X		X	X	X		X	X		X						
1110	Basalt - fine- to medium-grained			X							X		X	X	X		X	X								
1170	Basaltic breccia			X							X	X	X	X	X	X	X	X		X						
1230	Basalt - fine- to medium-grained			X							X		X	X	X	X	X	X								
1270	Basalt - fine-grained			X							X		X	X	X	X		X								
1318	Basaltic breccia			X							X		X	X	X	X	X	X								
1390	Basalt - fine-grained			X							X		X	X	X	X	X	X	X							
1510	Basalt - fine-grained			X							X		X	X	X			X								
1600	Basalt - fine-grained			X							X		X	X	X	X	X	X								
1700	Basalt - cryptocrystalline to fine-grained			X							X			X		X		X								

Table 3. *Secondary minerals noted in samples from well ÞG-5. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
480	Basalt - fine-grained	X	X	X		X	X				X		X	X	X											
560	Basaltic tuff			X		X	X					X	X	X	X		X			X						
600	Basalt - medium- to coarse-grained		X	X		X	X				X	X	X	X	X		X	X		X						
764	Basalt - medium-grained			X			X				X		X	X	X			X								
828	Basaltic breccia			X			X				X	X	X	X	X	X	X	X								
892	Basaltic breccia			X		X	X				X		X	X	X		X	X								
956	Basaltic breccia			X			X				X		X	X	X	X		X								
1022	Basaltic tuff			X			X				X		X	X	X	X	X	X		X						
1078	Glassy basalt			X			X				X		X	X	X		X	X	X							
1146	Glassy basalt			X			X				X		X	X	X		X	X								
1210	Basaltic breccia			X			X				X		X	X	X	X	X	X								
1280	Basalt (intr.) – cryptocrystalline to fine-grained			X							X		X	X	X			X		X						
1350	Glassy basalt			X			X				X	X	X	X	X	X		X								
1400	Glassy basalt			X									X	X	X			X								

Table 4. *Secondary minerals noted in samples from well ÞG-6. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
130	Glassy basalt	X	X			X	X				X	X	X													
350	Glassy basalt		X	X		X	X				X	X	X							X						
428	Basaltic tuff		X	X		X	X				X	X	X	X	X											
490	Basaltic tuff		X	X		X	X				X	X	X		X	X				X						
558	Basaltic breccia		X	X	X	X	X				X	X	X		X											
640	Glassy basalt		X	X		X	X				X	X	X		X					X						
690	Basaltic tuff		X	X		X	X				X	X	X		X					X						
760	Basaltic breccia			X		X	X				X	X	X		X	X	X	X		X						
840	Basalt - cryptocrystalline			X		X	X				X	X	X	X	X	X	X	X								
902	Basaltic breccia			X			X				X		X	X	X	X	X	X								
970	Basaltic tuff			X	X		X				X	X	X	X	X	X		X								
1040	Basaltic breccia			X			X				X	X	X	X	X	X	X	X								
1120	Basaltic breccia			X			X				X	X	X		X	X	X	X								
1200	Basaltic breccia			X			X				X	X	X	X	X	X		X								
1280	Glassy basalt			X			X				X	X	X	X	X	X	X	X								
1360	Glassy basalt			X			X				X	X	X	X	X	X	X	X								
1430	Glassy basalt			X			X				X	X	X	X	X		X	X								
1494	Glassy basalt			X			X				X		X	X	X	X	X	X								
1570	Glassy basalt			X			X				X	X	X	X	X	X	X	X		X						
1640	Glassy basalt			X			X				X		X	X	X	X		X								
1700	Basalt - cryptocrystalline to fine-grained			X			X				X		X	X	X	X		X		X						
1754	Glassy basalt			X			X				X	X	X	X	X			X								
1826	Basaltic breccia			X							X	X	X	X	X	X	X	X								
1906	Basaltic breccia			X			X				X	X	X	X	X	X	X	X		X						
1990	Glassy basalt			X		X	X				X	X	X	X	X		X	X								
2076	Basaltic breccia			X		X	X				X		X	X	X	X		X								
2160	Basalt - cryptocrystalline to fine-grained			X			X				X		X	X	X	X	X	X								
2250	Glassy basalt			X			X				X		X	X	X		X	X		X						
2350	Basalt - fine- to medium-grained			X			X				X		X	X	X			X		X			X			
2430	Basaltic breccia			X							X		X	X	X			X								
2500	Basaltic breccia			X		X	X				X		X	X	X	X		X								
2580	Basaltic breccia			X			X				X		X	X	X		X	X								
2700	Rhyolite			X	X	X	X				X		X	X	X	X		X		X			?	?	?	

Table 5. *Secondary minerals noted in samples from well ÞG-7. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
54	Basaltic breccia	X				X	X	X			X		X							X						
94	Basaltic tuff	X	X			X	X				X	X														
134	Basalt - cryptocrystalline to fine-grained	X	X	X		X	X				X	X	X							X						
204	Glassy basalt		X	X		X	X				X	X	X													
248	Andesitic breccia	X	X	X		X	X				X	X								X						
300	Basaltic breccia		X	X		X	X	X			X	X	X							X						
342	Basaltic breccia		X	X		X	X				X	X	X		X	X										
382	Glassy basalt		X	X		X	X				X	X	X		X											
462	Basaltic breccia		X	X		X	X		X		X	X	X		X	X										
550	Basaltic breccia		X	X		X	X				X	X	X							X						
610	Basaltic breccia		X	X		X	X				X	X	X			X				X						
682	Glassy basalt		X	X	X	X	X				X	X	X							X						
742	Basaltic breccia		X	X		X	X				X		X		X			X								
814	Basaltic tuff		X	X	X	X	X				X	X	X	X	X					X						
880	Silicic tuff				X	X	X				X	X	X		X			X								
950-54	Basaltic tuff		X	X	X	X	X				X	X	X	X		X										
1020	Basaltic breccia			X	X	X	X				X	X	X	X	X	X	X	X								
1096	Basaltic breccia			X		X	X				X	X	X	X	X	X		X								
1164	Glassy basalt			X	X	X	X				X	X	X	X	X			X								
1218	Glassy basalt			X		X	X				X		X	X	X	X	X	X								
1278	Basaltic breccia			X		X	X				X		X	X	X	X		X		X						
1352	Basaltic breccia			X	X	X	X				X		X	X	X			X								
1410	Basaltic breccia			X	X	X	X				X		X	X	X	X		X								
1480	Basaltic breccia			X	X		X				X		X	X		X		X		X						
1552	Basalt - cryptocrystalline to fine-grained			X							X		X	X	X	X		X								
1622	Basalt - cryptocrystalline to fine-grained			X	X	X					X	X	X	X	X	X	X	X	?							
1672	Glassy basalt			X			X				X		X	X	X		X	X	?							
1730	Silicic breccia				X	X					X		X	X	X			X	?	X						?
1790	Silicic breccia			X	X	X	X				X		X	X	X			X		X						
1864	Breccia			X	X	X	X				X	X	X	X	X	X		X		X						?
1926	Basaltic breccia			X	X	X	X				X	X	X	X	X	X	X	X		X						?
1986	Glassy basalt			X	X	X					X		X	X	X	X	X	X								?
2060	Basaltic breccia			X		X	X				X		X	X	X	X		X								
2120	Basalt - cryptocrystalline to fine-grained			X	X	X	X				X		X	X	X	X		X		X						
2194	Basalt - cryptocrystalline to fine-grained			X	X	X					X	X	X	X	X			X		X						
2256	Basalt - cryptocrystalline to fine-grained			X	X	X	X				X	X	X	X	X	X		X		X						
2320	Glassy basalt			X	X	X	X				X	X	X	X	X	X		X		X						
2374	Basalt - fine-grained			X	X	X	X				X		X	X	X			X		X						
2426	Basalt (intrusion) - medium-grained			X	X	X	X				X		X	X				X		X						
2490	Glassy basalt			X	X	X	X				X		X	X	X			X								

Table 6. *Secondary minerals noted in samples from well ÞG-8. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Rock type	Smc	Mlc	Chl	Ill	Cc	Py	Zeol	Lau	Cd	Qz	Wai	Ttn	Ep	Pre	Wo	Gt	Act	Alb	Hm	Idd	Xon	Hbl	Bt	Mt	Adl
100	Basalt - fine- to medium-grained																									
330-340	Basaltic breccia	X				X		X		X										X						
390	Basaltic breccia	X				X		X			X															
470	Basaltic tuff		X	X		X	X				X	X								X						
524	Breccia	X	X	X	X	X	X	X	X		X	X	X							X						
582	Breccia			X		X	X	X			X	X	X							X						
660	Basaltic breccia			X	X	X	X		X		X	X	X							X						
730	Basaltic tuff		X	X	X	X	X				X	X	X							X						
1532	Glassy basalt			X		X	X				X		X	X	X					X						
1580	Glassy basalt				X	X	X				X		X	X	X			X		X						
1626	Glassy basalt			X	X	X	X				X		X	X	X			X								
1700	Basaltic breccia			X	X	X	X				X		X	X		X		X								
1784	Basaltic breccia			X		X	X				X	X	X	X	X			X		X						
1834	Basalt (intrusion) - fine- to medium-grained			X	X	X	X				X		X	X		X		X		X						
1898	Basalt - fine- to medium-grained			X		X	X				X		X	X		X		X		X						
1962	Basalt - cryptocrystalline to fine-grained			X		X	X				X		X	X	X			X								
2022	Basalt - cryptocrystalline to fine-grained			X	X	X	X				X		X	X				X								
2090	Basalt (intrusion) - glassy to fine-grained			X		X	X		X		X		X	X	X			X		X						
2150	Basaltic tuff			X		X	X				X	X	X	X	X			X		X						
2240	Glassy basalt			X		X	X				X		X	X	X			X		X						
2300	Basaltic breccia			X		X	X		X		X		X	X	X			X		X						
2350	Glassy basalt			X		X	X				X		X	X	X		X	X		X						
2420	Basaltic breccia			X		X	X				X		X	X				X								
2490	Basaltic breccia			X		X	X				X		X	X				X								

Table 7. *Lithologies in well ÞG-3 along with comments. Thol = tholeiite, ol thol = olivine tholeiite, ol = olivine, plag = plagioclase, cpx = clinopyroxene, and see caption for Table 1 for abbreviations of names of secondary minerals.*

Depth (m)	Rock type	Comments
500	Basalt - fine-grained	Intergranular thol; evolved; plag and cpx phenocrysts
544	Basalt - fine- to medium-grained	Likely ol thol; ol, plag and cpx phenocrysts; somewhat glassy
604	Basalt - fine-grained	Intergranular thol; plag and cpx phenocrysts; somewhat glassy
674	Basaltic tuff	Mostly basaltic glass; considerable amount of precipitates; minor basalt
750	Basaltic breccia	Mixture of glass and basalt; considerably altered rock
820	Basaltic tuff	Highly porous basaltic glass
890	Basaltic tuff	Highly porous basaltic glass; some basalt
950	Basalt - fine- to medium-grained	Subophitic ol thol; some basaltic tuff
1020	Basaltic breccia	Mixture of glass and basalt; large amount of precipitates, especially pre
1100	Basaltic breccia	More glass than basalt fragments; subophitic ol thol; large amount of pre, small amount of cc
1170	Glassy basalt	Intergranular thol; evaluation of primary minerals difficult because of small size; small amount of cc, considerable amount of pre, ep
1270	Basaltic breccia	More glass than basalt fragments; porous glass; intergranular thol
1366	Glassy basalt	Glass particles are highly porous; large amount of ep, qz
1426	Basalt - fine-grained	Intergranular thol; evaluation of primary minerals difficult because of small size; large amount of ep
1470	Basalt - medium-grained	Subophitic ol thol; some basaltic glass; fair amount of act; minor amount of cc
1530	Glassy basalt	Intergranular thol; fair amount of glass; larger amount of ep; fair amount of act; small amount of cc
1610	Basalt - fine- to medium-grained	Subophitic ol thol; some glass and precipitates; medium-grained basalt, commonly lightly altered (intrusion?)
1678	Glassy basalt	Both intergranular and subophitic texture; less altered ol thol, intrusion?; small amount of small gt crystals; minor amount of cc
1740	Intermediate volcanic rock	Mt phenocrysts in intermediate rock; mixed with medium-grained, subophitic, relatively fresh basalt (intrusion?); fair amount of cc
1786	Glassy basalt	Fair amount of precipitates, some cc
1880	Basaltic breccia	Mixture of fine-grained basalt, thol, basaltic glass and basaltic tuff; large amount of precipitates; ep common
1940	Basalt (intrusion) - fine- to medium-grained	Subophitic likely ol thol; likely intrusion; fair amount of precipitates; small amount of cc
2000	Basalt (intrusion) - fine- to medium-grained	Intergranular thol, moderately altered; fair amount of cc; precipitates
2086	Glassy basalt	Fine-grained basalt, ol thol, and basaltic glass; large amount of precipitates; significant alteration
2142	Glassy basalt	Subophitic, likely ol thol; extensive alteration; no cc found
2210	Basaltic breccia	Fine-grained basalt, basaltic glass and basaltic tuff; intergranular thol; rich in precipitates
2256	Glassy basalt	Fair amount of precipitates; significant alteration
2350	Basalt - fine-grained	Intergranular thol, some glass; minor amount of cc, poorly developed, seen fill vesicles
2410	Basalt (intrusion) - fine- to medium-grained	Intergranular thol; fair amount of precipitates; likely intrusion
2482	Basalt (intrusion) - fine- to medium-grained	Intergranular thol; likely intrusion; small amount of cc
2542	Basalt (intrusion) - fine- to medium-grained	Intergranular thol; significant alteration; possibly secondary hbl
2568	Basalt (intrusion) - fine- to medium-grained	Subophitic, ol thol; moderately altered rock; mixed with extensively altered basalt; some cc, irregular, poorly formed
2604	Basalt - fine-grained	Intergranular thol; some glass; fair amount of precipitates; some small gt; small amount of poorly formed cc
2658	Basaltic breccia	Basalt with basaltic glass, basaltic tuff, precipitates; medium-grained basalt dense, less altered, ol thol; other basalt thol, significantly altered

Table 8. *Porosity, vein fillings and alteration of primary minerals in well ÞG-3. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
500	Minor - filled	Moderate - cc, qz	Complete - clay		Fair - alb, cc, chl	Fresh	Minor - ttn
544	Minor - filled	Moderate - cc, chl	Complete - clay	Complete - clay, hm	Fair - alb, cc, chl	Minor - chl	Minor - ttn
604	Minor - filled	Minor	Complete - clay		Moderate - alb, cc, chl	Minor - chl	Minor - ttn
674	Minor - filled	Moderate - cc, qz	Complete		Moderate - alb, chl	Minor - chl	Minor - ttn
750	None apparent	Minor - qz	Complete		Moderate - alb, cc	Moderate - act	Moderate - ttn
820	Major - filled	Minor - qz, pre	Complete - mostly chl				
890	Major - filled	None apparent	Complete - mostly chl		Moderate - alb, clay		
950	Minor - filled	None apparent	Complete - mostly clay	Complete - mostly clay	Minor - alb, clay	Minor	Minor - ttn
1020	Major - filled	Minor - pre	Complete - mostly chl		Moderate - alb, clay	Minor	Moderate - ttn
1100	Moderate - mostly filled	None apparent	Complete - mostly chl, pre		Moderate - ep, clay	Minor - clay	Minor - ttn
1170	Minor - filled	None apparent	Complete		Minor	Minor	Minor - ttn
1270	Moderate - filled	None apparent	Complete - mostly chl		Moderate - alb, clay	Moderate - act	Major - ttn
1366	Moderate - filled	None apparent	Complete		Major - alb, ep, chl	Major - act	Moderate - ttn
1426	Minor - filled	Minor - ep	Complete		Major	Major	Major - ttn
1470	None apparent	None apparent	Complete - mostly chl		Moderate - alb, clay, ep	Major - act	Major - ttn
1530	None apparent	Minor - ep, qz	Complete		Major - alb, clay, ep	Major - act	Major - ttn
1610	Minor - filled	None apparent	Complete		Major - alb, clay, ep	Major - act, chl, ep	Major - ttn
1678	Moderate - filled	None apparent	Complete - mostly chl		Major - alb, clay, ep	Major - act, chl, ep, gt?	Major -ttn
1740	Minor - filled, mostly qz	Minor - qz	Complete - mostly chl, ep, pre	Complete - chl, act	Major - alb, cc, ep, chl	Major - act, chl	Major - ttn
1786	Minor - filled	Fair amount - qz, ep, pre	Complete - mostly chl, ep, pre		Major - alb, act, ep, ttn	Major - act	Major - ttn
1880	Moderate - filled, qz, chl, ep	Minor - qz, ep, py?	Complete - mostly chl		Major - alb, act, chl, ep	Major - act	Major - ttn
1940	None apparent	None apparent	Complete	Complete - act	Moderate - alb, chl, act	Moderate - act	Minor - ttn
2000	None apparent	None apparent	Complete - mostly chl		Moderate - act, ep	Moderate - act	Fair - ttn
2086	Moderate - filled	None apparent	Complete		Major - alb, act, ep	Major - act	Major - ttn
2142	None apparent	None apparent	Complete		Moderate - alb, chl, ep	Major - act	Moderate - sph
2210	Moderate - filled	Fair amount	Complete		Moderate - alb, act	Major - act	Major - ttn, hm
2256	Moderate - filled	None apparent	Complete		Major - alb, act, ep	Major - act	Major - ttn, py
2350	Moderate - filled	Minor - qz, ep	Complete		Moderate - alb, act, chl	Major - act	Moderate - ttn
2410	Moderate - filled	None apparent	Complete		Moderate - alb, act	Moderate - act	Variable - ttn
2482	Minor - filled	None apparent	Complete		Moderate - act	Major - act	Moderate - ttn
2542	Minor - filled	Minor - qz, ep	Complete		Major - alb, act, ep	Major - act	Moderate - ttn, py
2568	Minor - filled	None apparent	Complete - mostly chl		Moderate - alb, act	Moderate - act	Moderate - ttn, py
2604	Minor - filled, some cc	None apparent	Complete		Extensive - alb, act, chl, ep	Extensive - act	Extensive - ttn
2658	Minor - filled	Minor - act, qz, wo, cc	Complete - mostly chl		Moderate - alb, act	Moderate - act	Moderate - ttn

Table 9. *Lithologies in well ÞG-4 along with comments. See captions for Tables 1 and 7 for abbreviations of names of secondary and primary minerals and rock types.*

Depth (m)	Rock type	Comments
310	Basaltic tuff	Completely altered glass; significant amount of pre, qz and wai
380	Basaltic tuff	Mostly completely altered tuff particles; some basalt grains; large amount of precipates, especially pre
462	Basalt - cryptocrystalline to medium-grained	Subophitic thol, moderately vesicular; some glass; considerable amount of precipitates
532	Basaltic tuff	Mostly completely altered tuff particles; some tachylite glass and fine-grained basalt; some siliceous particles; large amount of cc; minor act
604	Basalt - medium-grained	Moderately vesicular, medium-grained dolerite, appears olivine-rich; calcification of plag common
672	Basaltic tuff	Highly vesicular basaltic glass; large amount of cc; fair amount of ttn
736	Basaltic tuff	Highly vesicular basaltic glass; a grain of fine-grained basalt, ol thol; large amount of precipitates; large amount of pre; dogtooth cc
794	Basalt - fine-grained	Intergranular thol, even grain size, plag phenocrysts; small amount of glass; possibly intrusion
860	Basaltic tuff	Large amount of precipitates
930	Basaltic breccia	Mostly vesicular glass; some cryptocrystalline to fine-grained basalt, thol; significant amount of precipitates
970	Basaltic breccia	Vesicular basaltic glass; mixed with fine-grained basalt, thol; moderately altered, likely intrusion; small amount of act; no cc seen
1010	Glassy basalt	Vesicular cryptocrystalline to fine-grained thol and glass; increasing amount of act; no cc seen
1078	Basaltic breccia	Vesicular basaltic glass, precipitates, individual plag and cpx crystals
1110	Basalt - fine- to medium-grained	Subophitic ol thol; mixed with basaltic glass and tuff; increasing amount of act; no cc seen
1170	Basaltic breccia	Basaltic glass, basaltic tuff, basalt fragments, ol thol (lesser amounts), precipitates; significant amount of small gt, especially in glass
1230	Basalt - fine- to medium-grained	Subophitic ol thol; mixed with basaltic glass; considerably less precipitates than in tuff above
1270	Basalt - fine-grained	Subophitic ol thol; mixed with basaltic glass, many fragments vesicular; alteration somewhat variable; small amount of act
1318	Basaltic breccia	Cryptocrystalline to fine-grained, intergranular thol; basaltic glass; significant amount of wo
1390	Basalt - fine-grained	Intergranular thol; mixed with glass and precipitates; variable alteration
1510	Basalt - fine-grained	Intergranular thol; mixed with glass and precipitates; difficult to see vesicles and vein fillings because of small grain size
1600	Basalt - fine-grained	Fine-grained, even-grained, intergranular thol; mixed with glass and precipitates; uralite abundant
1700	Basalt - cryptocrystalline to fine-grained	Cryptocrystalline to fine-grained, subophitic ol thol; mixed with glass and precipitates

Table 10. *Porosity, vein fillings and alteration of primary minerals in well ÞG-4. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
310	Moderate - mostly filled	None apparent	Complete		Moderate - alb, cc, chl		
380	Moderate - mostly filled	Fair amount - cc, pre, chl	Complete	Complete - chl, ttn	Moderate - alb, chl		Moderate - ttn
462	Fair - filled	Moderate - chl, ep, cc	Complete	Complete - chl, idd	Fair - chl	Minor - chl	Minor - ttn
532	Moderate - filled	Moderate - cc, qz, pre	Complete - mostly chl		Moderate - chl	Minor	Moderate - ttn
604	Minor - filled	Moderate - cc	Complete - mostly chl	Complete - chl, hm	Moderate - alb, cc, chl, ep	Moderate - chl, hm	Moderate - ttn, hm
672	Major - filled	Fair amount - cc, qz	Complete		Moderate - alb, chl, ttn	Minor	Minor - ttn
736	Major - mostly filled	Moderate - pre, chl, qz	Complete		Moderate - cc, chl	Minor	Moderate - ttn
794	Minor - filled	Minor	Complete - mostly chl, qz		Moderate - alb, ep, chl	Minor	Minor - ttn
860	Major - filled	Minor - ep	Complete				
930	Major - filled	None apparent	Complete	Complete - act	Moderate - alb, act, chl, ep, ttn	Minor - ttn	Minor - ttn
970	Major - filled	Minor - qz	Complete		Moderate - alb, chl	Minor - chl	Minor
1010	Moderate - filled	None apparent	Complete		Major - alb, chl, ttn, ep	Major - act	Moderate - ttn
1078	Moderate - filled	None apparent	Complete		Major - alb, ep, act, ttn	Moderate - act	Moderate - ttn
1110	Minor - filled	None apparent	Complete - mostly chl	Complete - act	Major - alb, act, ttn	Minor - act	Moderate - ttn
1170	Fair - filled	None apparent	Complete		Major - alb, ep, act	Major - act, ep, ttn	Major - ttn
1230	Fair - filled	None apparent	Complete - mostly chl		Major - alb, ttn, ep	Minor	Moderate - ttn
1270	Moderate - filled	None apparent	Complete		Major - alb, act, ttn	Moderate - chl, act, ttn	Moderate - ttn
1318	Moderate - filled	None apparent	Complete		Major - alb, chl, ttn	Major - act, chl	Major - ttn
1390	Fair - filled	None apparent	Complete		Major - alb, act, ttn	Major - act	Major - ttn
1510	None apparent	None apparent	Complete		Major - alb, act, ep	Major - act	Major - ttn
1600	None apparent	None apparent	Complete		Major - alb, act, ttn	Major - act	Major - ttn
1700	None apparent	None apparent	Complete		Major - alb, act, ttn	Major - act	Major - ttn

Table 11. *Lithologies in well ÞG-5 along with comments. See captions for Tables 1 and 7 for abbreviations of names of secondary and primary minerals and rock types.*

Depth (m)	Rock type	Comments
480	Basalt - fine-grained	Fine-grained, even-grained, plag-phyric, intergranular thol; mixed with glass and silicic fragments; extensive calcification
560	Basaltic tuff	Rich in precipitates, especially pre; noticable amount of small gt
600	Basalt - medium- to coarse-grained	Ophitic ol thol; mixed with small amount of glass; large amount of precipitates; small amount of act, uralite
764	Basalt - medium-grained	Subophitic, likely ol thol, fairly plag-rich (intrusion?); alteration variable; increased amount of act, uralite; no cc
828	Basaltic breccia	Partly glassythol basalt fragments and glass fragments; small amount of act, no cc
892	Basaltic breccia	Partly crystalline, cryptocrystalline thol basalt, glass and precipitates; small amount of act; one cc grain seen
956	Basaltic breccia	Thol basalt, basaltic glass, precipitates
1022	Basaltic tuff	Predominantly basaltic glass, partly vesicular; lesser amounts of thol basalt and precipitates
1078	Glassy basalt	Fine-grained ol thol, partly glassy basalt, glass particles; precipitates; probably pillow lava; some small gt in glass particles
1146	Glassy basalt	Fine-grained basalt, partly glassy basalt, basaltic glass, precipitates; uralite alteration of cpx
1210	Basaltic breccia	Subequal amounts of thol basalt and basaltic glass, some precipitates; significant amount of ep; fair amount of act
1280	Basalt (intrusion) - crystocrystalline to fine-grained	Intergranular thol, small amount of glass and precipitates; plag and cpx phenocrysts; alteration from minor to moderate
1350	Glassy basalt	Partly glassy to fine-grained, intergranular thol; small amount of glass and precipitates; significant alteration, uneven
1400	Glassy basalt	Partly glassy to fine-grained, intergranular thol; small amount of glass and precipitates; major alteration; uralitization of cpx

Table 12. *Porosity, vein fillings and alteration of primary minerals in well ÞG-5. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
480	Fair - filled	Fair - qz	Complete		Moderate - alb, chl, cc	Moderate - chl	Minor - ttn
560	Major - mostly filled	Minor - qz	Complete		Moderate - alb, ttn		Fair - ttn
600	Minor - filled	Minor - wai	Complete		Major - alb, cc, act, chl, ep	Moderate - act, ttn, chl	Minor - ttn
764	None apparent	None apparent	Complete	Complete - act	Major - alb, act	Major - act, ttn	Moderate - ttn
828	Fair - filled	Minor - ep, pre	Complete - mostly chl	Complete - act	Major - alb, ttn, chl	Moderate - act, chl	Moderate - ttn
892	Minor - mostly filled	Minor - ep, pre, qz	Complete - mostly chl		Moderate - alb, ttn, chl		
956	None apparent	Minor - ep	Complete		Major - alb, act	Moderate - act	Moderate - ttn
1022	Moderate - filled	None apparent	Complete		Major - alb, ep, ttn, chl	Major - act	Major - ttn
1078	Fair - filled	None apparent	Complete		Moderate - alb, ep ttn, chl	Moderate - act, ttn, chl	Moderate - ttn
1146	Fair - mostly filled	None apparent	Complete - mostly chl		Major - alb, ttn, ep, chl	Major - act	Major - ttn
1210	Minor - filled	None apparent	Complete		Major - alb, ep	Moderate - act, chl	Moderate - ttn
1280	None apparent	None apparent	Complete - mostly chl		Fair - alb, chl, ep act, ttn	Minor - act	Fair - ttn
1350	Minor - filled	None apparent	Complete - mostly chl		Moderate - alb, chl, ttn, ep	Moderate - act	Moderate - ttn
1400	Fair - filled	Minor - ep	Complete		Major - alb, ep, act	Major - act	Major - ttn, hm

Table 13. *Lithologies in well ÞG-6 along with comments. See captions for Tables 1 and 7 for abbreviations of names of secondary and primary minerals and rock types.*

Depth (m)	Rock type	Comments
130	Glassy basalt	Intergranular thol; large amount of cc; groundmass glass mostly alted to mlc
350	Glassy basalt	Partly glassy to fine-grained, vesicular, intergranular thol and glass, plag and cpx phenocysts and minor ol; significant calcification of plag
428	Basaltic tuff	Mostly vesicular glass particles; some cryptocrystalline thol basalt grains; fair amount of precipitates; pre and ep; large amounts of cc, qz
490	Basaltic tuff	Mostly basaltic glass, variable porosity; also thol basalt and precipitates; large amount of cc, partly platy cc; alteration of plag variable
558	Basaltic breccia	Partly glassy to fine-grained, evolved basalt and dense basaltic glass; some silicic fragments; cc abundant; plag alteration variable
640	Glassy basalt	Ol-rich fine- to medium-grained basalt; mixed with glass and precipitates; pervasive calcification
690	Basaltic tuff	Mostly vesicular glass; some dense basaltic glass, precipitates and basalt; large amount of cc; minor pre; no ep
760	Basaltic breccia	Majority vesicular basaltic glass; lesser amounts of thol basalt and precipitates; large amount of cc; some small gt; rare cpx with act
840	Basalt - cryptocrystalline	Cryptocrystalline, plag-phyric, intergranular thol, likely intrusion; uneven alteration; fair amount of ep, wo; little cc
902	Basaltic breccia	Mostly glassy basalt and basaltic glass; significant amount of precipitates; fair amount of gt; no cc
970	Basaltic tuff	Mostly variably vesicular basaltic glass; fair amount of precipitates; small amount of crystalline fragments, thol
1040	Basaltic breccia	Variably vesicular glass, partly glassy to fine-grained, subophitic ol thol and precipitates; uralite seen; lots of pre
1120	Basaltic breccia	Basaltic glass and partly glassy to cryptocrystalline thol basalt and precipitates; uralite abundant
1200	Basaltic breccia	Partly glassy to cryptocrystalline basalt, thol; less basaltic glass; fair amount of precipitates; significant alteration; albitization of plag extensive
1280	Glassy basalt	Partly glassy to fine-grained ol thol; lesser amounts of glass and precipitates; probably pillow lava
1360	Glassy basalt	Dominantly partly glassy to medium-grained ol thol; fair amount of glass and precipitates; could be mixed with intrusive rock fragments
1430	Glassy basalt	Mostly fine-grained, intergranular thol, extensively altered; also less altered medium-grained basalt and precipitates; uneven alteration
1494	Glassy basalt	Mostly partly glassy to fine-grained basalt; some glass and precipitates; extensive alteration; abundant ttn
1570	Glassy basalt	Mostly partly glassy to fine-grained intergranular thol; fair amount of basaltic glass
1640	Glassy basalt	Mostly partly glassy to fine-grained, intergranular thol; some basaltic glass; decreasing amount of precipitates
1700	Basalt - cryptocrystalline to fine-grained	Intergranular thol; some glass and precipitates; small amount of precipitates; variable alteration
1754	Glassy basalt	Partly glassy to medium-grained, subophitic ol thol; some basaltic glass and precipitates; variable alteration; wai common
1826	Basaltic breccia	Partly glassy to fine-grained, intergranular thol; fair amount of glass; some precipitates; fair amount of precipitates; more ep
1906	Basaltic breccia	Probably mixture of breccia and intrusive rock, fine- to medium-grained, moderately altered; breccia thol, intrusion ol thol
1990	Glassy basalt	Partly glassy to fine-grained, intergranular thol; some glass and precipitates; extensive alteration; cpx altered to act; minor cc
2076	Basaltic breccia	Partly glassy to fine-grained, subophitic ol thol and glass; some precipitates; one cc found
2160	Basalt - cryptocrystalline to fine-grained	Basalt of different origin; more altered thol; less altered, medium-grained, subophitic ol thol, likely intrusion; fair amount of precipitates
2250	Glassy basalt	Partly glassy to fine-grained basalt, ol thol; some basaltic glass and precipitates
2350	Basalt - fine- to medium-grained	Basalt with some glass and precipitates; possibly intrusion; secondary hbl noted
2430	Basaltic breccia	Partly glassy to fine-grained, subophitic ol thol; some glass and precipitates; notable act alteration of plag
2500	Basaltic breccia	Mixture of two formations; basaltic breccia and less altered, medium-grained, non-vesicular basalt, likely intrusion
2580	Basaltic breccia	Mixture of two formations; basaltic breccia (thol) and less altered, fine- to medium-grained, non-vesicular basalt (ol thol), likely intrusion
2700	Rhyolite	Abundant qz-rich grains, some basalt mixed in; rich in precipitates; abundant act; bt seen; micrographic texture

Table 14. *Porosity, vein fillings and alteration of primary minerals in well ÞG-6. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
130	Moderate - mostly filled	Moderate - cc, qz, wai	Complete - mlc		Fair - cc, mlc	Minor - mlc	Minor
350	Moderate - partly filled	Moderate - cc, qz, chl	Complete - mostly chl, mlc	Complete - mlc	Fair - alb, cc, chl	Minor	Minor
428	Major - mostly filled	Fair - cc, qz	Complete	Complete - mlc	Moderate - alb, cc, chl, ep	Minor - ttn, chl	
490	Major - filled	Major - cc, qz, chl, py	Complete		Moderate - alb, cc, chl, ep	Minor	Minor
558	Major - mostly filled	Moderate - cc, wai	Complete		Major - alb, cc, ill	Minor	Minor
640	Moderate - filled	Moderate - cc	Complete - mostly chl	Complete - chl, qz, hm, mlc	Major - alb, cc, ttn, chl	Minor - chl	Moderate - ttn
690	Major - mostly filled	Moderate - cc, qz	Complete		Moderate - alb, cc, chl	Minor	
760	Major - mostly filled	Fair - cc, qz, wai	Complete		Major - alb, ttn, act, cc	Major - act	Major - ttn
840	Minor - filled	Fair - chl, act	Complete		Major - alb, act, ep	Moderate	Moderate - ttn
902	Fair - filled	Fair - qz, pre, ep, wo	Complete - mostly chl		Major - alb, ttn, chl		
970	Major - filled	Fair - qz	Complete		Moderate - alb	Moderate - ttn	Moderate - ttn
1040	Moderate - filled	Minor - pre	Complete	Complete - chl	Moderate - alb, act	Major - act	Major - ttn
1120	Fair - filled	Fair - wai	Complete		Major - alb, ep	Major - act	Major - ttn
1200	Moderate - filled	Minor - ep, pre	Complete		Major - alb, ep, ttn	Major - act	Major - ttn
1280	Moderate - filled	None apparent	Complete		Major - alb, ep	Moderate - act	Moderate - ttn
1360	Minor - filled	None apparent	Complete	Complete - act	Major - alb, ep	Moderate - act	Major - ttn
1430	Fair - filled	Minor - qz	Complete		Major - alb, ttn, act	Moderate - act	Moderate - ttn
1494	Fair - filled	Minor - qz	Complete		Major - alb, ttn, ep	Major - act	Major - ttn
1570	Fair - filled	Fair - ep, qz	Complete		Major - alb, ep	Moderate - act, ttn	Moderate - ttn
1640	Fair - filled	None apparent	Complete		Major - alb	Moderate - act	Moderate - ttn
1700	Minor - filled	None apparent	Complete - mostly chl		Major - alb, ep, ttn, act	Major - act	Major - ttn
1754	Fair - filled	None apparent	Complete		Major - alb, ep, act	Major - act	Major - ttn
1826	Fair - filled	Fair - ep	Complete		Major - alb, act	Major - act	Major - ttn
1906	Moderate - filled	None apparent	Complete		Major - alb, ep, act	Moderate - act	Major - ttn
1990	Moderate - filled	None apparent	Complete		Major - alb, ep	Major - act	Major - ttn
2076	Fair - filled	Fair	Complete	Complete - act	Major - alb, act, ep	Major - act	Major - ttn
2160	Fair - filled	Minor - qz, chl, ep	Complete		Major - alb, act, ttn, ep	Major - act	Major - ttn
2250	None apparent	None apparent	Complete		Major - alb, act, ttn, ep	Major - act	Major - ttn
2350	None apparent	None apparent	Complete - mostly chl, act		Extensive - alb, ep, sph, act	Major - act	Major - ttn
2430	Moderate - filled	Fair	Complete		Extensive - alb, act, ep	Major - act	Major - ttn
2500	Fair - filled	Minor - qz	Complete		Extensive - alb, act, ep	Major - act	Major - ttn
2580	Fair - filled	Minor	Complete		Extensive - alb, ep, act	Major - act	Extensive - ttn
2700	None apparent	None apparent	Complete		Extensive - alb, act, ep	Extensive - act	Extensive - ttn

Table 15. *Lithologies in well ÞG-7 along with comments. See captions for Tables 1 and 7 for abbreviations of names of secondary and primary minerals and rock types.*

Depth (m)	Rock type	Comments
54	Basaltic breccia	Mixture of vesicular glass and cryptocrystalline to fine-grained, plag-phyric, intergranular thol; 2 to 3 types of zeol
94	Basaltic tuff	Dominantly vesicular basaltic glass; some basalt fragments, thol; smc the main alteration mineral; some mlc also
134	Basalt - cryptocrystalline to fine-grained	Vesicular, intergranular thol; some glass; large amount of cc
204	Glassy basalt	Partly glassy to fine-grained, intergranular thol; some glass and precipitates; some oxidation; fair amount of large; euhedral wai
248	Andesitic breccia	Mostly cryptocrystalline andesite; some vesicular basaltic glass; hard to judge alteration in andesite groundmass
300	Basaltic breccia	Partly glassy to fine-grained ol thol and vesicular glass; fairly oxidized
342	Basaltic breccia	Basaltic tuff; fair amount of ol thol basalt and precipitates; small amount of pre seen for first time
382	Glassy basalt	Partly glassy to medium-grained basalt, ol thol; some glass and precipitates; mostly cement fragments; alteration has increased significantly
462	Basaltic breccia	Partly glassy to fine-grained, intergranular thol, glass and large amount of precipitates
550	Basaltic breccia	Partly glass to fine-grained thol, vesicular basaltic glass, some precipitates; flow-textured thol with large ol phenocrysts
610	Basaltic breccia	Partly glassy to medium-grained basalt, lots of large plag phenocrysts; glass; some precipitates; considerable oxidation
682	Glassy basalt	Partly glassy to medium-grained ol thol; fair amount of glass; some silicic fragments; significant calcification of plag
742	Basaltic breccia	Partly glassy to fine-grained ol thol and glass, commonly vesicular; variable alteration; probably mixed with thol intrusion
814	Basaltic tuff	Mostly vesicular basaltic glass; some cryptocrystalline basalt and precipitates; fair amount of illite, suggests evolved composition
880	Silicic tuff	Silicic tuff; mixed with medium-grained ol thol, probably intrusive; alteration of plag, ol, cpx and Fe-Ti refers to basalt
950-54	Basaltic tuff	Vesicular glass; evolved basaltic composition; fair amount of precipitates; qz-rich; fair amount of ill; not much chl
1020	Basaltic breccia	Mixture of thol basalt, glass and precipitates; minor amount of small gt; grains with ill and qz
1096	Basaltic breccia	Thol basalt and glass; fair amount of precipitates; some uralite
1164	Glassy basalt	Partly glassy to fine-grained ol thol; some glass and precipitates; act alteration of cpx apparent; little ep
1218	Glassy basalt	Mixed cuttings; heavily altered, glassy ol thol basalt; cryptocrystalline to fine-grained, non-porous thol, probably intrusion
1278	Basaltic breccia	Partly glassy to fine-grained basalt, ol thol, and vesicular glass; fair amount of precipitates; fair amount of wo; minor amount of cc
1352	Basaltic breccia	Partly glassy to fine-grained ol thol and glass; fair amount of precipitates; albitization of plag pervasive
1410	Basaltic breccia	Partly glassy to fine-grained ol thol and vesicular glass; fair amount of precipitates; minor amounts of cc, ill
1480	Basaltic breccia	Mixed cuttings; thol basaltic breccia; medium-grained ol thol basalt, less altered, probably intrusion; lots of ep
1552	Basalt - cryptocrystalline to fine-grained	Intergranular thol; some glass; not much precipitates; fair amount of ep; little pre
1622	Basalt - cryptocrystalline to fine-grained	Intergranular thol; some glass and precipitates; fair amount of cc; uralite common; possibly alb precipitates
1672	Glassy basalt	Partly glassy to medium-grained ol thol; fair amount of glass and precipitates; no cc; possibly alb precipiates
1730	Silicic breccia	Mostly recrystallized rhyolite; some silicic glass and basalt; rhyolite altered to likely adul and some qz and ill; minor cc
1790	Silicic breccia	Mixture of devitrified silicic glass and medium-grained, moderately altered, non-porous ol thol, likely intrusion
1864	Breccia	Mixure of different lithologies; silicic glass, rhyolite, partly glassy to medium-grained ol thol and basaltic glass; minor precipitates
1926	Basaltic breccia	Partly glassy to fine-grained ol thol and glass; some silicic glass, rhyolite and precipitates; increased amounts of ep, pre, wai
1986	Glassy basalt	Partly glassy to fine-grained basalt, probably ol thol; some glass; mixed with silicic glass, rhyolite and precipitates
2060	Basaltic breccia	Partly glassy to fine-grained thol and basaltic glass; extensive alteration; large amount of precipitates, especially ep; minor amount of cc
2120	Basalt - cryptocrystalline to fine-grained	Probably thol mixed with glass and significant amount of precipitates; fair amount of poorly developed cc; large amount of ttn
2194	Basalt - cryptocrystalline to fine-grained	Probably thol; some glass and precipitates; some oxidation; moderate amount of ep; minor cc, ill
2256	Basalt - cryptocrystalline to fine-grained	Intergranular thol, possibly intrusion; some silicic fragments and minor precipitates; small and poorly developed cc; minor ill
2320	Glassy basalt	Partly glassy to fine-grained basalt, probably ol thol; some glass and precipitates; some oxidation; minor cc, ill
2374	Basalt - fine-grained	Probably ol thol; mixed with less altered, medium-grained basalt, probably intrusion; minor cc, ill
2426	Basalt (intrusion) - medium-grained	Probably ol thol intrusion; mixed with extensively altered, fine-grained basalt; some silicic grains; minor cc; not much ep, pre
2490	Glassy basalt	Partly glassy to fine-grained basalt, likely ol thol; some glass and precipitates; fair amount of cc, flakes and in groundmass

Table 16. *Porosity, vein fillings and alteration of primary minerals in well ÞG-7. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
54	Major - partly filled	Major - qz, cc	Complete - mostly smc		Minor - alb, cc, smc	Fresh	Minor - ttn
94	Major - partly filled	Major - qz, cc	Complete - mostly smc		Fair - alb, cc	Minor	Minor
134	Major - partly filled	Moderate - cc, qz	Complete - chl, smc, mlc		Minor	Minor	Fresh
204	Moderate - mostly filled	Fair - cc, qz	Complete - mostly chl, mlc		Fair - cc, mlc	Minor	Minor
248	Fair - partly filled	Minor - qz	Complete		Minor		Minor
300	Major - mostly filled	Fair - cc	Complete	Complete - idd, mlc	Fair - chl	Minor	Minor
342	Major - mostly filled	Fair - qz, cc, wai	Complete	Complete - idd, mlc	Minor - chl	Fresh	Fresh
382	Moderate - filled	None apparent	Complete	Complete - mlc	Major - alb, mlc, ttn, wai	Moderate - ttn, mlc	Moderate - ttn
462	Moderate - filled	Fair - cc, qz, mlc	Complete		Major - alb, cc, mlc	Minor	Minor
550	Moderate - filled	Moderate - qz, cc, wai, ttn	Complete	Complete - cc, hm	Fair - alb, cc, mlc	Minor	Minor
610	Major - mostly filled	Moderate - cc, wai, ttn, qz	Complete	Complete - chl, hm	Major - alb, cc, ttn, chl	Moderate	Moderate - ttn
682	Fair - filled	Moderate - cc	Complete	Complete - hm, chl, mlc	Major - cc, chl, alb	Moderate - cc, chl	Moderate - ttn
742	Major - filled	Fair - qz, cc	Complete	Complete - cc, hm, mlc, act	Major - alb, cc, chl	Moderate - act	Moderate - ttn
814	Major - filled	Minor	Complete		Moderate - alb, ttn		
880	None apparent	None apparent	Complete - mostly ill, qz	Complete - act	Major - alb, cc, act	Fair - act, ttn	Major - ttn
950-54	Major - filled	Fair - qz, cc	Complete - qz-rich		Major - alb, chl, ttn		
1020	Moderate - filled	None apparent	Complete		Major - alb, chl	Moderate - chl	Moderate - ttn
1096	Minor - filled	None apparent	Complete		Major - alb, chl, cc	Moderate - chl, ttn, act	Moderate - ttn
1164	Moderate - filled	Fair - wai, qz, cc	Complete	Complete - act	Major - alb, cc, chl	Major - act	Major - ttn
1218	Moderate - filled	Fair - qz, chl, cc	Complete	Complete - act	Major - act, cc, alb, ttn	Major - act	Major - ttn
1278	Moderate - filled	None apparent	Complete		Major - alb, ep, ttn, act	Moderate - act	Moderate - ttn
1352	Moderate - filled	Fair - ep, pre	Complete	Complete - act	Major - alb, act, cc, ep, ttn, chl	Moderate - act, ttn, chl	Major - ttn
1410	Moderate - filled	Fair - ep, pre, qz	Complete	Complete - act, chl	Major - alb, act, ttn, ep	Major - act	Major - ttn
1480	Moderate - filled	Minor - qz, ep	Complete	Complete - act	Major - alb, act, ttn, ep	Major - act	Major - ttn
1552	Fair - filled	Fair - ep, qz, pre, ttn	Complete		Major - alb, ttn, ttn	Major - act	Major - ttn
1622	Minor - filled	Minor - qz	Complete		Major - alb, ep, act, ttn	Major - act	Major - ttn
1672	Moderate - filled	Minor - ep	Complete		Major - alb, act	Major - act	Major - ttn
1730	Minor - filled	Minor - qz	Complete - mostly qz, ill		Major - alb, act, adul?	Major - act	Major - ttn
1790	None apparent	None apparent	Complete - mostly qz	Complete - act	Moderate - act, alb	Moderate - act, ttn	Major - ttn
1864	Minor - filled	None apparent	Complete	Complete - act	Major - alb, act	Major - act	Major - ttn
1926	Fair - filled	Minor - qz	Complete - mostly chl, act	Complete - act, chl	Major - alb, act, ep, ttn	Major - act	Major - ttn
1986	Fair - filled	Fair - ep	Complete		Major - alb, act, ttn	Major - act	Major - ttn
2060	Fair - filled	None apparent	Complete		Major - alb, ttn, act	Major - act	Major - ttn
2120	Minor - filled	None apparent	Complete		Major - alb, act, ttn, ep	Major - act	Major - ttn
2194	Moderate - filled	Fair - qz, ep	Complete		Major - alb, ttn, act, ep	Major - act	Major - ttn
2256	None apparent	None apparent	Complete		Major - alb, ttn, act	Major - act	Major - ttn
2320	None apparent	None apparent	Complete		Major - alb, ep, act, ttn	Major - act	Major - ttn
2374	Fair - filled	None apparent	Complete		Major - alb, act, ttn, ep	Major - act	Major - ttn
2426	None apparent	None apparent	Complete		Moderate - alb, act, ep, ttn	Moderate - act	Moderate - ttn
2490	Minor - filled	Minor - ep	Complete		Extensive - alb, act, ttn	Extensive - act	Extensive - ttn

Table 17. *Lithologies in well ÞG-8 along with comments. See captions for Tables 1 and 7 for abbreviations of names of secondary and primary minerals and rock types.*

Depth (m)	Rock type	Comments
100	Basalt - fine- to medium-grained	Significantly plag- and ol-phyric ol thol; some tachylite; deuteric oxidation of ol
330-340	Basaltic breccia	Vesicular basaltic glass; large amount of cc, smc; plus partly glassy ol thol; large amount of cc, palagonitization; some oxidation, some fresh ol
390	Basaltic breccia	Mixture of vesicular basaltic glass and partly glassy ol thol; lots of precipitates; considerble alteration of plag; likely zeol
470	Basaltic tuff	Highly vesicular basaltic glass, rich in precipitates; some partly glassy to cryptocrystalline, plag-phyric thol; lots of cc; some oxidation
524	Breccia	Mixed cuttings; basaltic glass, silicic glass, basalt and precipitates
582	Breccia	Mixture of a medium-grained, highly plag-phyric ol thol and basaltic glass; large amount of cc
660	Basaltic breccia	Mixture of partly glassy to fine-grained thol and basaltic glass; some silicic glass
730	Basaltic tuff	Mostly vesicular basaltic glass with some partly glassy basalt; a few silicic fragments; significant amount of precipitates; lots of cc
1532	Glassy basalt	Partly glassy to fine-grained ol thol; some glass and precipitates; fair amount of cc; albitization of plag conspicuous
1580	Glassy basalt	Mixture of partly glassy to cryptocrystalline thol and glass; some less altered, fine-grained ol thol, possibly intrusion
1626	Glassy basalt	Partly glassy to fine-grained ol thol; some glass and precipitates; a few silicic fragments; fair amount of cc
1700	Basaltic breccia	Mixture of basaltic glass and partly glassy to cryptocrystalline thol; significant amount of precipitates; cc as particles and in groundmass
1784	Basaltic breccia	Basaltic glass and partly glassy to fine-grained thol; significant amount of cc; increasing act; considerable ep; little pre, wai
1834	Basalt (intrusion) - fine- to medium-grained	Basalt mixed with some glass and precipitate; many basalt grains relatively mildly altered, possibly intrusion; fair amount of cc
1898	Basalt - fine- to medium-grained	Varible alteration; possibly mixed with intrusive rock; intrusion appears ol thol, host rock thol
1962	Basalt - cryptocrystalline to fine-grained	Less altered, fine- to medium-grained ol thol, possibly intrusion; more altered basalt host rock, thol; fair amount of act; small amount of cc
2022	Basalt - cryptocrystalline to fine-grained	Intergranular thol; some precipitates; not much glass; fair amount of cc, very little in groundmass
2090	Basalt (intrusion) - glassy to fine-grained	Partly glassy to fine-grained ol thol; some glass and precipitates; some grains mildly altered, likely intrusion; lots of cc, pre
2150	Basaltic tuff	Vesicular basaltic glass; some partly glassy to fine-grained thol and precipitates; minor amount of cc
2240	Glassy basalt	Mostly partly glassy to fine-grained thol; some glass and precipitates; fair amount of ep; little pre; some cc grains
2300	Basaltic breccia	Mixture of partly glassy to fine-grained thol and basaltic glass; some fine- to medium-grained ol thol, likely intrusion; some cc, lau
2350	Glassy basalt	Partly glassy to fine-grained ol thol; some glass and precipitates; fair amount of ep; minor cc, pre
2420	Basaltic breccia	Partly glassy to fine-grained ol thol and basaltic glass; some precipitates; fair amount of cc as grains and in groundmass
2490	Basaltic breccia	Partly glassy to fine-grained basalt, basaltic glass; some fine- to medium-grained basalt, mildly altered, likely intrusion, ol thol; precipitates

Table 18. *Porosity, vein fillings and alteration of primary minerals in well ÞG-8. See caption for Table 1 for abbreviations of mineral names.*

Depth (m)	Porosity	Vein fillings	Glass alteration	Olivine alteration	Plagioclase alteration	Clinopyroxene alteration	Fe-Ti oxide alteration
100	Moderate - empty	None apparent	Fresh	Fresh	Fresh	Fresh	Fresh
330-340	Major - mostly empty	Major - cc	Major - smc	Major - idd, cc	Minor - cc, smc	Fresh	Fresh
390	Moderate - partly filled	Fair - cc, qz	Major - smc, plg	Complete - smc, cc	Moderate - cc, smc	Fresh	Fresh
470	Major - partly filled	Major - cc, hm	Complete	Complete - hm, chl, cc	Fair - cc	Fresh	Fresh
524	Moderate - filled	Moderate - cc, chl	Complete - mostly chl, ill	Complete - mlc, smc	Moderate - alb, cc, chl	Minor	Minor - ttn
582	Moderate - filled	Fair - cc	Complete	Complete - chl, hm	Moderate - cc, alb, ttn	Minor	Fair - ttn, hm
660	Moderate - mostly filled	Minor - qz, cc	Complete		Moderate - alb, cc, chl, ttn	Minor	Moderate - ttn
730	Major - mostly filled	None apparent	Complete		Moderate - alb, cc	Minor	Moderate - ttn
1532	Moderate - filled	Fair - ep, qz	Complete	Complete - chl, hm, cc	Major - alb, ep, cc, ttn	Moderate - chl	Major - ttn
1580	Moderate - filled	Fair - qz, cc	Complete	Complete - act	Major - alb, act, cc, ep	Moderate - act	Moderate - ttn
1626	Moderate - filled	Moderate - ep, qz, cc	Complete	Complete - chl	Major - alb, chl, ttn	Moderate - chl	Moderate - ttn
1700	Major - filled	Fair - ep, qz, cc	Complete		Major - alb, cc, chl	Major - act	Major - ttn
1784	Moderate - filled	Fair - ep, cc, qz	Complete		Major - alb, ep, ttn, chl	Major - act	Major - ttn
1834	Moderate - filled	None apparent	Complete		Major - alb, ttn, ep, act	Moderate - act	Major - ttn
1898	Fair - filled	Minor - qz, ep	Complete		Major - alb, ep, act, cc, ttn	Moderate - act	Major - ttn
1962	Fair - filled	None apparent	Complete		Major - alb, chl, act, ttn, ep	Major - act	Moderate - ttn
2022	Fair - filled	None apparent	Complete		Major - alb, act, ttn	Major - act	Major - ttn
2090	Fair - filled	Minor - qz	Complete	Complete - act	Major - alb, act, ttn	Major - act	Major - ttn
2150	Moderate - filled	Minor - qz, ep	Complete		Major - alb, act, ttn, ep	Major - act	Major - ttn
2240	Moderate - filled	Minor - ep, cc	Complete		Major - alb, act, ep, ttn	Major - act	Major - ttn
2300	Moderate - filled	Moderate - ep, cc, qz	Complete		Major - alb, cc, ep, ttn	Major - act	Major - ttn
2350	Fair - filled	Fair - ep, qz	Complete	Complete - act	Extensive - alb, cc, act, ttn	Extensive - act	Extensive - ttn
2420	Moderate - filled	Fair - ep, qz, cc	Complete		Extensive - alb, ep, ttn, act, cc	Extensive - act, ttn	Extensive - ttn
2490	Major - filled	Minor - ep	Complete		Extensive - alb, cc, act, ep, ttn	Extensive - act, ttn, ep	Extensive - ttn

Table 19. *Mineral sequences as observed in thin sections. The arrows point in the direction of later precipitation. Sample depths listed are measured depths. See caption for Table 1 for abbreviations of mineral names.*

Well	Depth (m)	Secondary mineral sequences
ÞG-3	500	qz → chl → pre chl → qz → cc
	544	chl → cc qz → chl → cc
	890	ep → pre
	1020	ep, qz → pre
	1426	ep → qz
	1530	ep → qz
	1786	qz, ep → chl
	1880	ep → chl, ep
	1940	ep → act, pre, qz
	2086	ep, chl → qz, act
	2256	ep → pre
	2410	qz → pre, act ep → qz
	2482	ep → pre ep, ttn → qz
	2542	ep → qz
	2568	ep → pre, qz, chl
	2604	qz → ep
	2658	act → wo → qz qz → cc
ÞG-4	310	ep → pre chl → wai → cc
	462	chl → qz chl → cc chl → ep ep → cc chl → ep → cc
	532	ep → chl → wai chl → cc, pre chl → cc → qz chl → wai
	604	qz → cc chl → qz → ep
	672	chl → cc → qz → cc ep → qz → cc
	736	ep → pre chl → ep → qz pre → cc
	794	chl → qz → ep → cc ep → pre
	860	ep → qz ep → pre
	930	ep → pre
	970	ep → qz chl → ep
	1010	ep → pre ep → qz
	1078	ep → pre
	1110	pre → qz ep → pre ep → qz
	1318	ep → qz ep → wo chl → ep → qz
	1510	ep → qz
	1700	ep → wo → qz

Table 19. *(Continued.)*

Well	Depth (m)	Secondary mineral sequences
ÞG-5	480	qz → cc qz → chl qz → ep qz → pre
	560	qz → ep ep → pre
	600	qz → pre
	764	chl → ep → pre
	828	qz → pre ep → qz ep → wai
	892	ep → pre ep → chl qz → pre ep → qz → pre
	956	ep → pre → wo
	1146	ep → act ep → qz
	1210	ep → pre ep → qz
	1280	ep → qz qz → chl
	1350	ep → qz qz → chl
	1400	ep → pre ep → act → qz
ÞG-6	130	cc → mlc qz → wai mlc → qz → cc qz → mlc
	350	qz → wai
	428	mlc → qz → cc
	640	chl → wai
	690	qz → wai
	760	chl → qz
	902	qz → ep, wo
	1120	qz → act
	1200	chl → ep, pre
	1494	chl → qz
ÞG-7	54	smc → qz
	134	cc → mlc smc → qz
	204	chl → wai qz → wai
	300	cc → chl chl → qz
	462	mlc → cc, qz pre → mlc mlc → wai
	682	chl → qz
	1480	ep → qz ep → wo
	1552	ep → ttn
	1730	qz → cc
	1926	qz → chl
	2120	ep → wo → qz

Table 19. *(Continued.)*

Well	Depth (m)	Secondary mineral sequences		
ÞG-8	390	smc → qz		
	470	qz → mlc	chl → wai → qz	
	582	qz → cc		
	660	qz → cc	qz → chl	qz → wai
	1532	qz → chl, ttn	chl → cc	
	1580	pre → cc	qz → chl	qz → act
	1962	ep → pre		
	2090	ep → pre		
	2150	ep → qz	act → qz	ep → cc
	2240	ep → qz	ep → cc	
	2300	ep → qz	pre → qz	ep → cc
	2350	ep → cc	ep → qz	qz → cc
	2420	ep → cc	ep → qz	
	2490	ep → qz	ep → cc	

Table 20. *Depth of the shallowest appearance of secondary minerals in different wells as determined in thin sections, except in the case of calcite where the deepest occurance is indicated. Also shown are the shallowest and greatest depths of thin section samples, and the elevation of well heads. All depths are meters below sea level. Empty space means that the mineral was not seen in the thin sections from that particular well.*

	ÞG-3	ÞG-4	ÞG-5	ÞG-6	ÞG-7	ÞG-8
Quartz	144	-40	129	-247	-323	50
Wairakite	144	-40	207	-247	-283	129
Mixed-layer clay			129	-247	-283	129
Chlorite	144	-40	129	-27	-243	129
Illite	318	178		176	286	181
Epidote	144	-40	129	50	394	1052
Prehnite	144	-40	129	50	-35	1052
Wollastonite	594	110	451	111	-35	1197
Garnet	1322	30	207	359	564	1775
Actinolite	394	178	245	359	335	1092
Calcite	2302	468	506	2001	1688	1892
First thin section	144	-40	129	-247	-323	-240
Last thin section	2302	1145	928	2001	1688	1892
Well head elev.	-356	-350	-350	-377	-377	-340

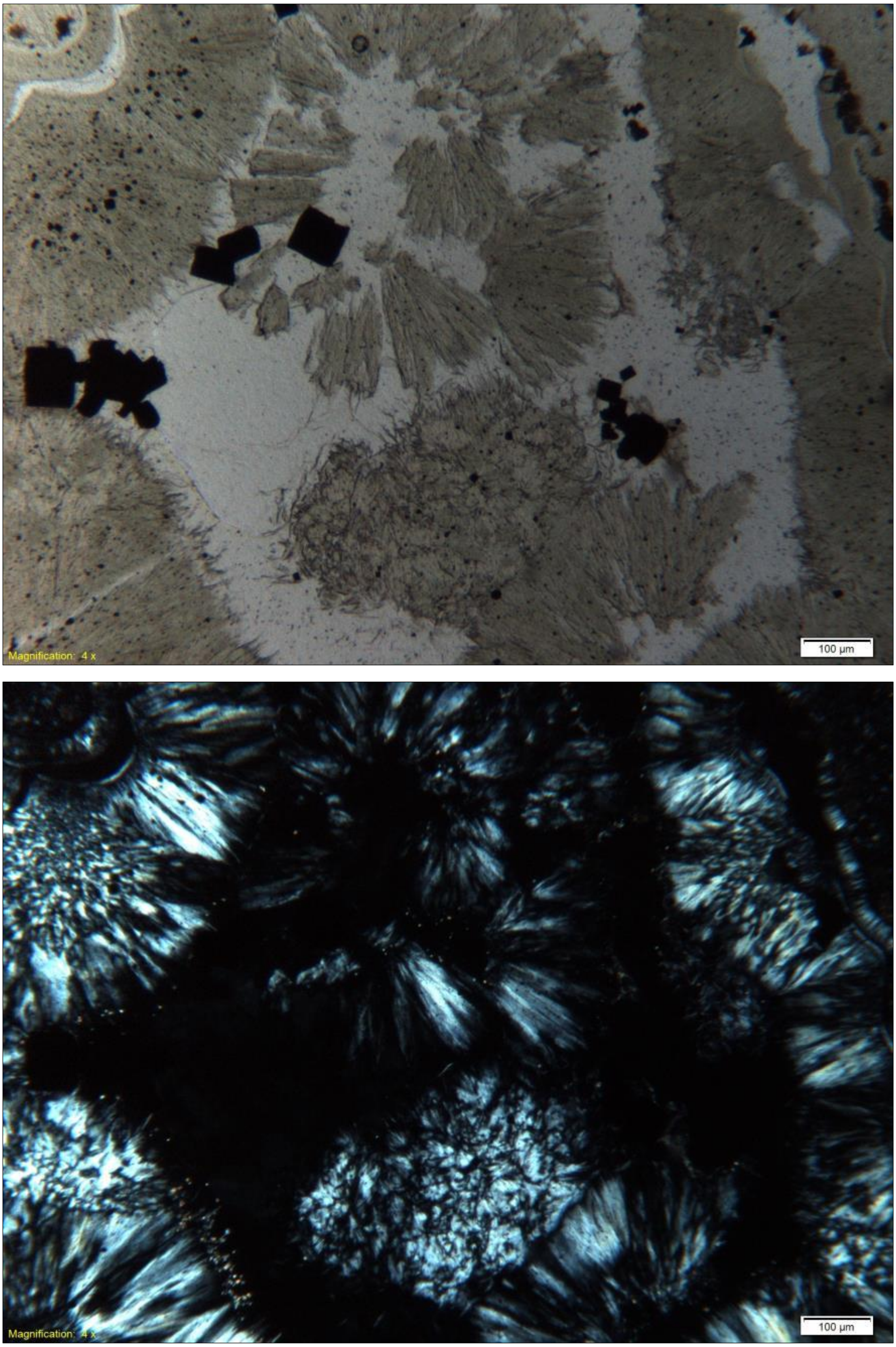


Figure 1. *Likely occurrence of pyrite (cubic opaque mineral). Green, fibrous mineral is chlorite replacing basaltic glass. Well ÞG-7, 134 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

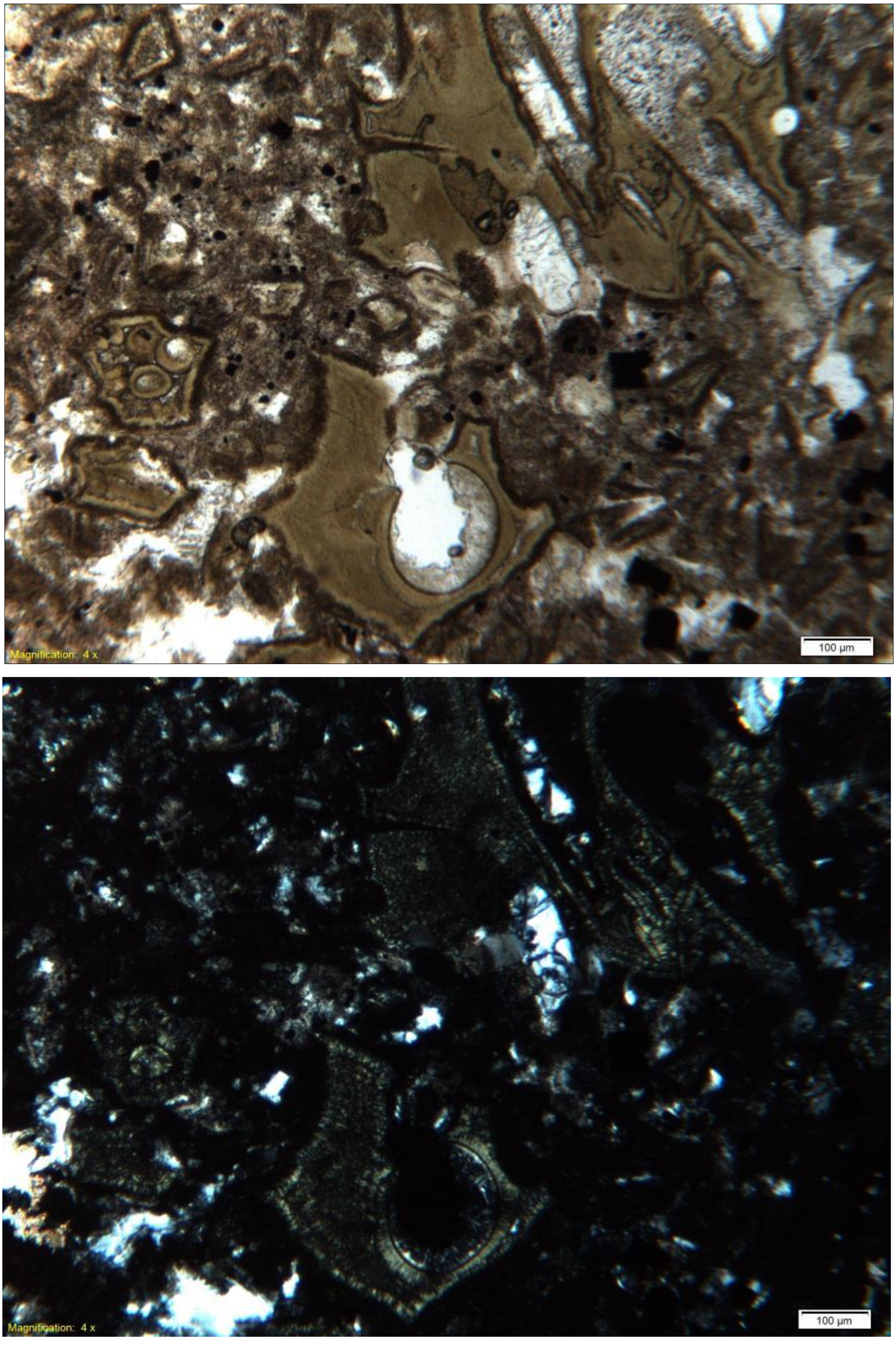


Figure 2. *Basaltic tuff mostly altered to smectite with some quartz in pores. Well ÞG-7, 94 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

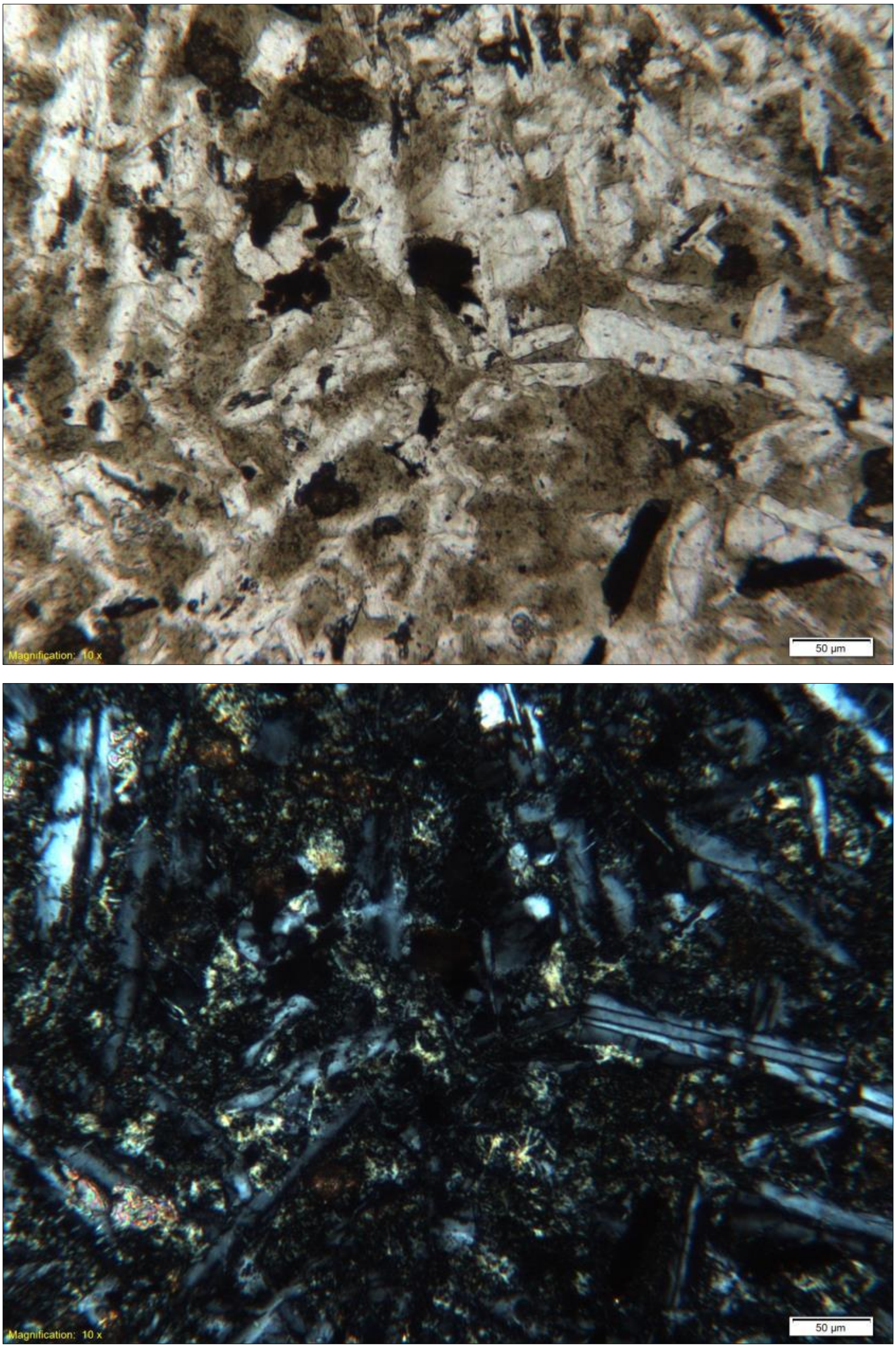


Figure 3. *Grain of basalt with intersertal texture typical of glassy basalt. Interstitial glass has mostly altered to mixed-layer clay. Plagioclase laths show some replacement by clay and albite. Oxides appear slightly altered. Well ÞG-6, 130 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

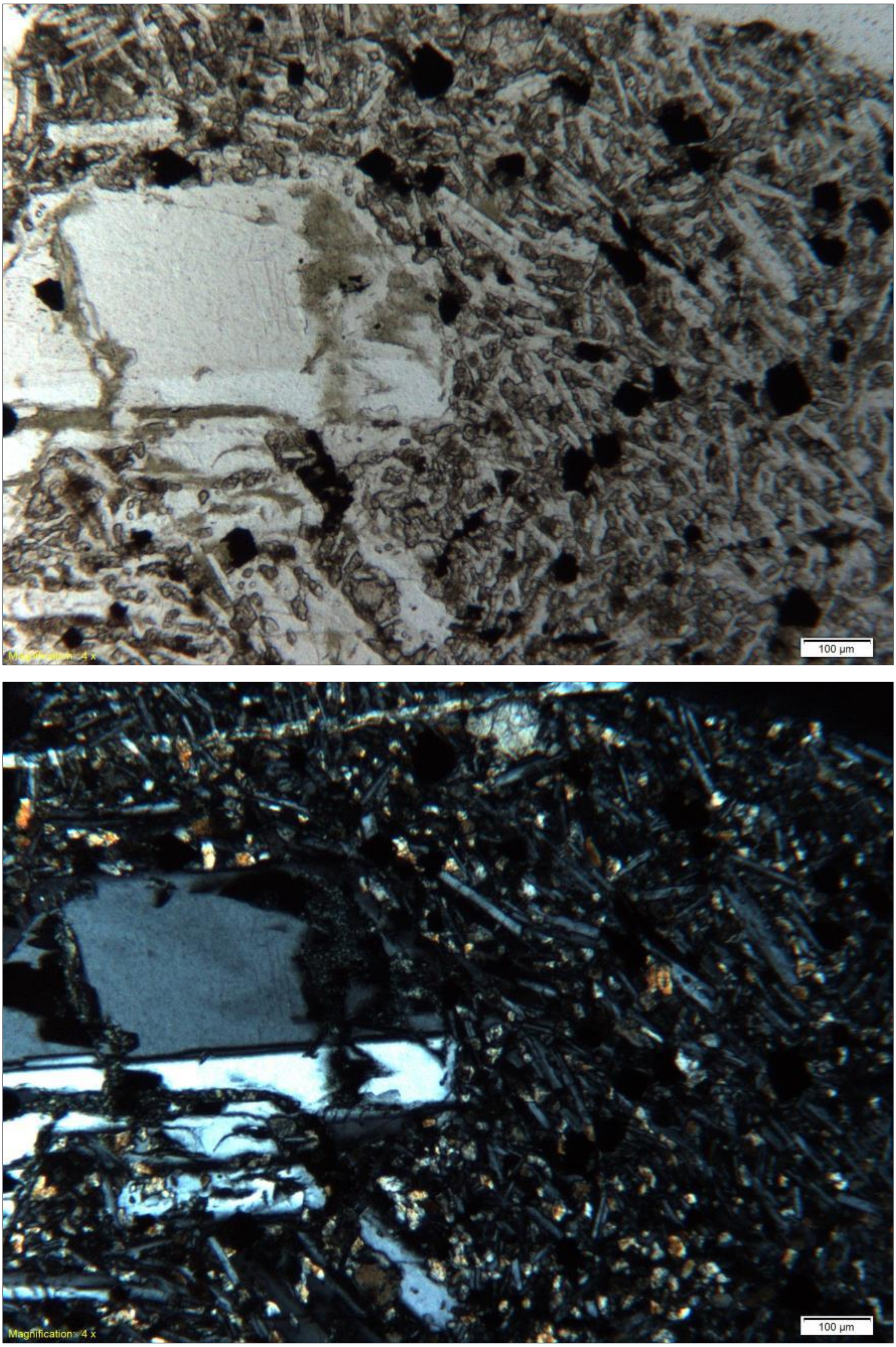


Figure 4. *Intergranular, plagioclase-phyric tholeiite with cryptocrystalline to fine-grained groundmass. Well ÞG-7, 550 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

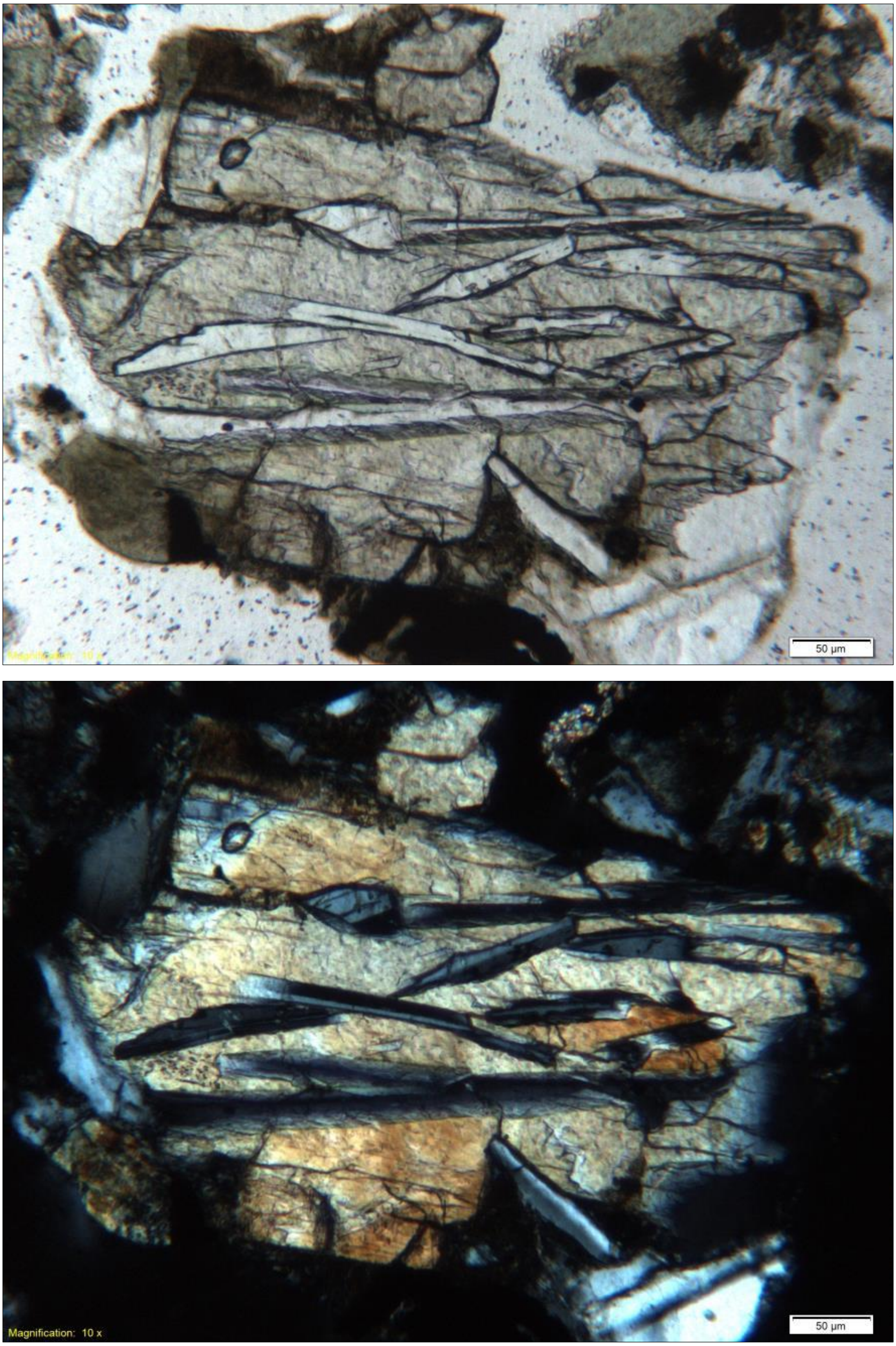


Figure 5. *Medium-grained, ophitic basalt, likely olivine-tholeiite intrusion. Well ÞG-8, 2300 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

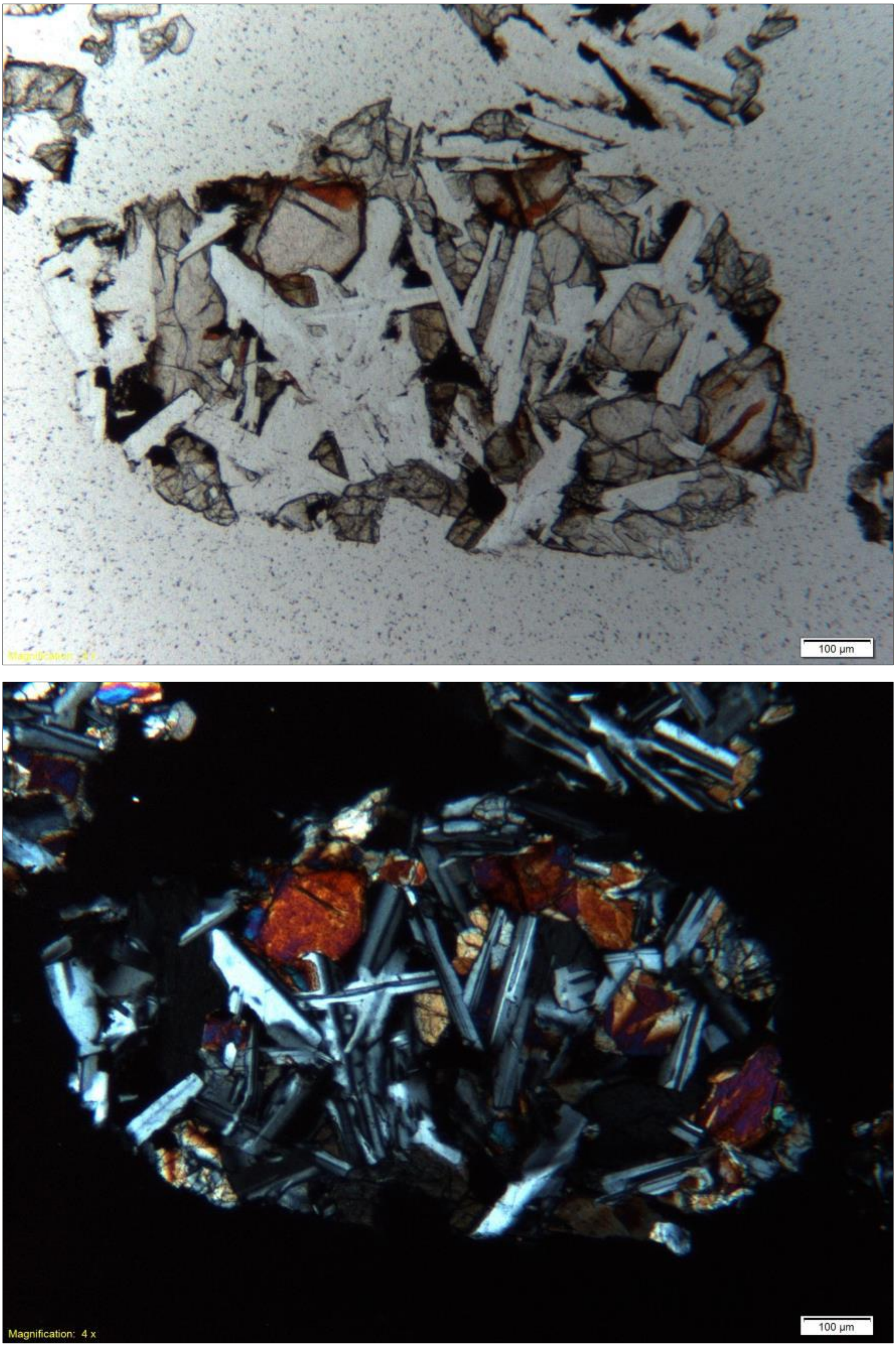


Figure 6. *Fine-grained, subophitic olivine tholeiite. Notice slight oxidation of olivine and relatively small amount of interstitial Fe-Ti oxide. Well ÞG-8, 100 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

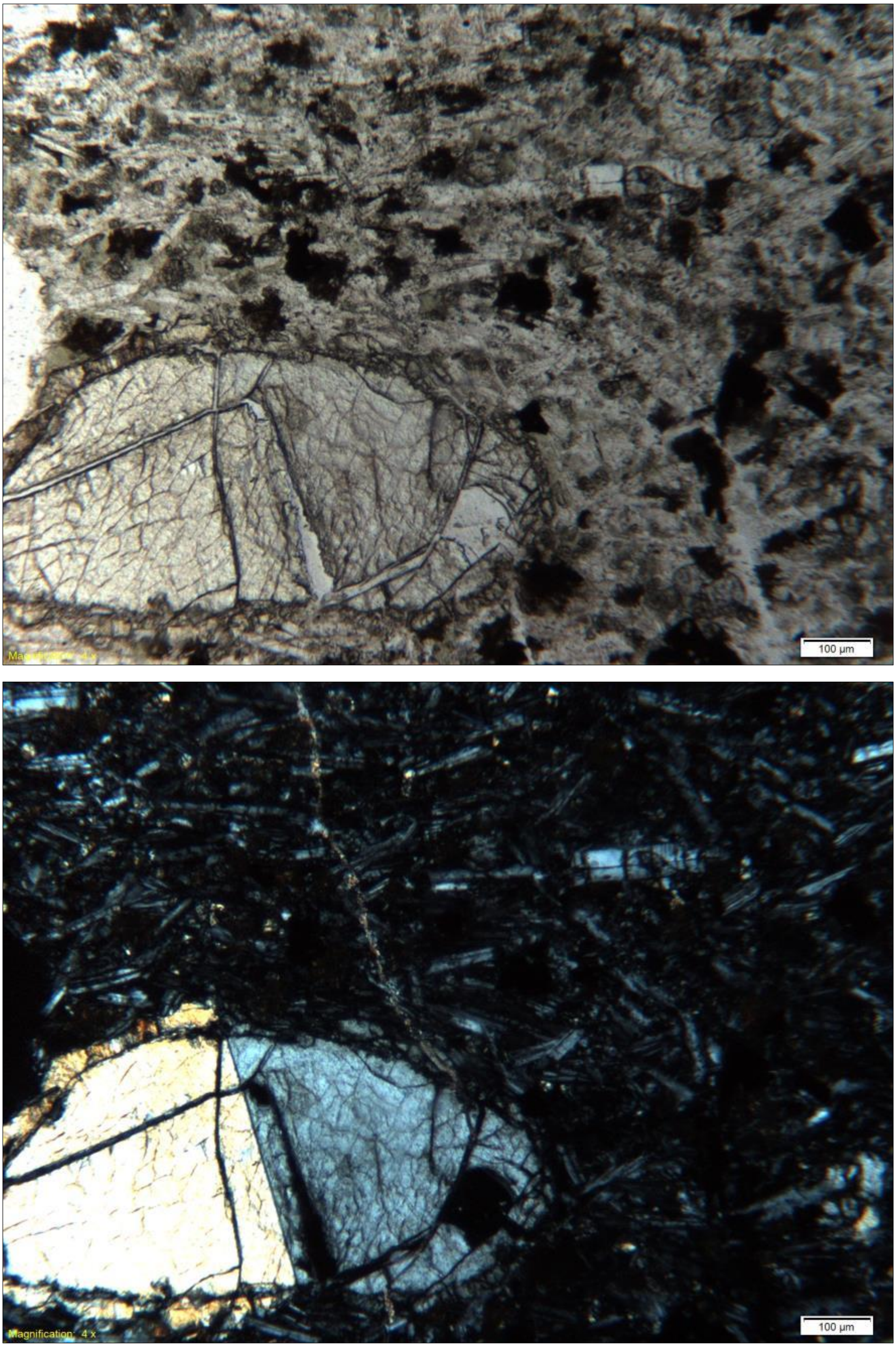


Figure 7. *Cryptocrystalline to fine-grained, intergranular tholeiite with a clinopyroxene phenocryst. Notice subhedral Fe-Ti oxide grains and hint of flow texture. Well ÞG-7, 742 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

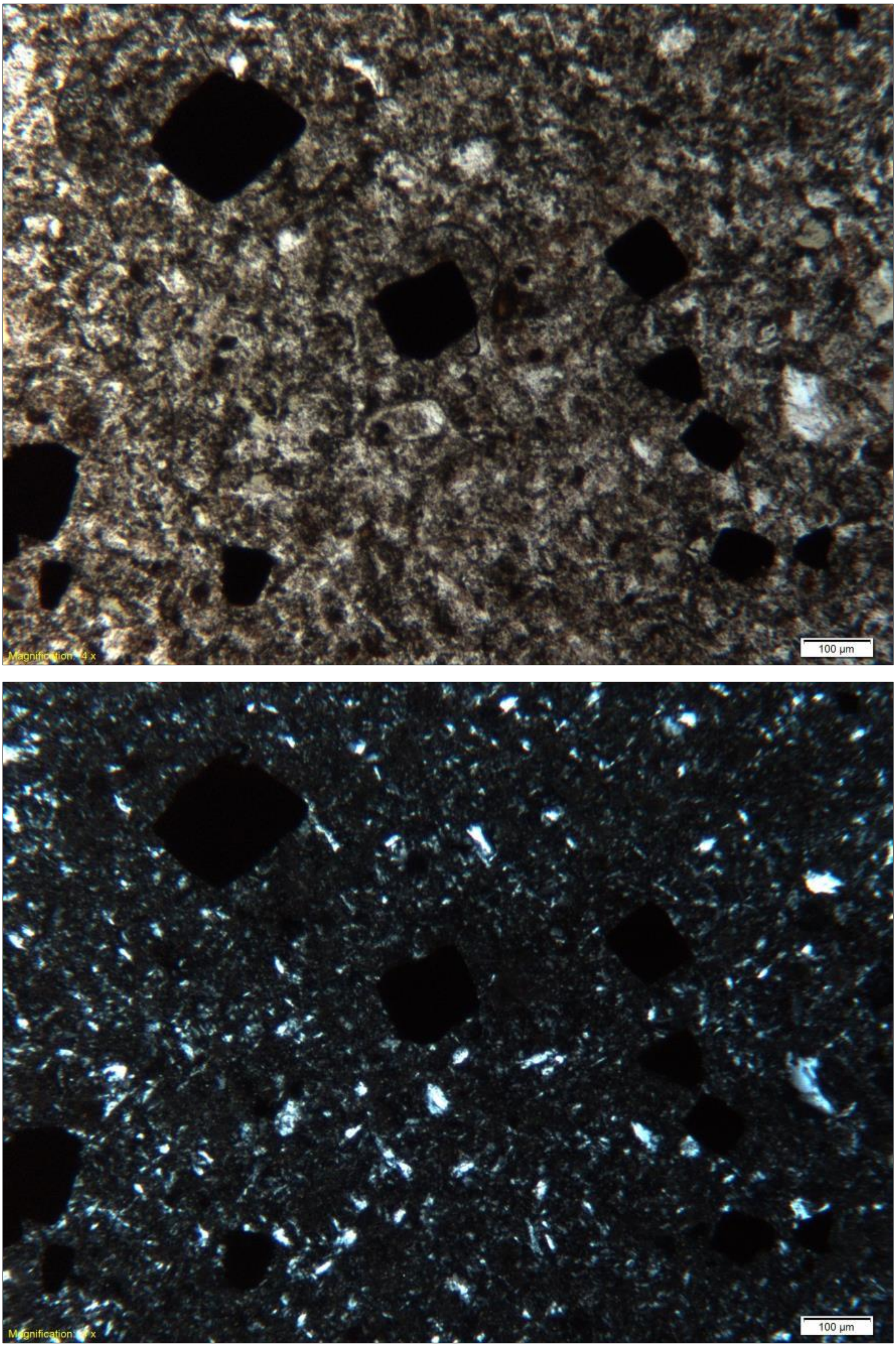


Figure 8. *Cryptocrystalline or recrystallized glassy andesite, likely containing titanomagnetite phenocrysts. Well ÞG-7, 248 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

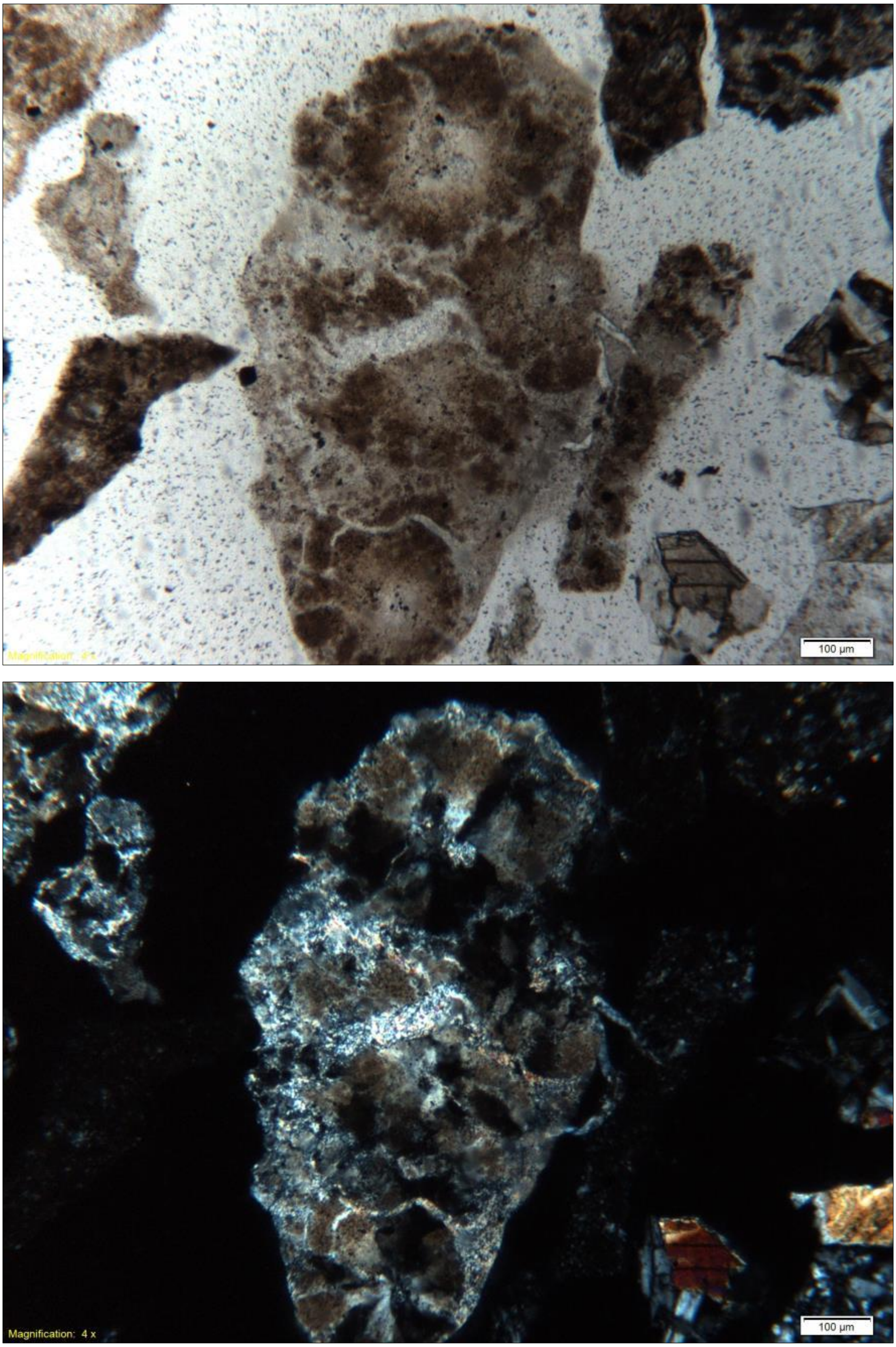


Figure 9. *Grain of altered rhyolite in the middle. Probably mainly composed of adularia (brown, very fine-grained mineral), illite and quartz. Well ÞG-7, 1864 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

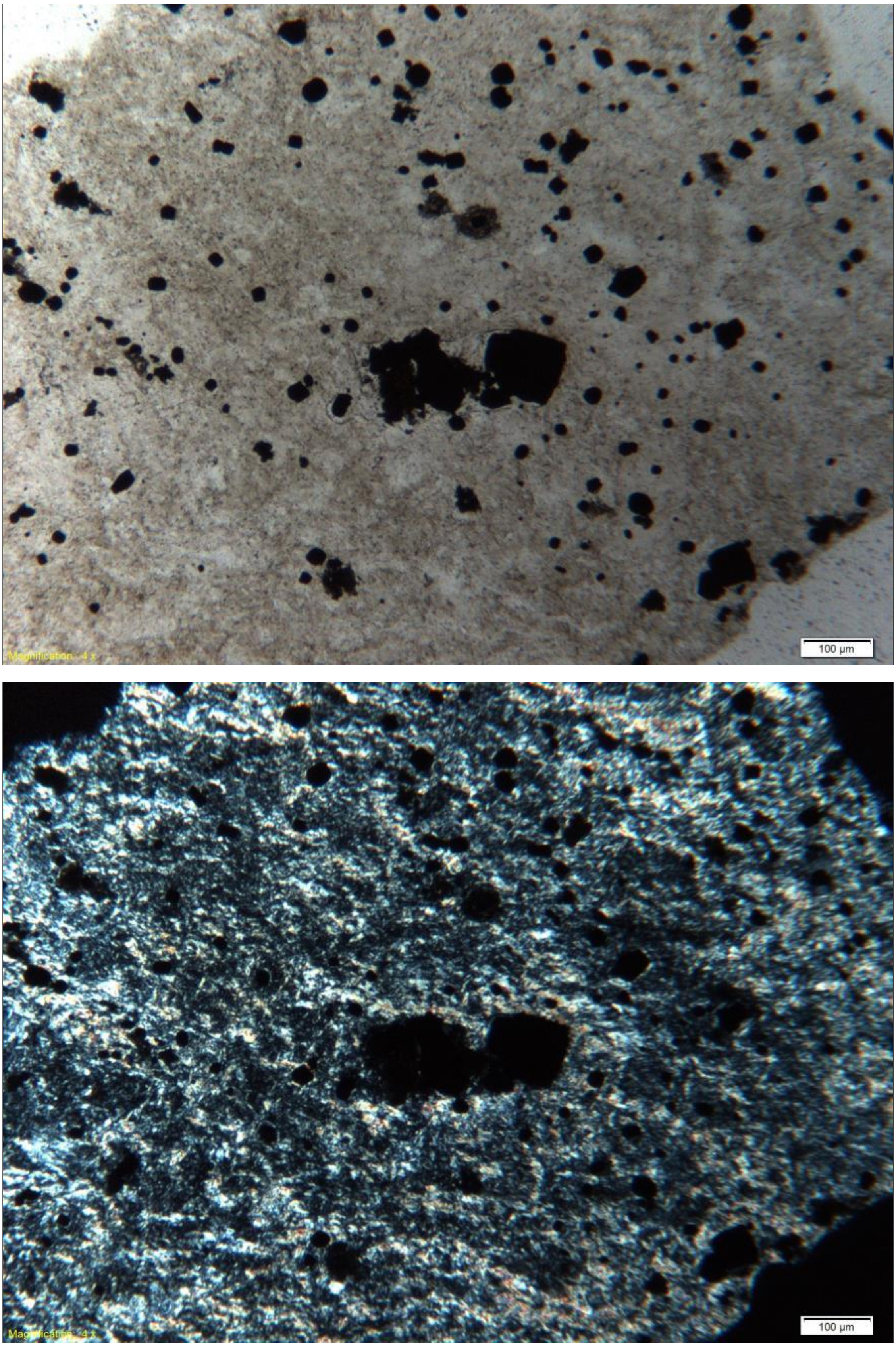


Figure 10. *Devitrified silicic (rhyolitic) tuff, mostly altered to illite and an opaque mineral, possibly pyrite. Well ÞG-7, 880m. Upper panel plane-polarized light, lower panel crossed polarizers.*

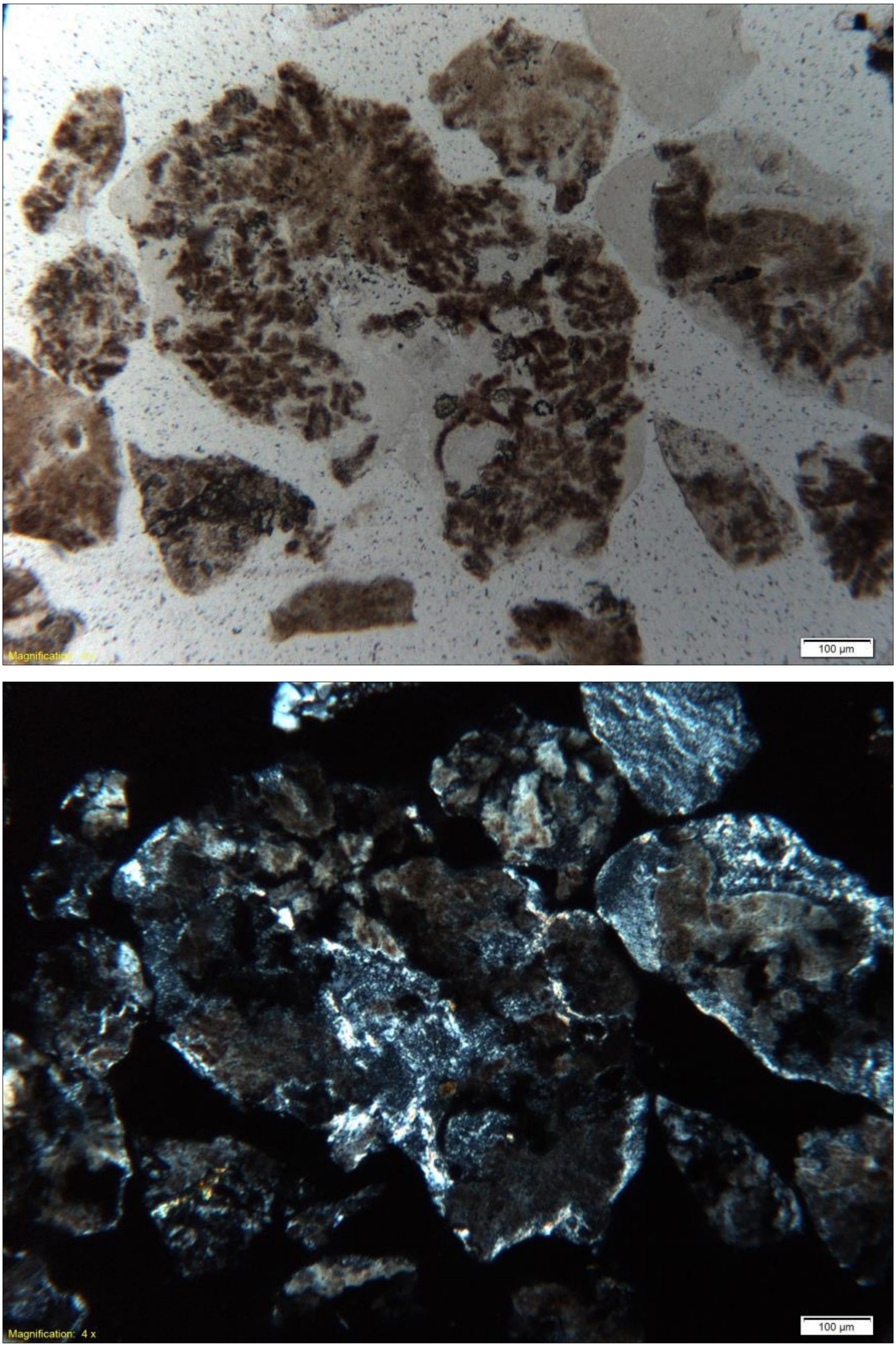


Figure 11. *Altered silicic breccia with fragments of rhyolite and devitrified glass. Illite, quartz and likely adularia can be seen. Well ÞG-7, 1730 m. Upper panel plane-polarized light, lower panel crossed polarizers.*

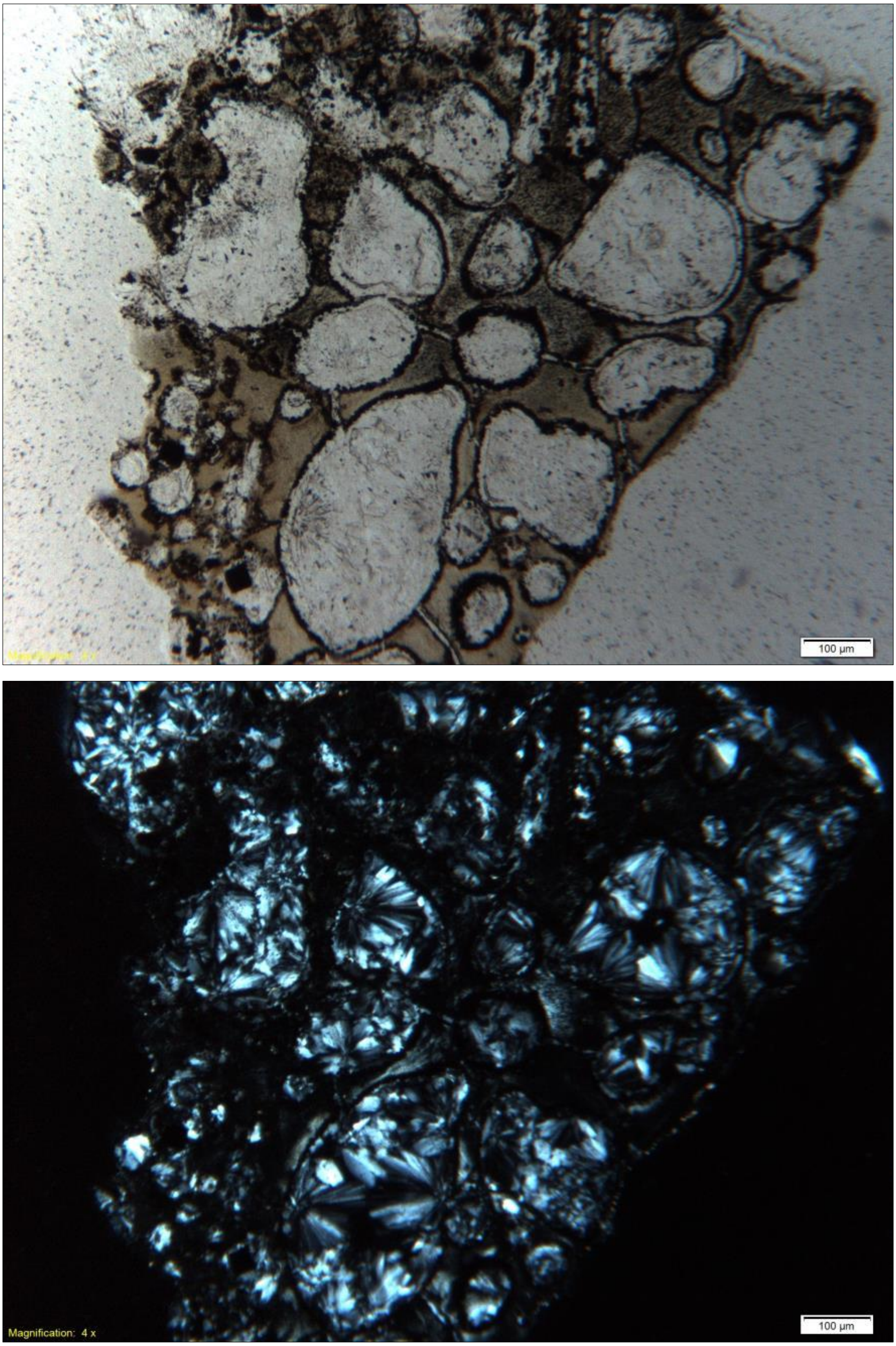


Figure 12. *Highly vesicular basaltic tuff. The sideromelane glass has altered to smectite and the pores are filled with a zeolite. Well ÞG-7, 54 m.*

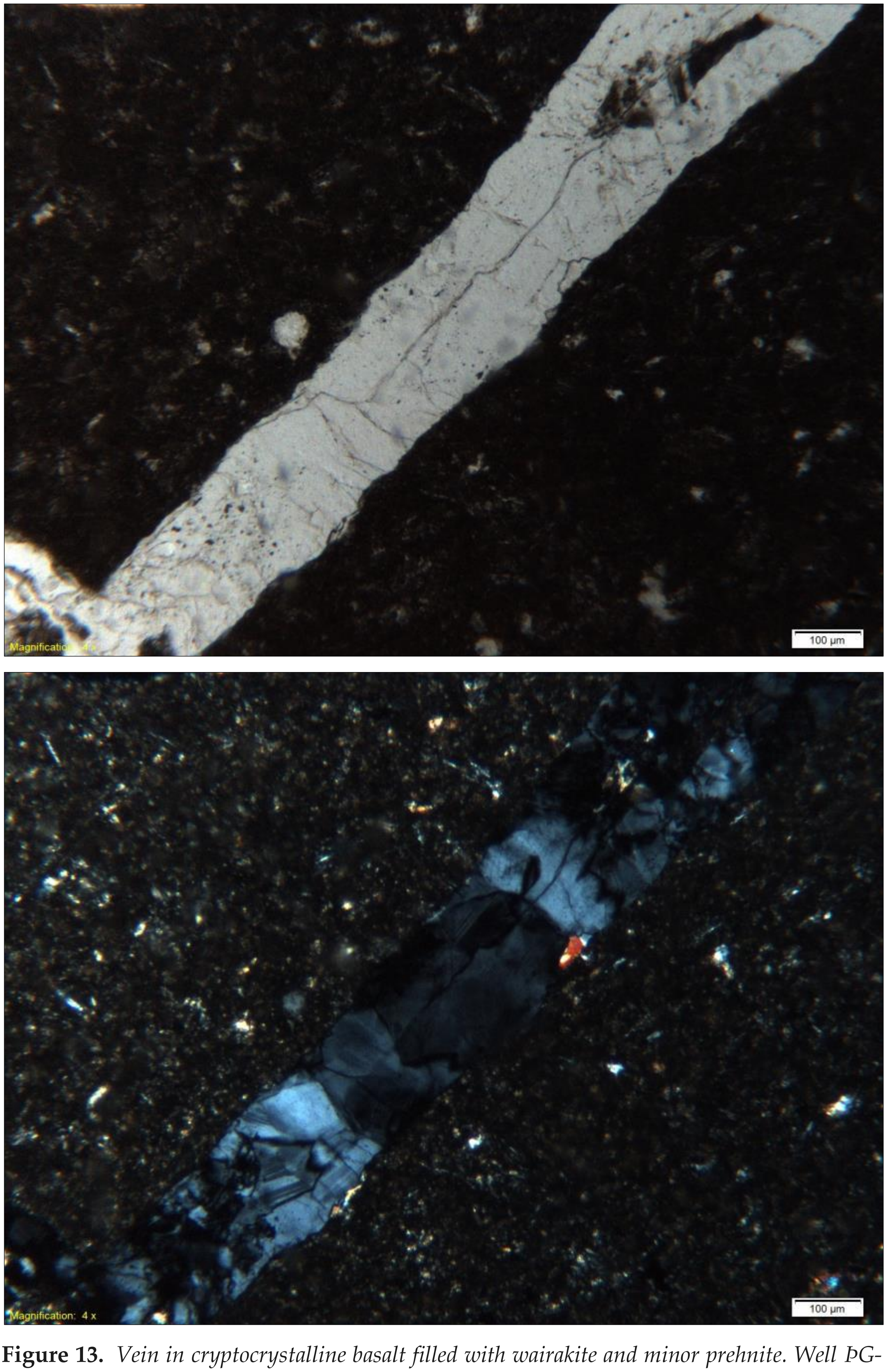
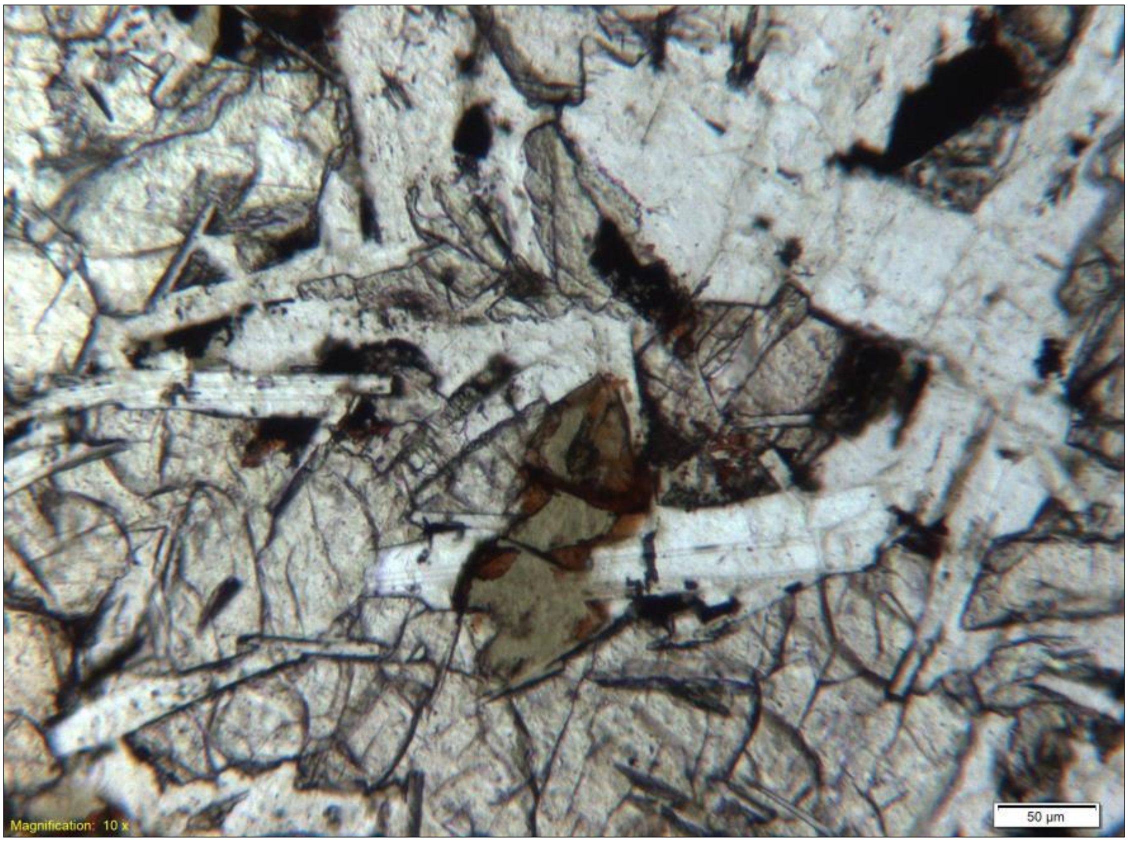


Figure 13. *Vein in cryptocrystalline basalt filled with wairakite and minor prehnite. Well ÞG-6, 1120 m.*



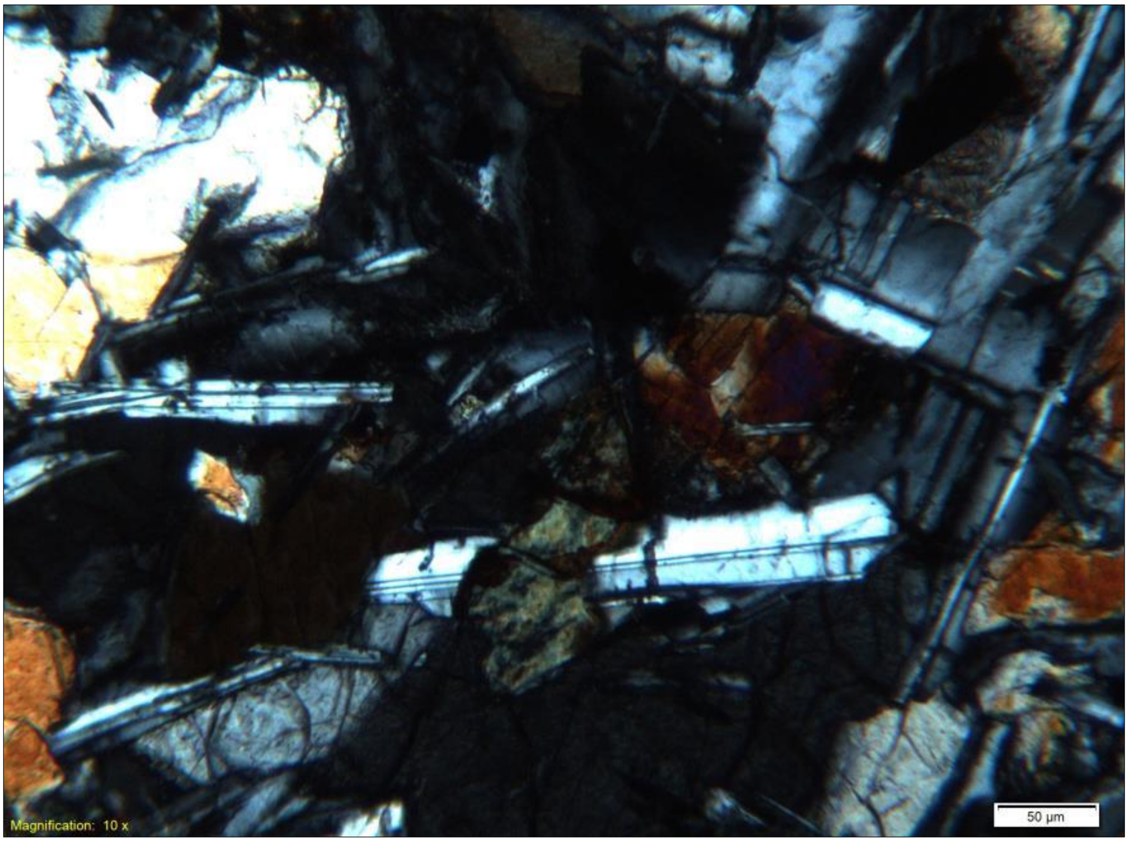


Figure 14. *Fine-grained, subophitic olivine tholeiite. Plagioclase and pyroxene exhibit minor alteration, Fe-Ti oxide shows slight oxidation and olivine is completely altered to mixed-layer clay and a ferric iron oxide. Well ÞG-7, 300 m.*

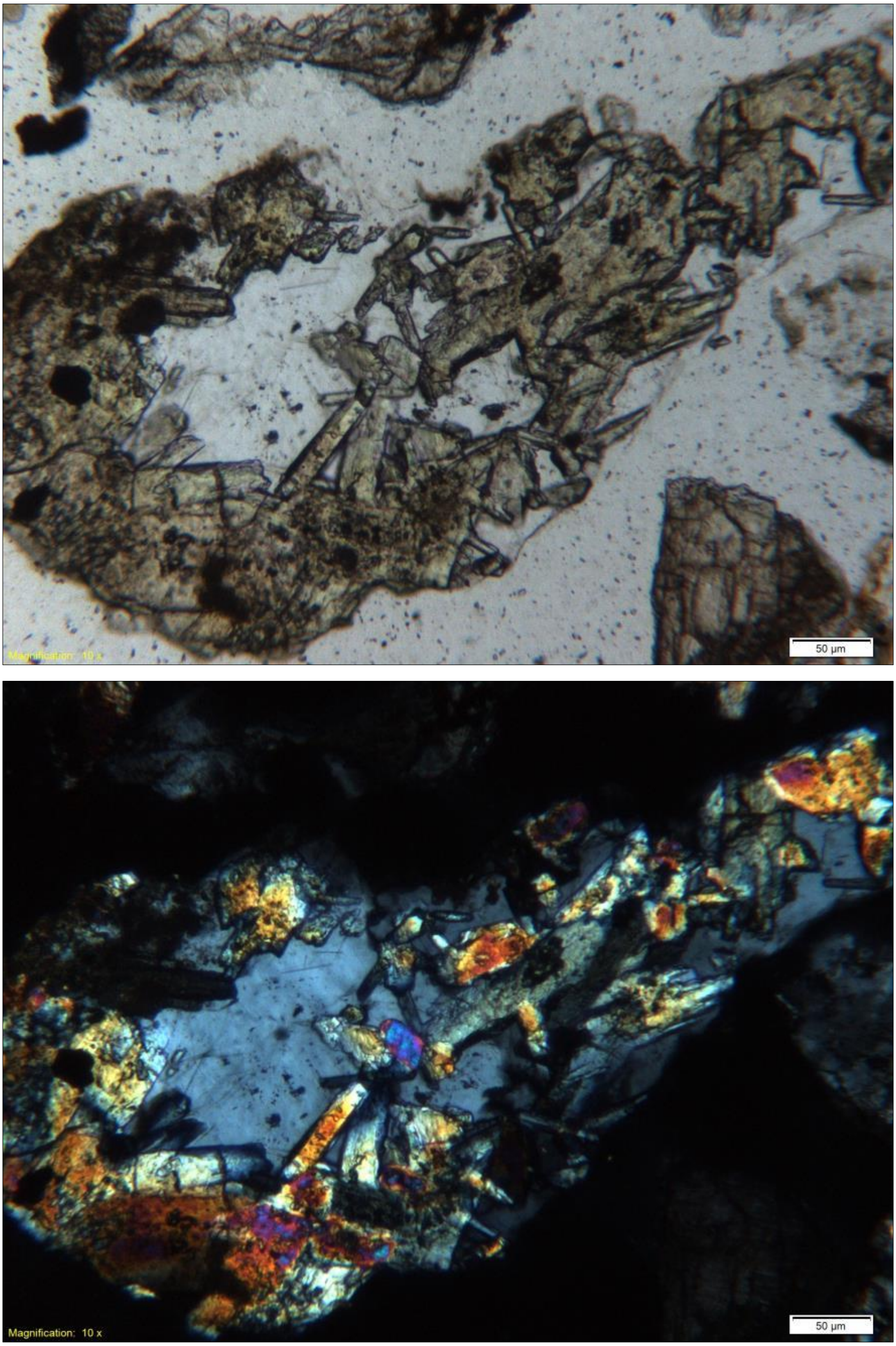


Figure 15. *Precipitate with epidote and quartz where the epidote appears to have been the first mineral to form. Well ÞG-6, 2160 m.*

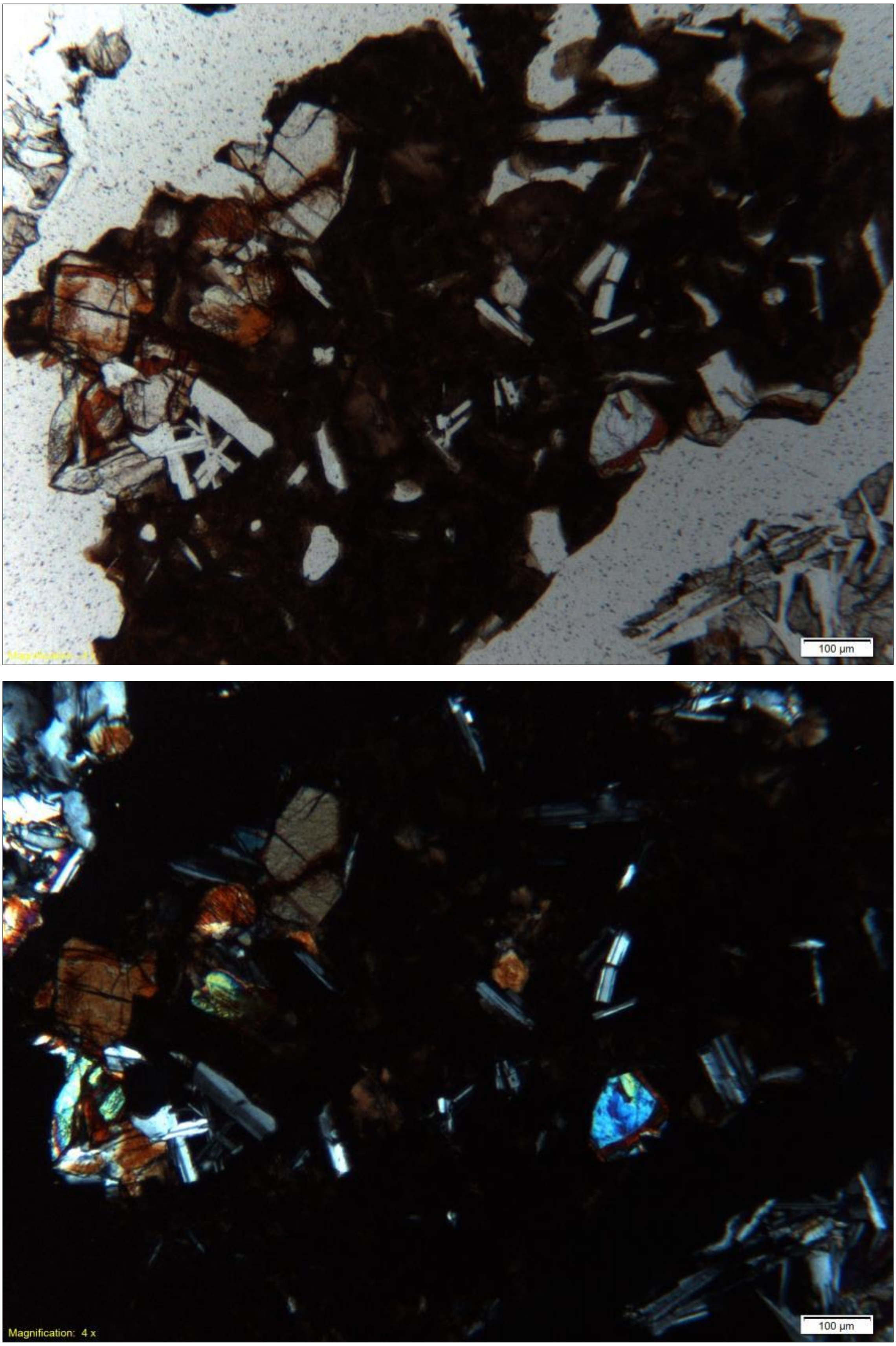


Figure 16. *Plagioclase and olivine microphenocrysts in tachylite glass groundmass. Well ÞG-8, 100 m.*

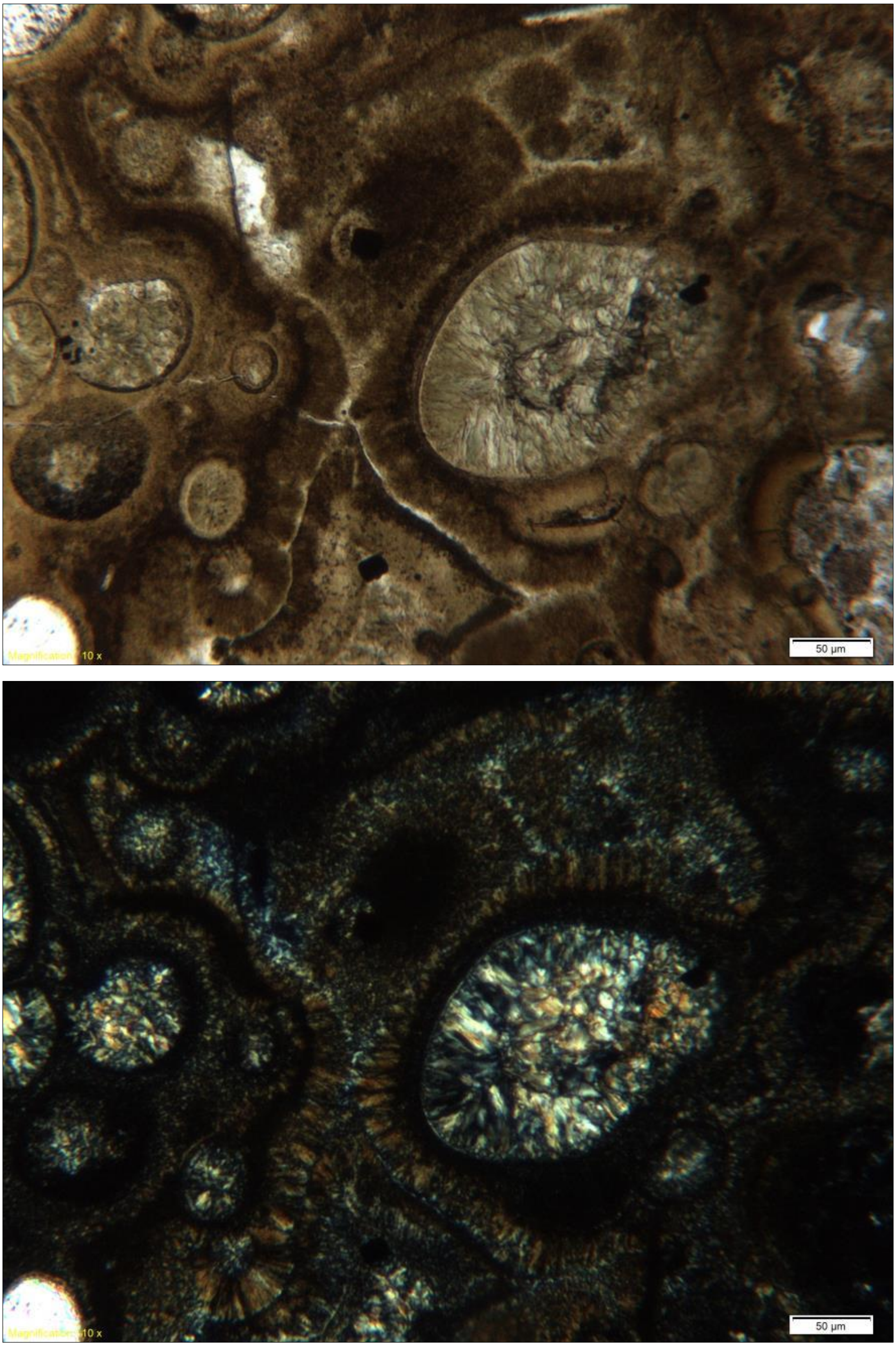


Figure 17. *Sideromelane glass altered to smectite. The largest vesicles probably contain mixed-layer clay. Well ÞG-7, 94 m.*

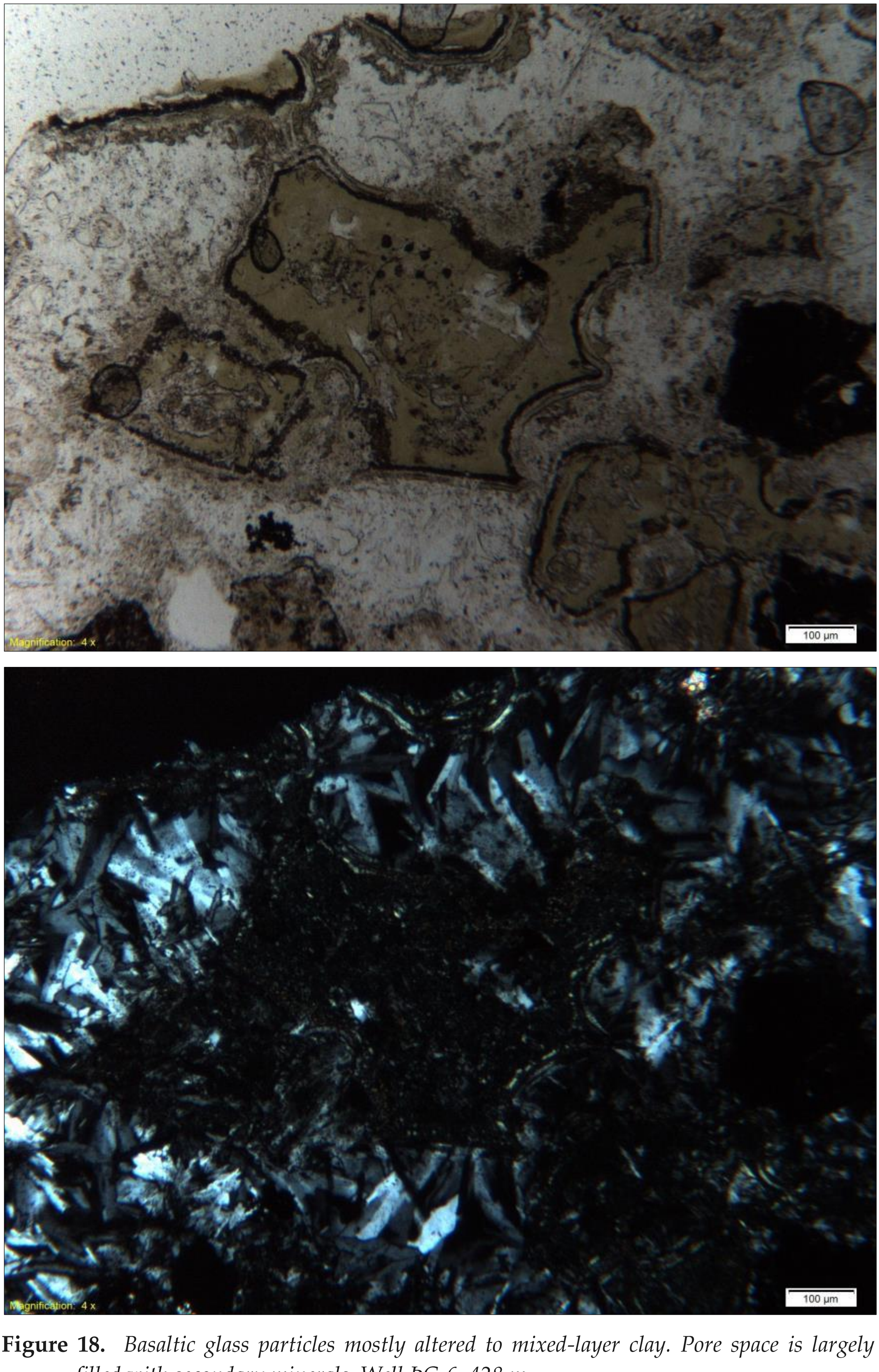


Figure 18. *Basaltic glass particles mostly altered to mixed-layer clay. Pore space is largely filled with secondary minerals. Well ÞG-6, 428 m.*

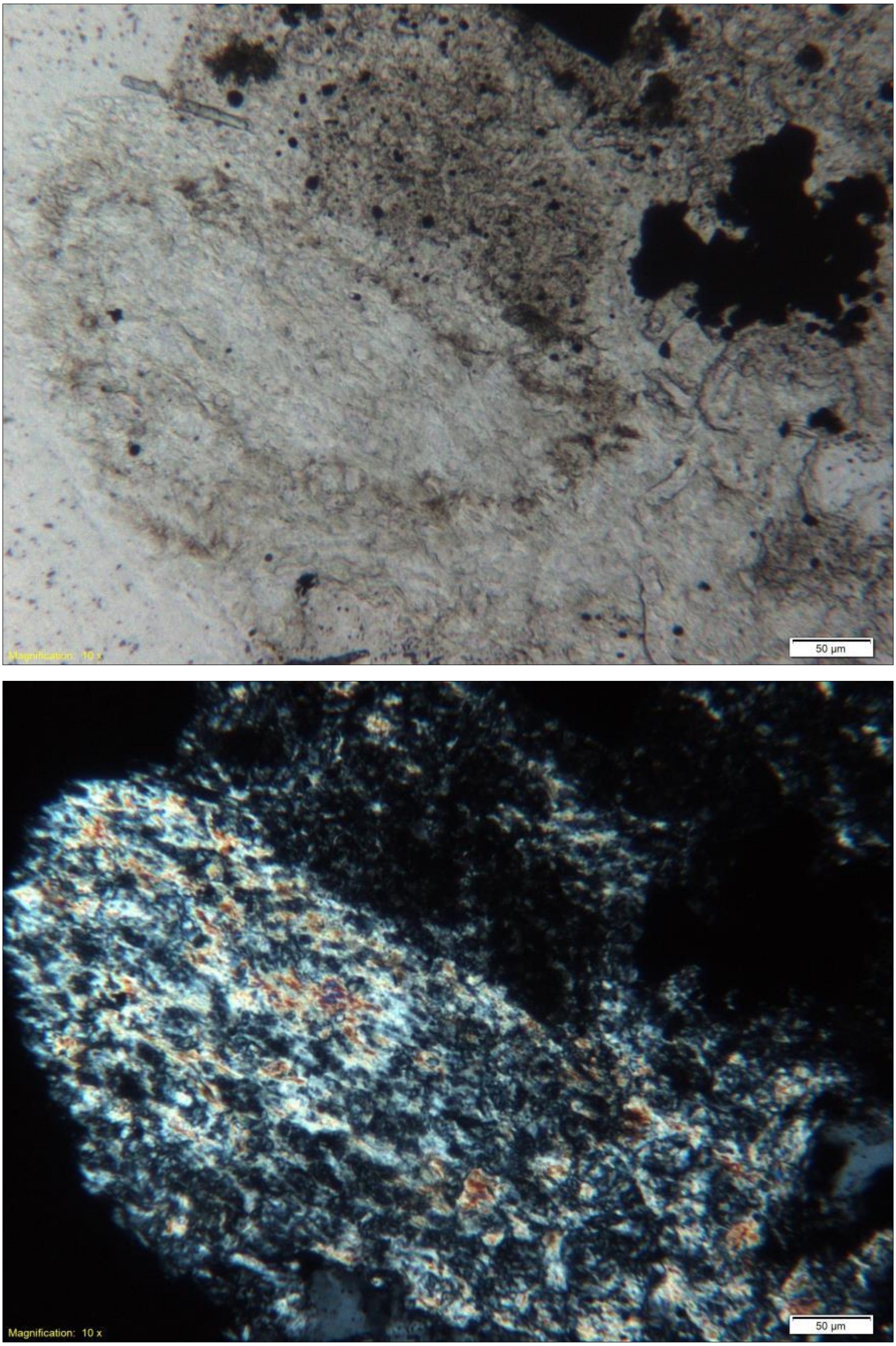


Figure 19. *Fragment of altered silicic glass replaced by illite, an opaque mineral and some quartz. Well ÞG-7, 880 m.*

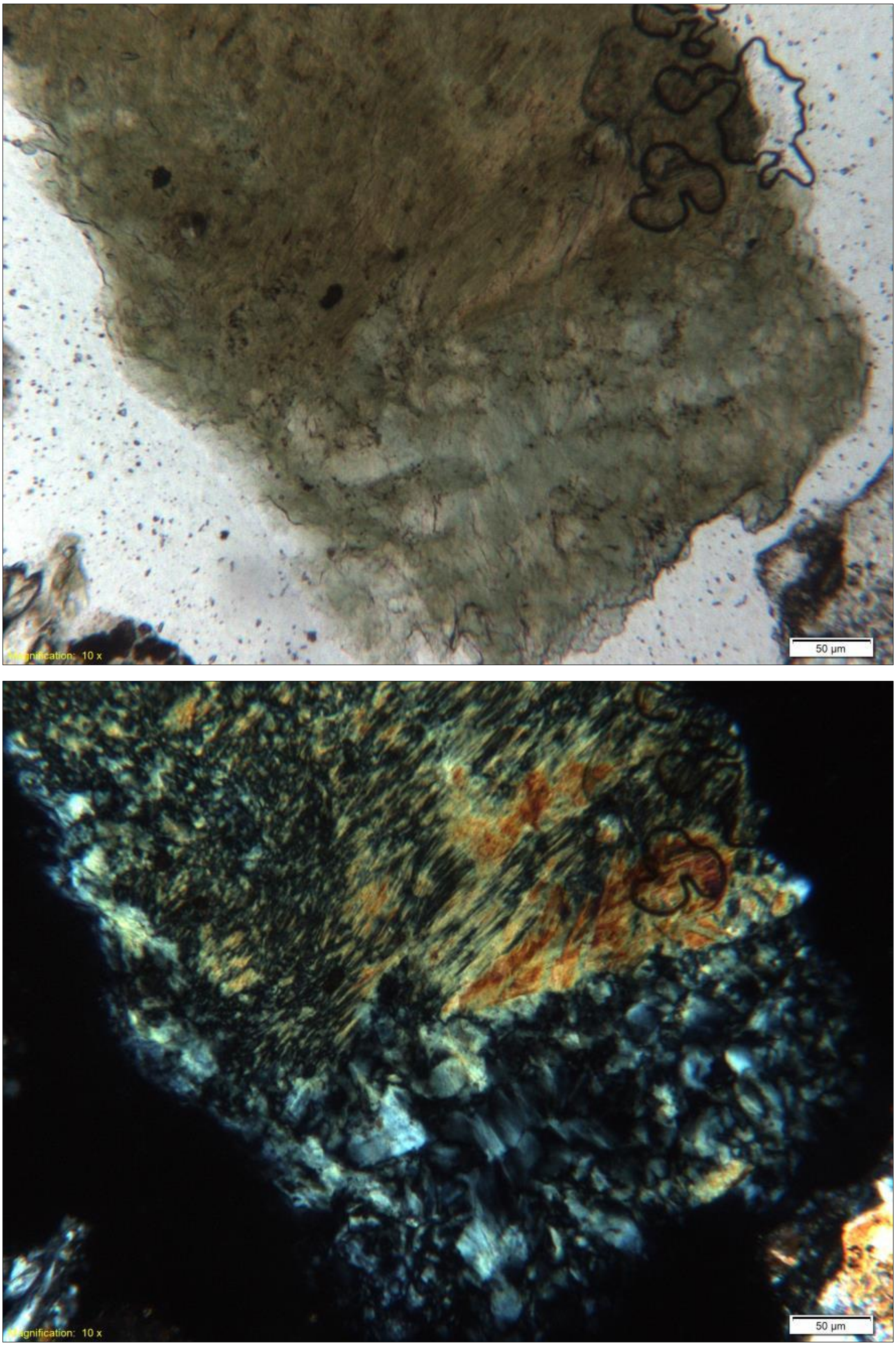
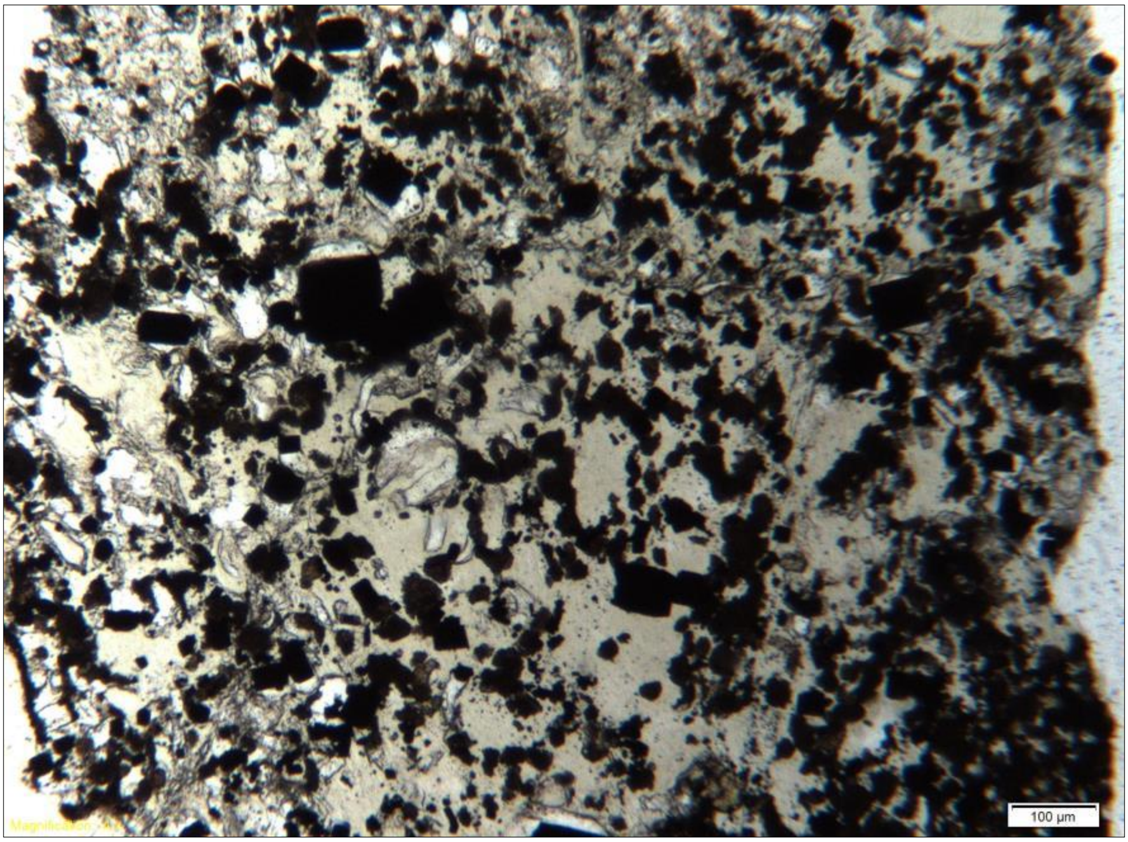


Figure 20. *Actinolite probably replacing basaltic glass. Well ÞG-7, 1278 m.*



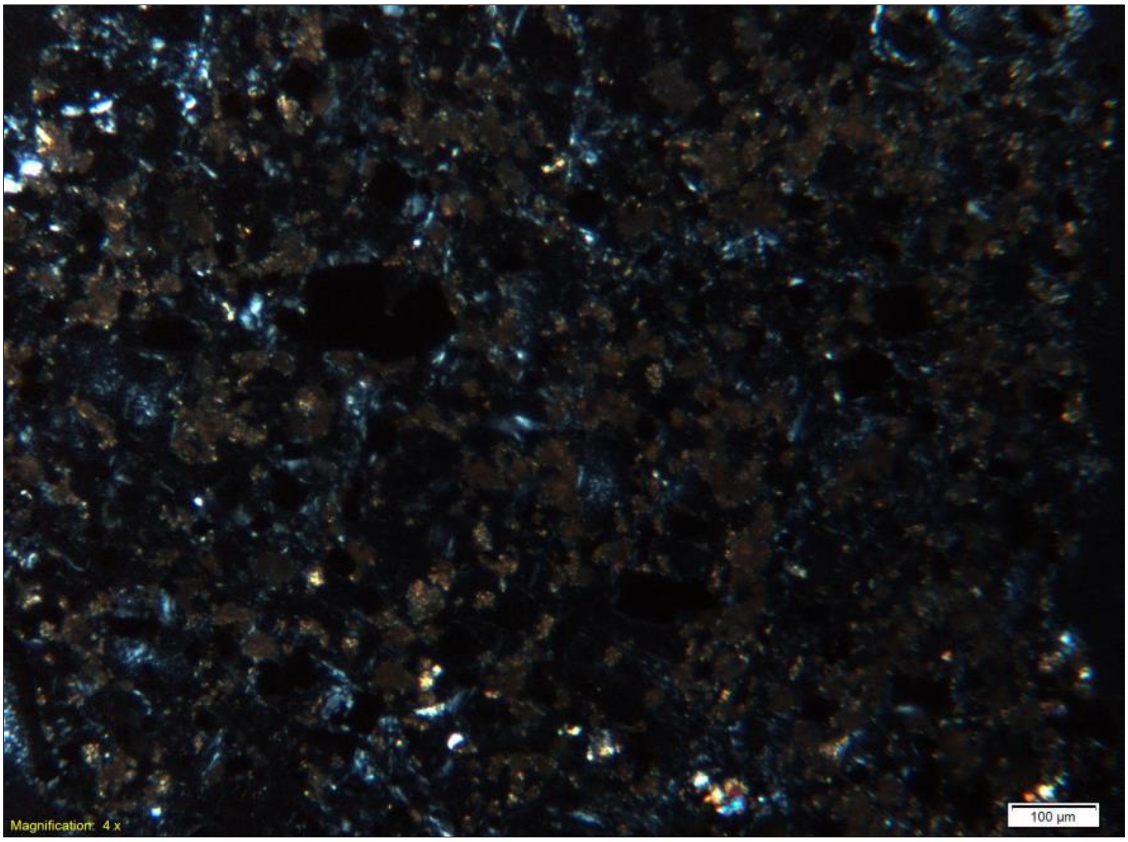


Figure 21. *Basaltic glass replaced by chlorite, quartz, titanite (irregular patches with high interference colors) and a cubic opaque mineral, possibly pyrite. Well ÞG-7, 950–954 m.*

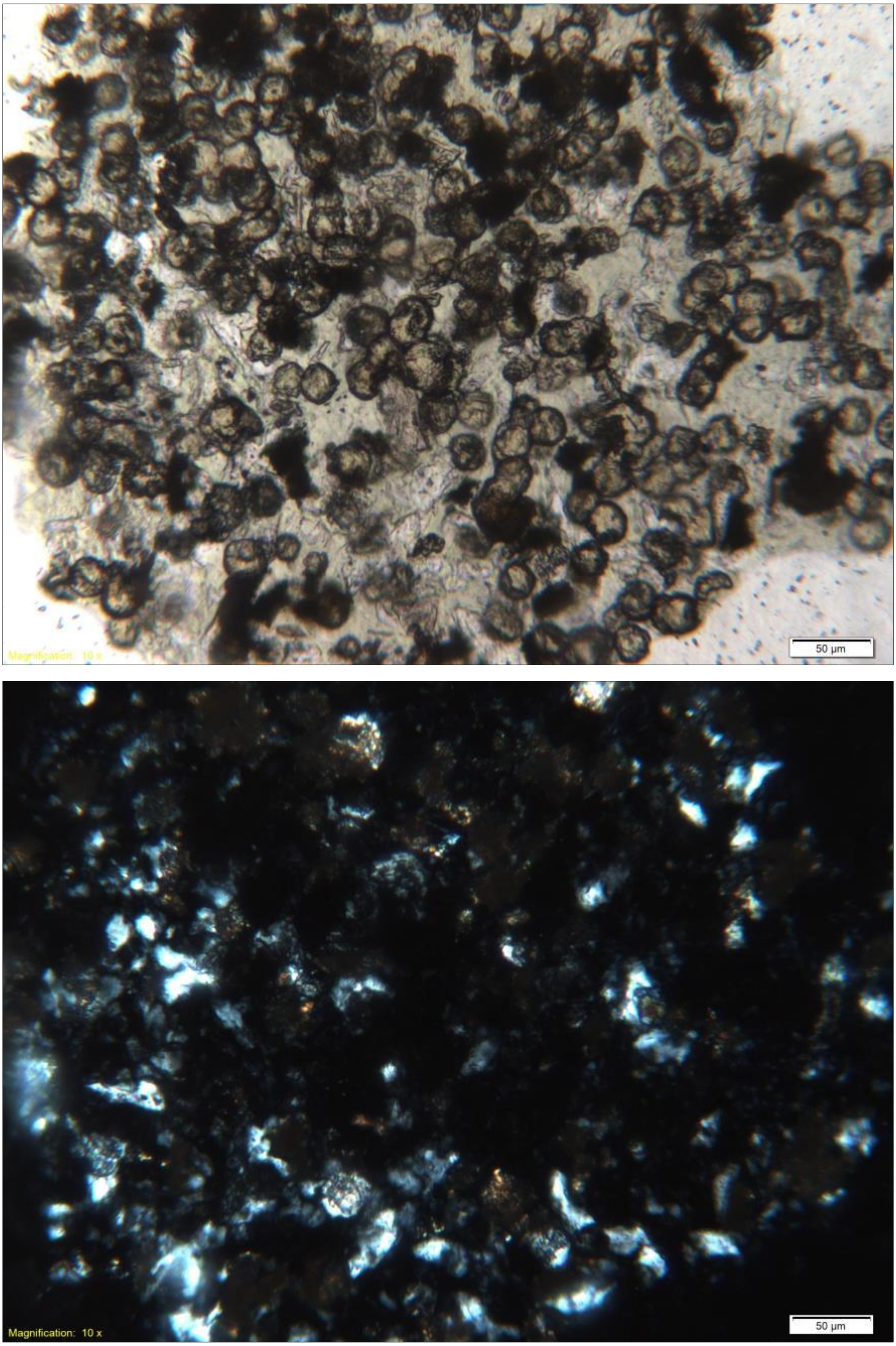


Figure 22. *Basaltic glass replaced by chlorite, quartz, garnet and titanite (poorly developed grains forming dark patches). Well ÞG-4, 1170 m.*

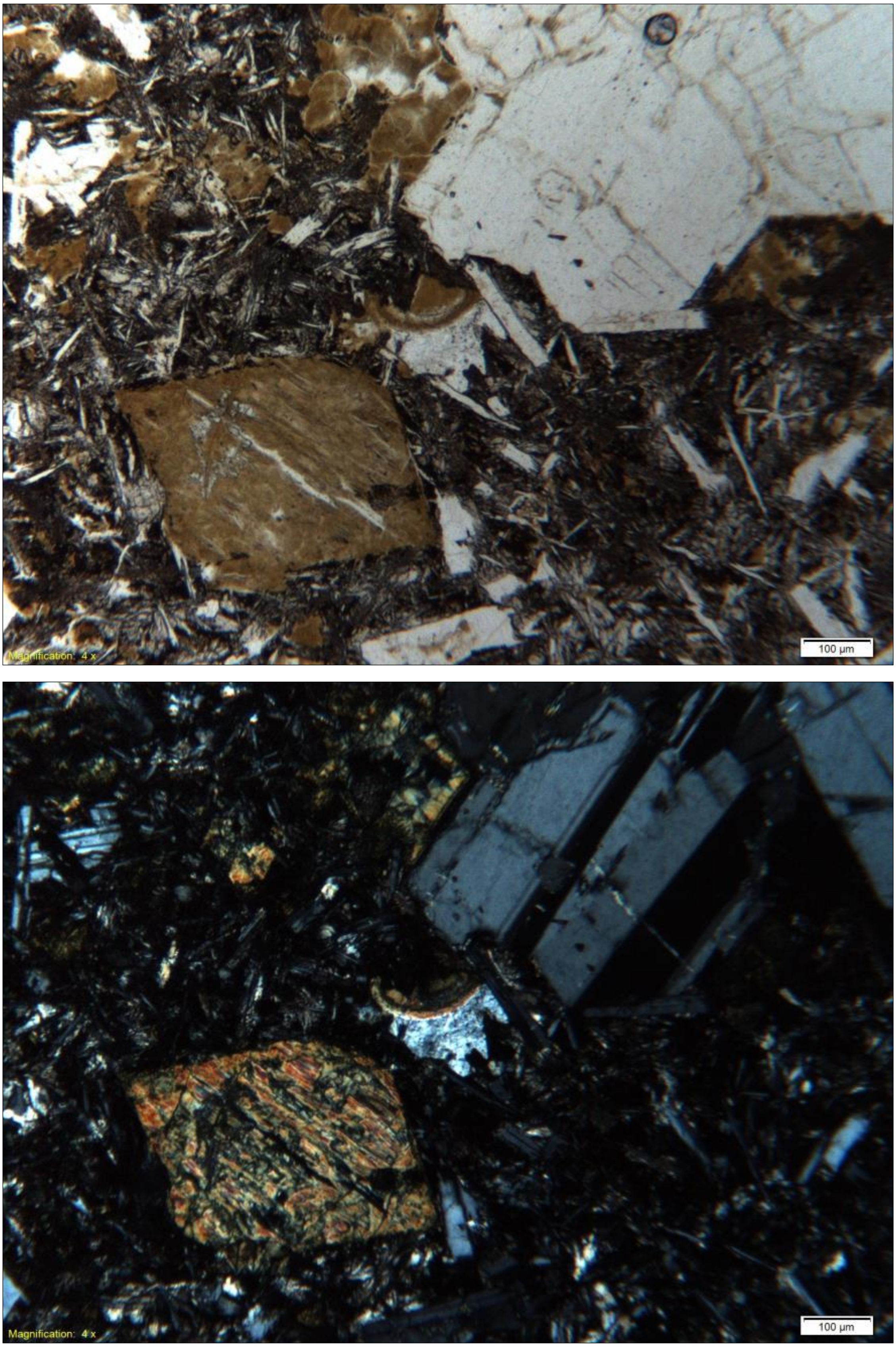


Figure 23. *Phenocrysts of olivine and plagioclase in a glass-rich groundmass. Olivine has been replaced by smectite, and plagioclase has minor amount of smectite in fractures. Well ÞG-8, 390 m.*

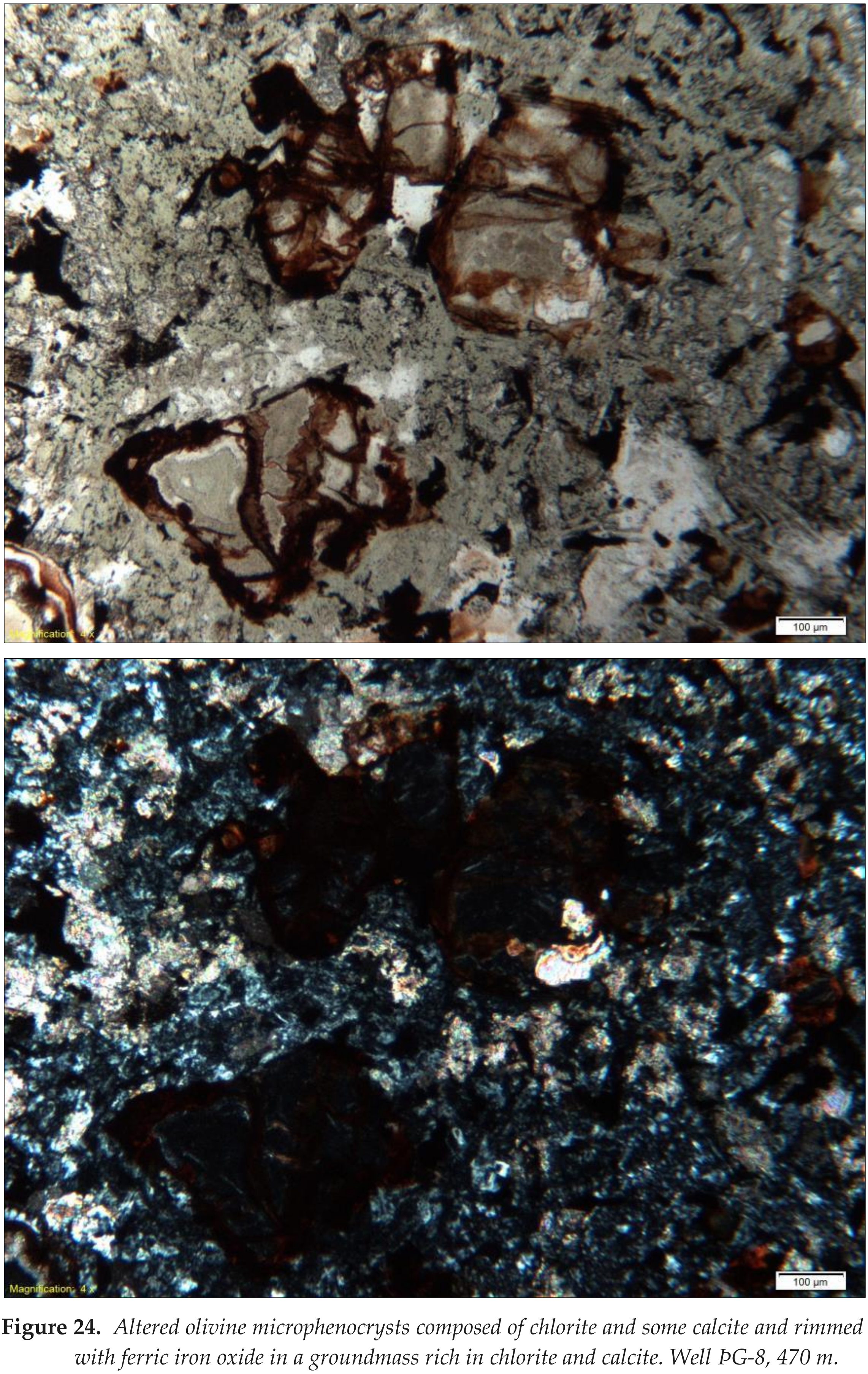


Figure 24. *Altered olivine microphenocrysts composed of chlorite and some calcite and rimmed with ferric iron oxide in a groundmass rich in chlorite and calcite. Well ÞG-8, 470 m.*

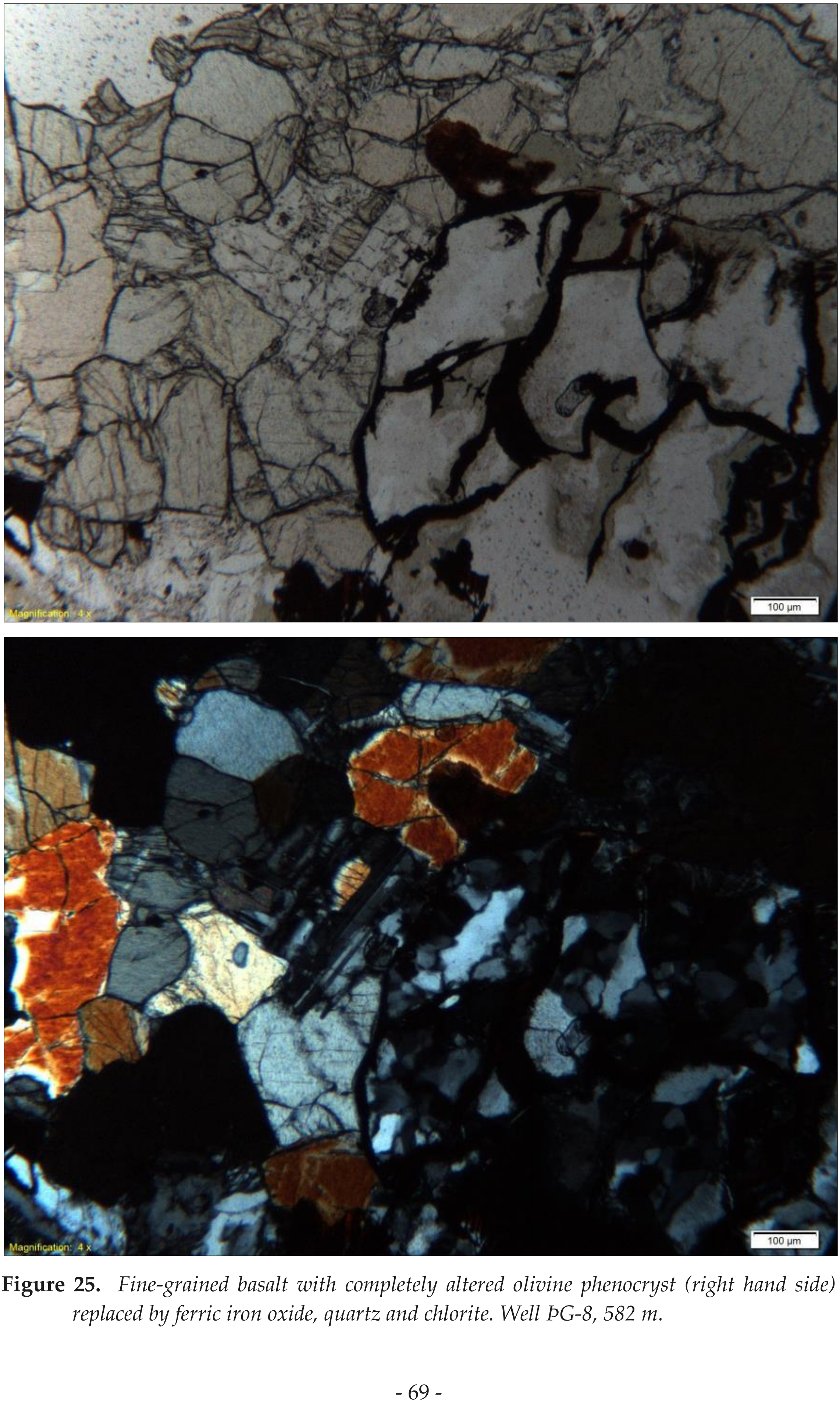


Figure 25. *Fine-grained basalt with completely altered olivine phenocryst (right hand side) replaced by ferric iron oxide, quartz and chlorite. Well ÞG-8, 582 m.*

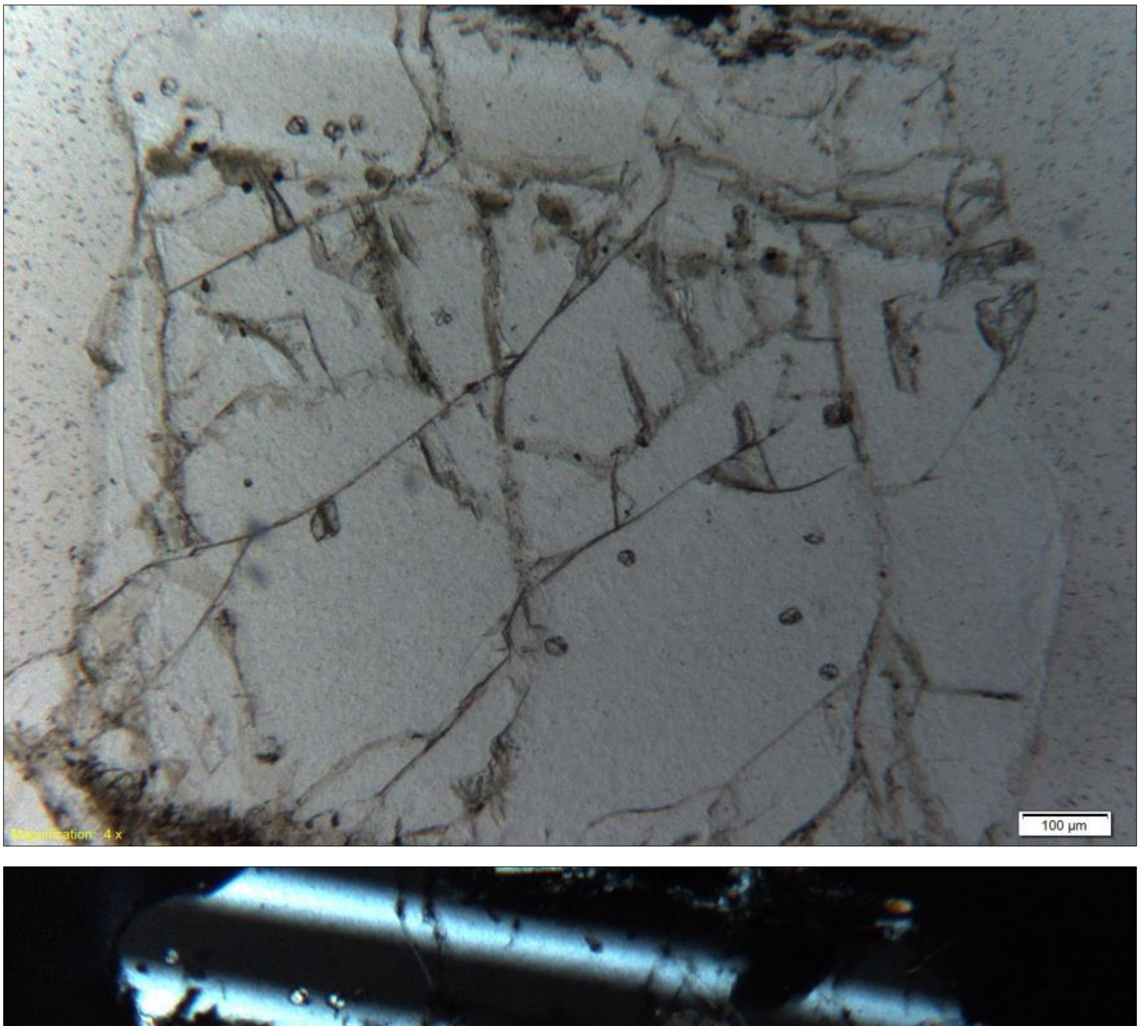


Figure 26. *Plagioclase with signs of beginning alteration in fractures, including mixed-layer clay, calcite and albitization. Well ÞG-7, 204 m.*

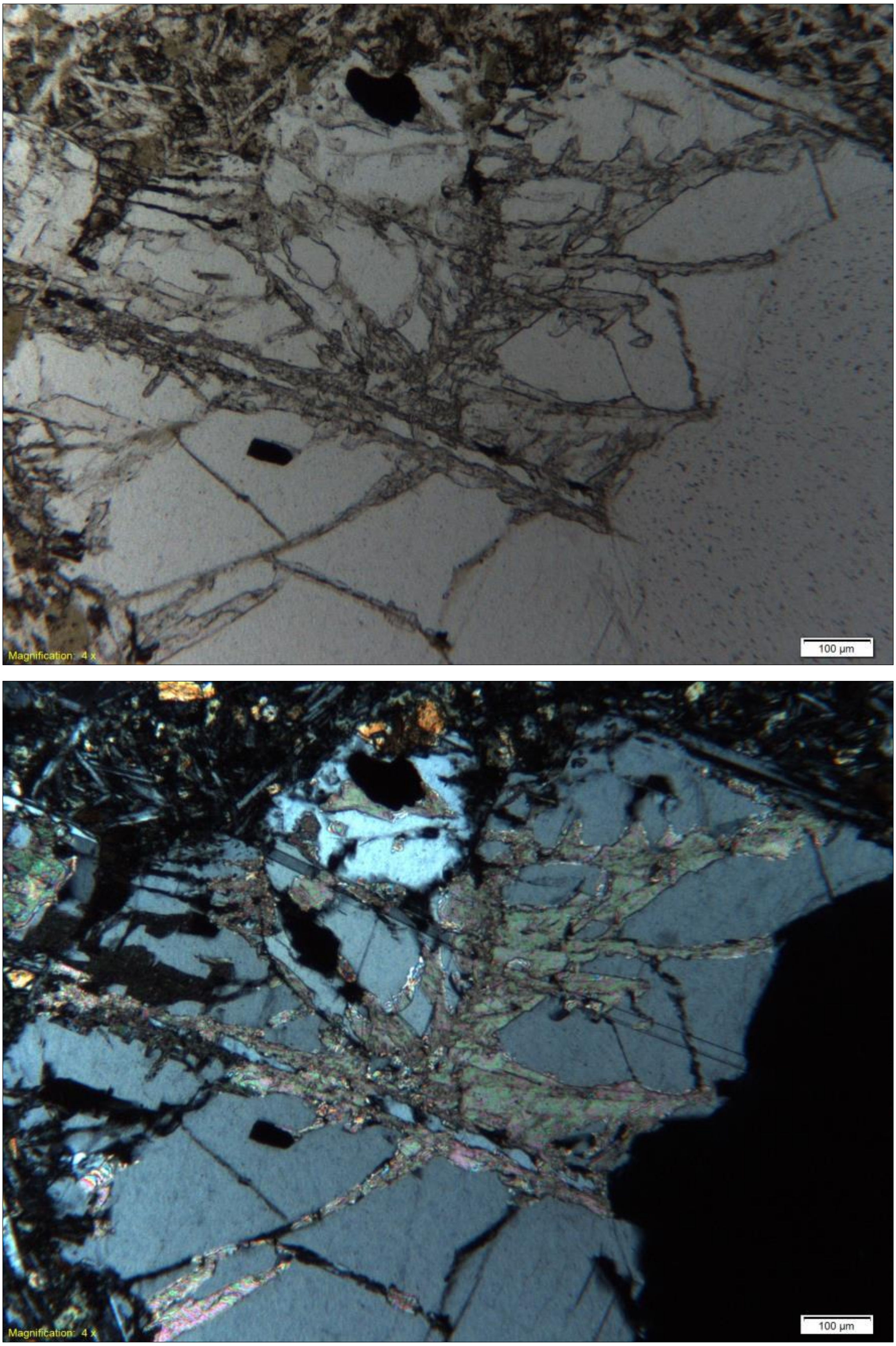


Figure 27. *Intense calcite alteration of a plagioclase phenocryst. Well ÞG-6, 558 m.*

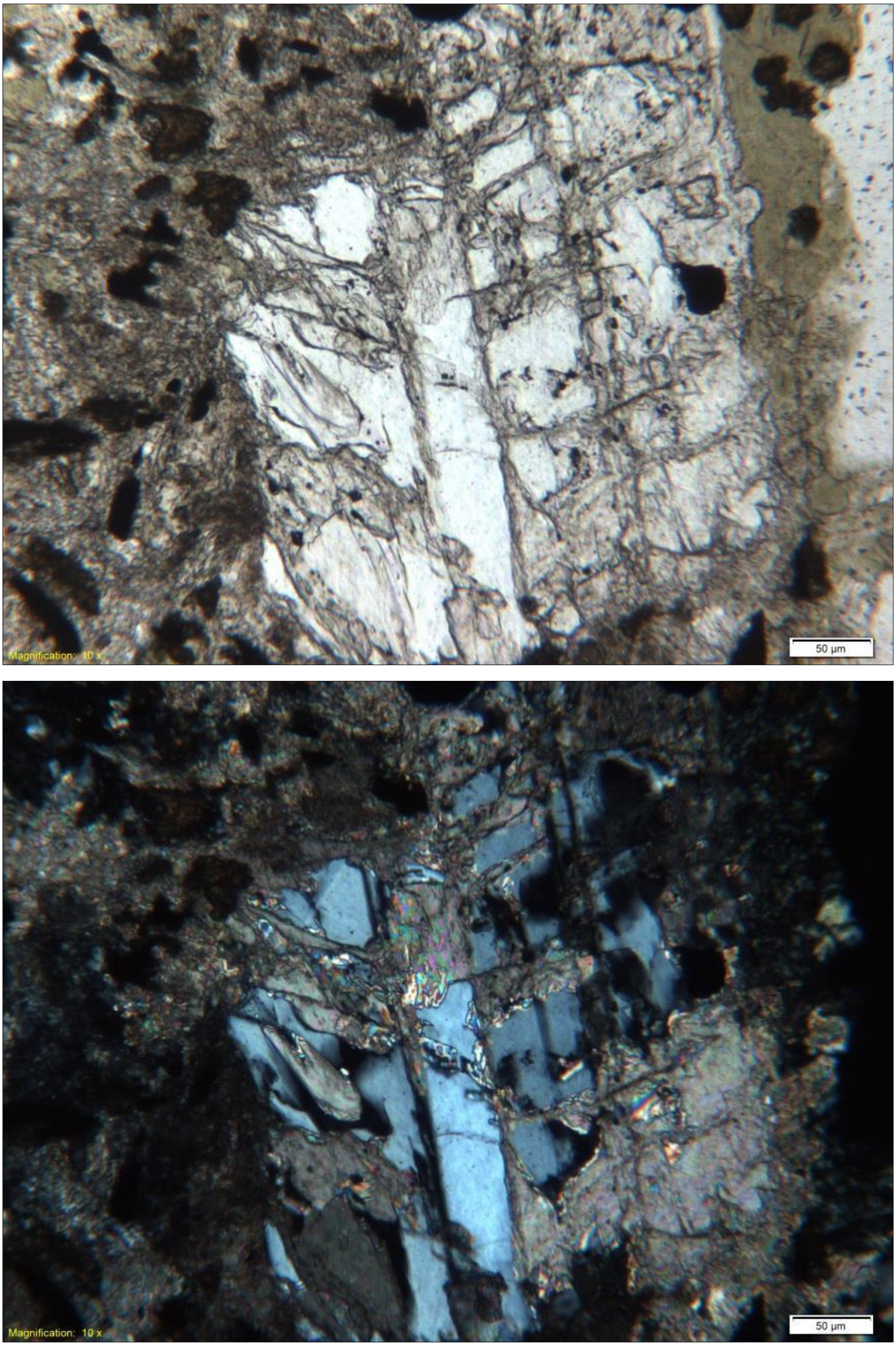


Figure 28. *Intense calcite alteration of plagioclase. Also note widespread calcite formation in groundmass. Well ÞG-7, 1096 m.*

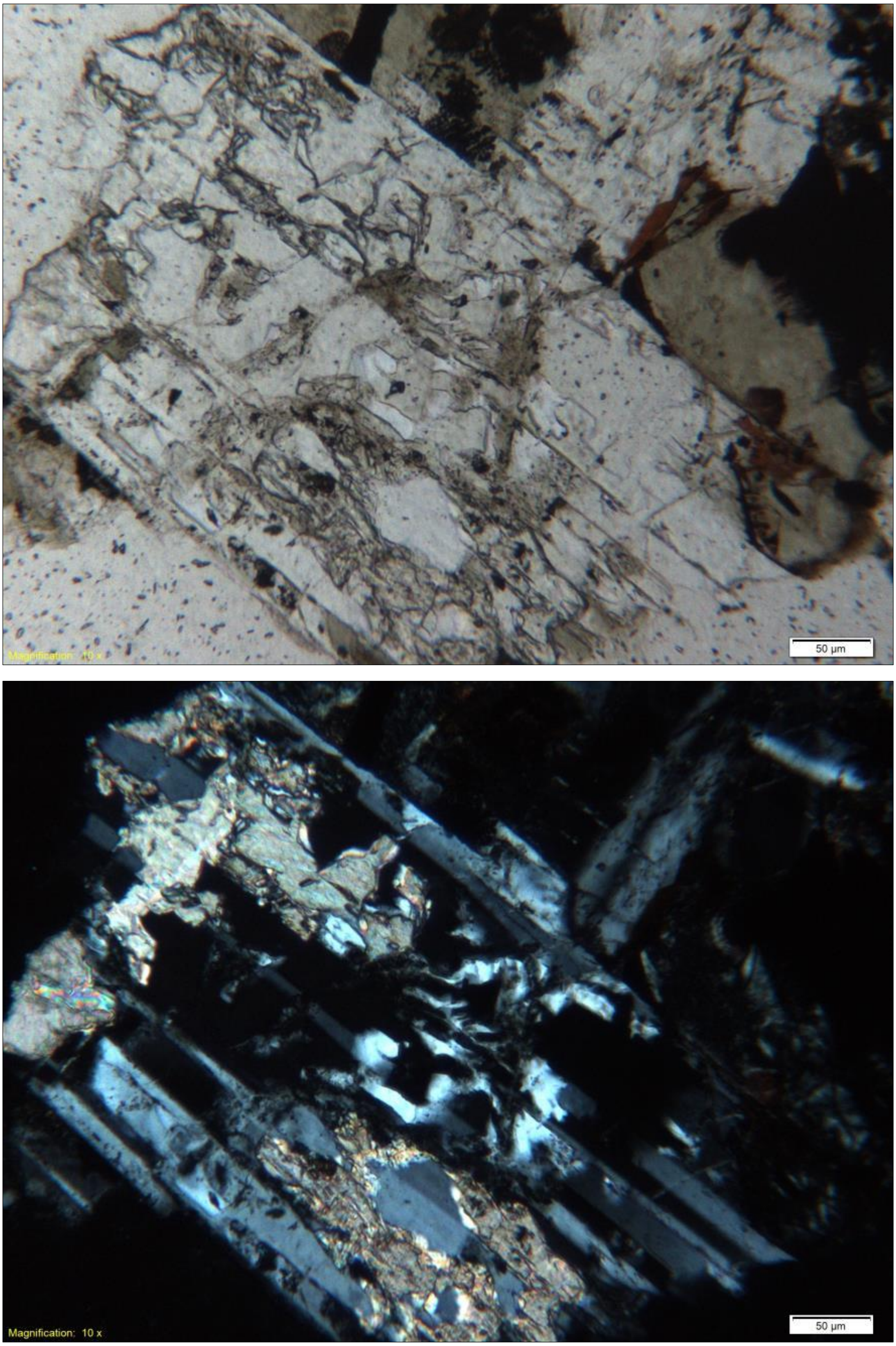


Figure 29. *Plagioclase phenocryst with significant alteration to calcite, chlorite and albite. Well ÞG-8, 524 m.*

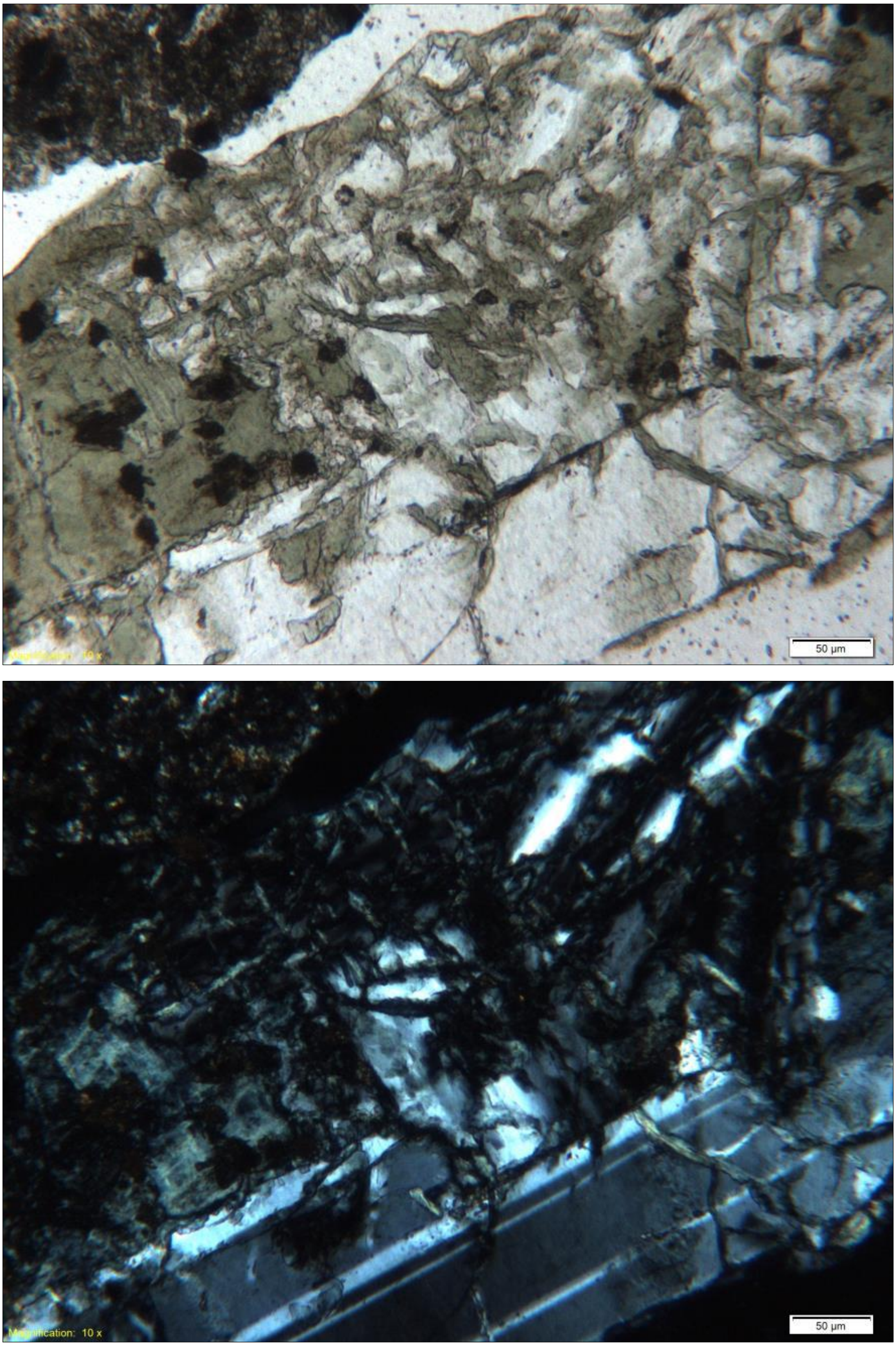


Figure 30. *Plagioclase greatly affected by actinolite and albite replacement. Well ÞG-8, 2022 m.*

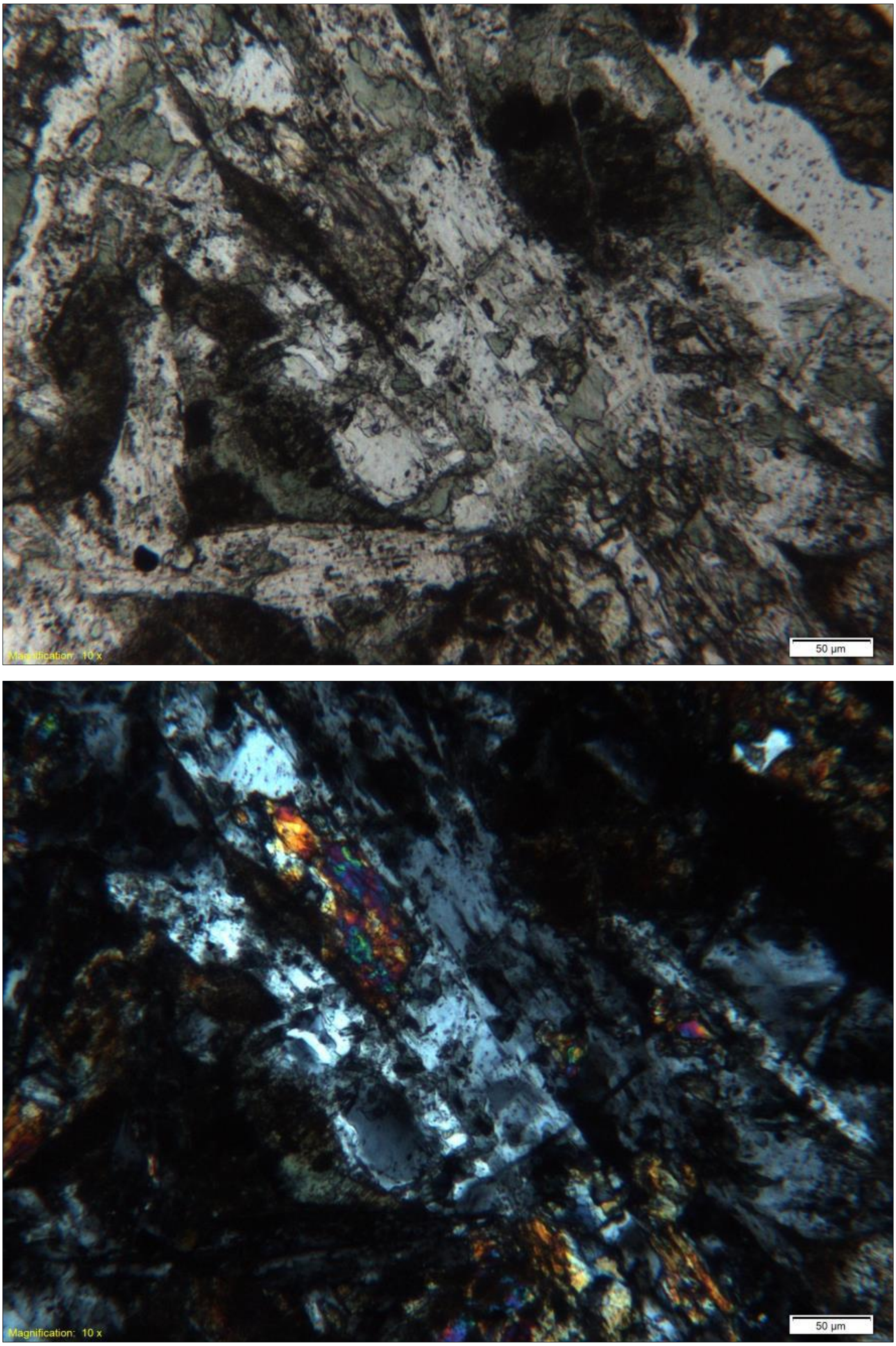


Figure 31. *Heavily altered basalt. Plagioclase is largely replaced by albite, epidote, titanite and actinolite. Well ÞG-8, 2420 m.*

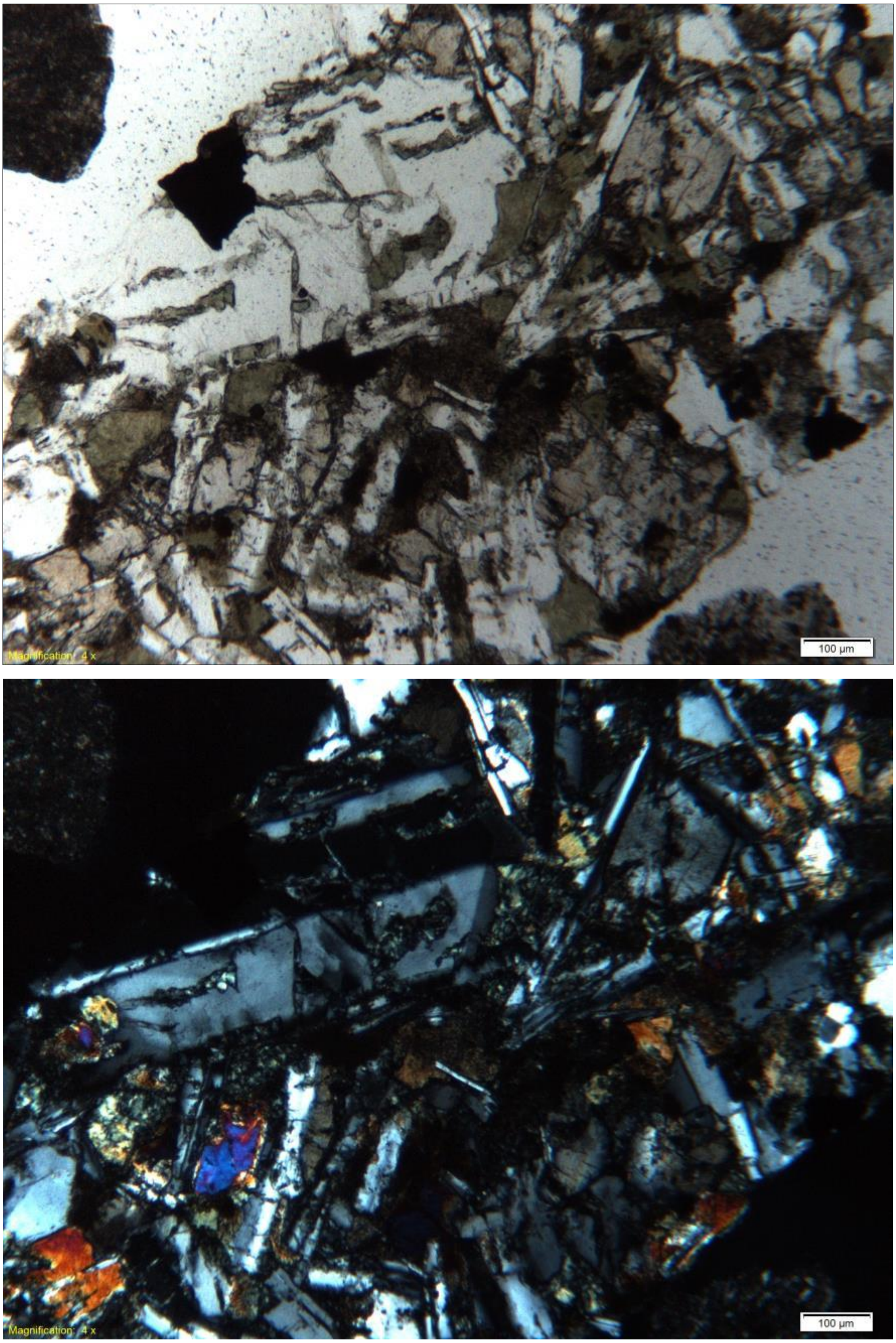


Figure 32. *Altered basalt with plagioclase being partly replaced by actinolite and albite, and clinopyroxene starting to be affected by actinolite formation. Fe-Ti oxides appear nearly unaffected. Well ÞG-7, 1410 m.*

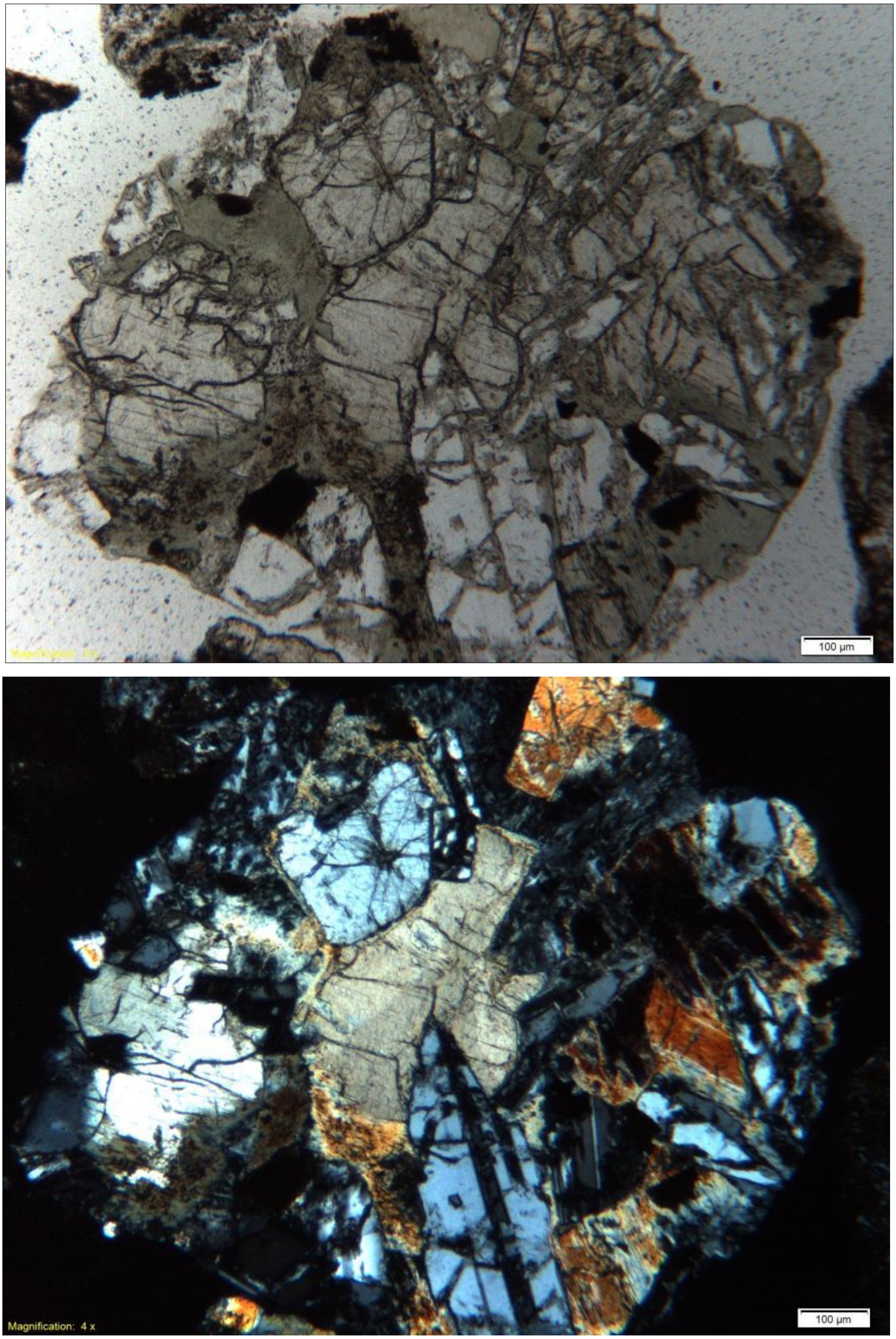


Figure 33. *Basalt grain showing subophitic texture. Plagioclase laths are partially replaced by actinolite and albite, but clinopyroxene shows early stages of uralite formation. Fe-Ti oxides appear little affected by alteration. Well ÞG-7, 1672 m.*

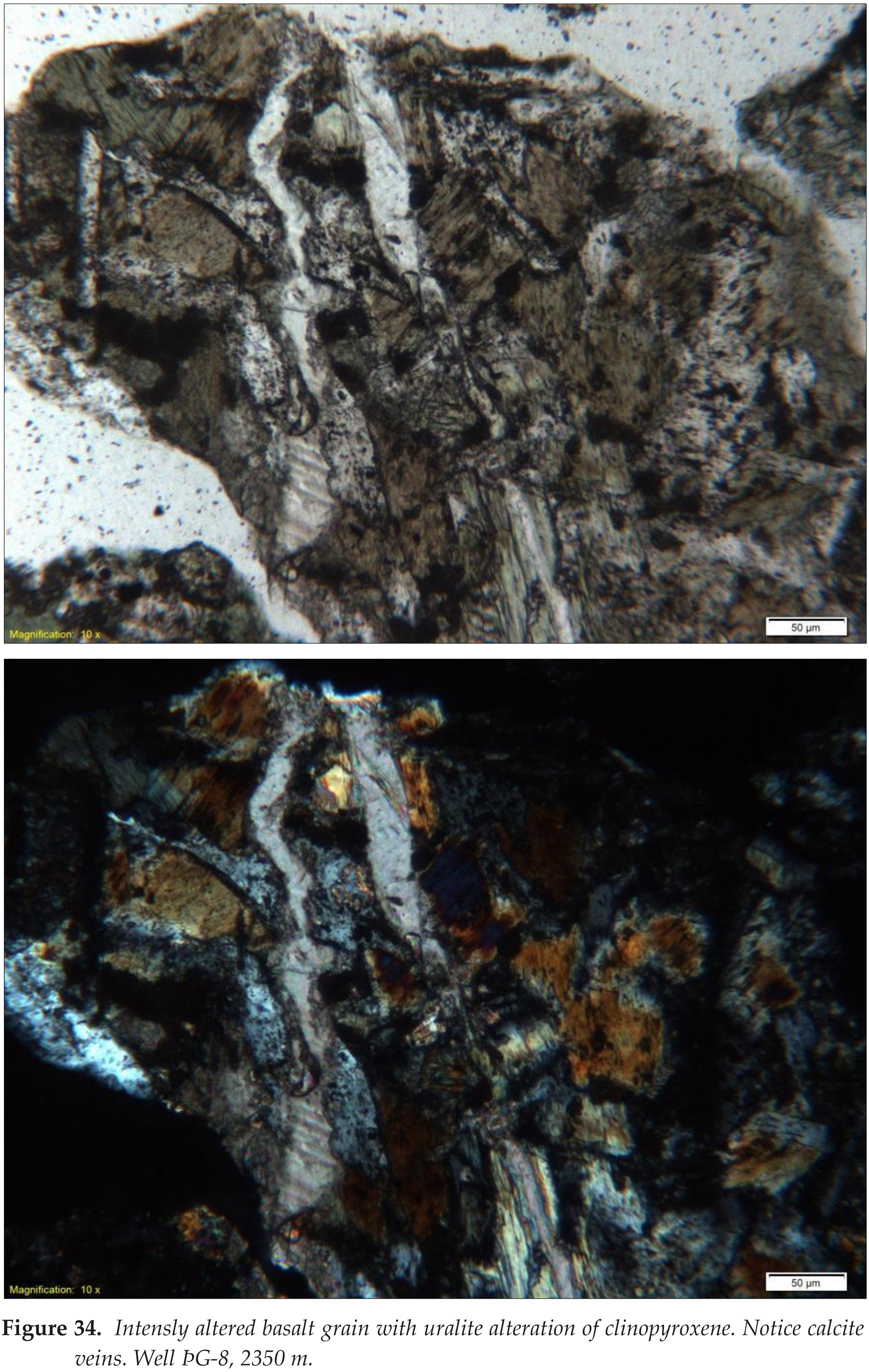


Figure 34. *Intensly altered basalt grain with uralite alteration of clinopyroxene. Notice calcite veins. Well ÞG-8, 2350 m.*

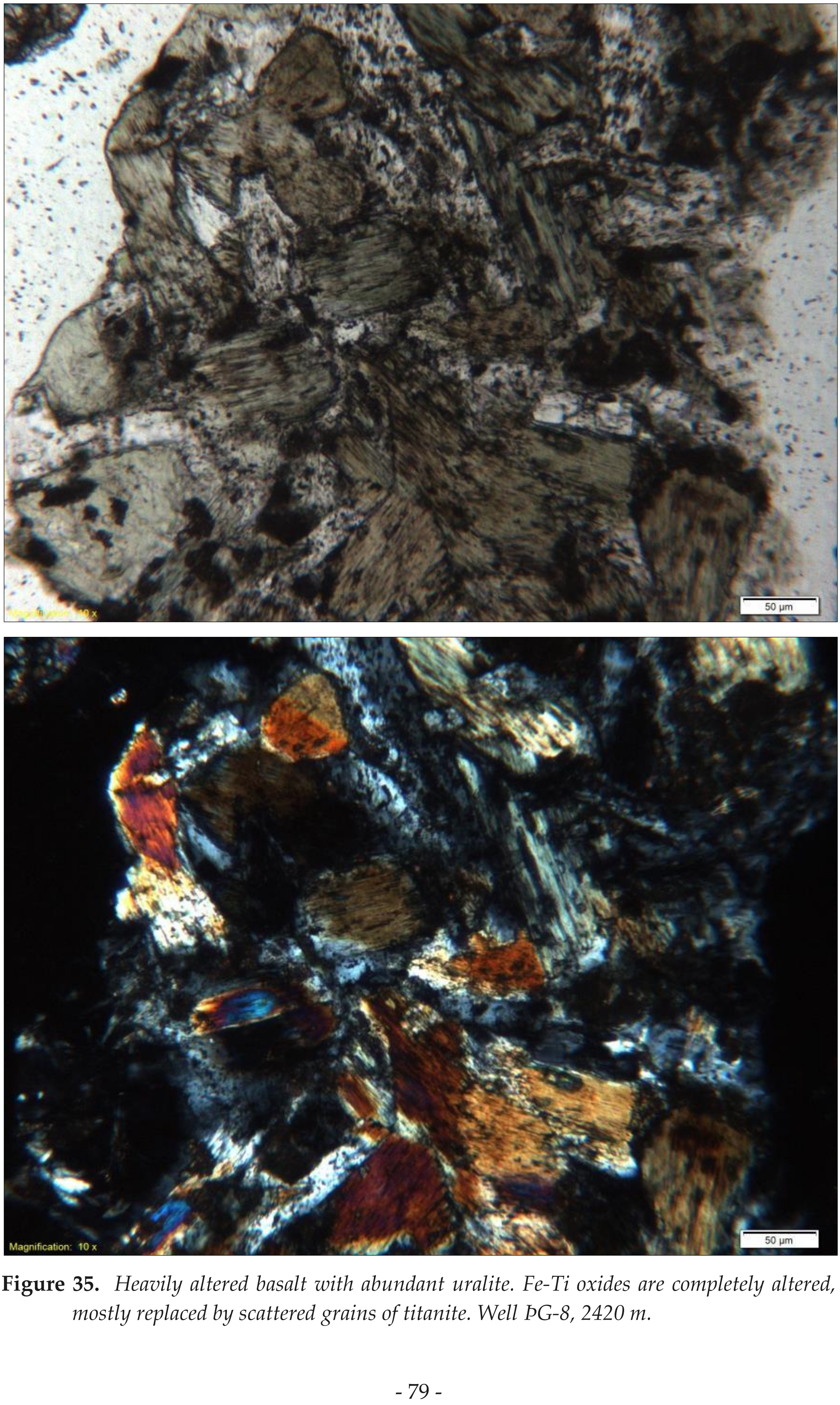


Figure 35. *Heavily altered basalt with abundant uralite. Fe-Ti oxides are completely altered, mostly replaced by scattered grains of titanite. Well ÞG-8, 2420 m.*

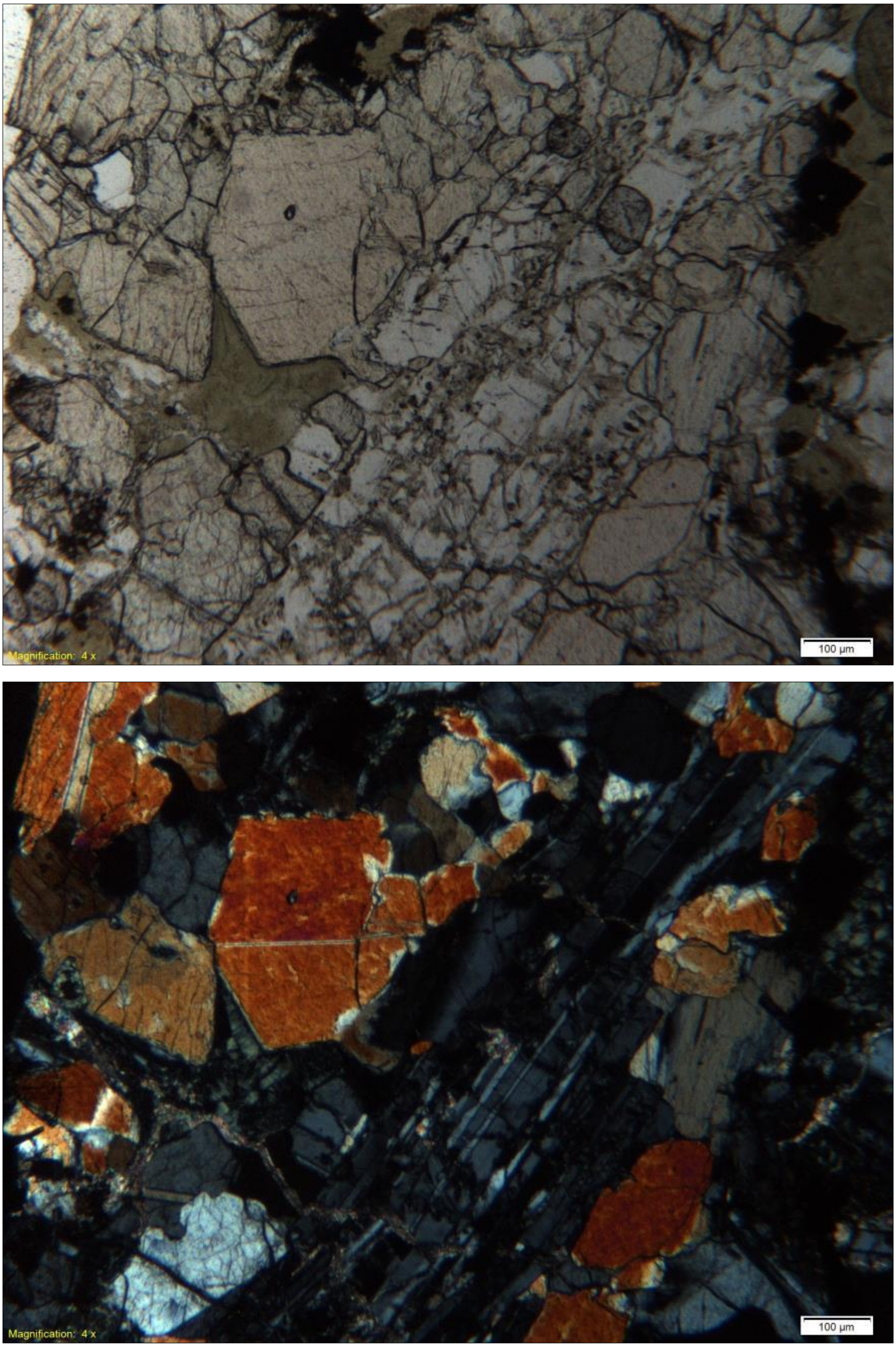


Figure 36. *Moderately altered fine-grained basalt. Plagioclase is partly replaced by clay and albite whereas clinopyroxene and Fe-Ti oxides have only suffered minor alteration. Well ÞG-6, 640 m.*

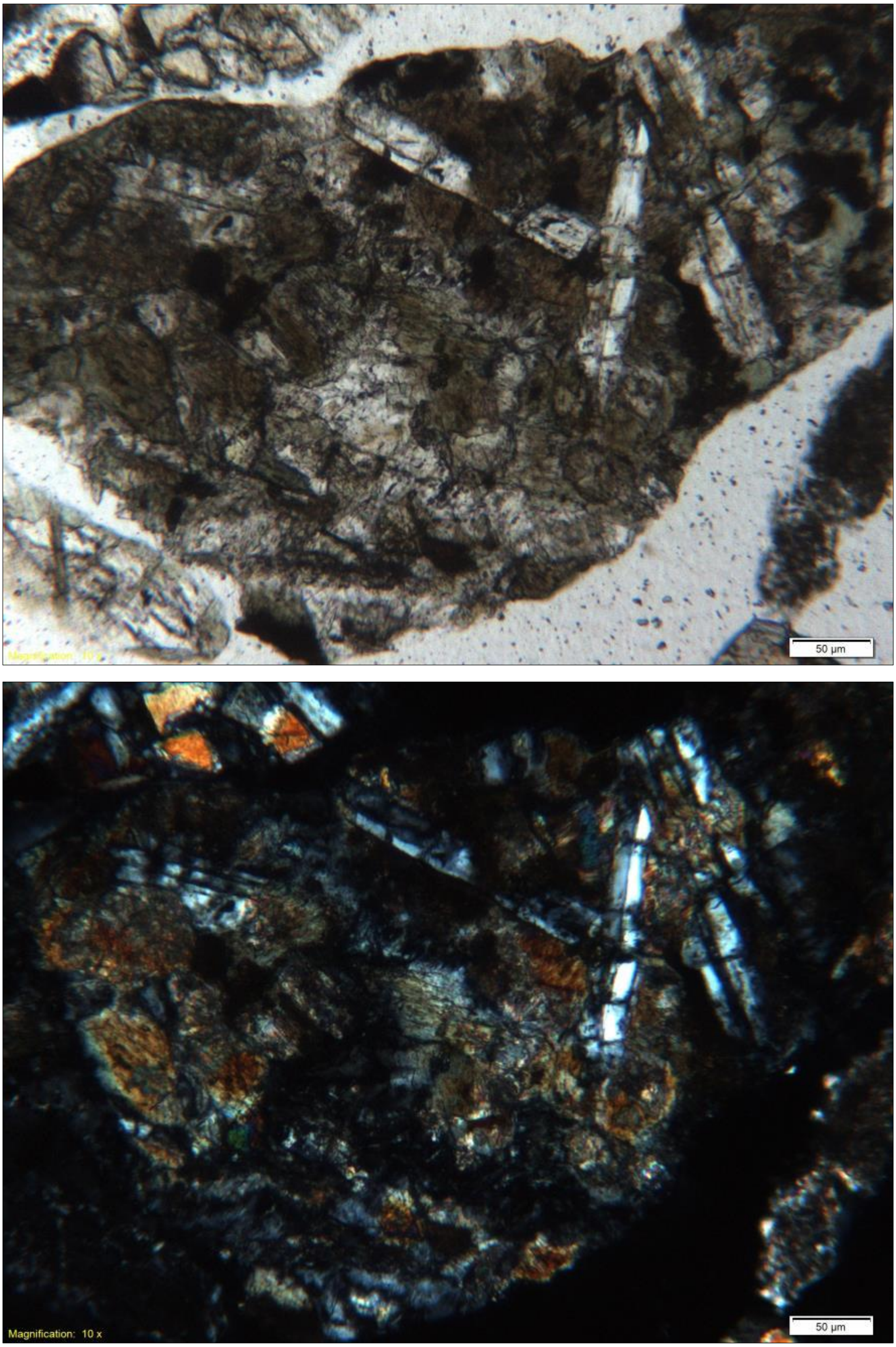


Figure 37. *Significantly altered grain of basalt. Plagioclase contains albite and actinolite and clinopyroxene is mostly altered to actinolite. Fe-Ti oxides appear to be largely replaced by titanite. Well ÞG-8, 2300 m.*

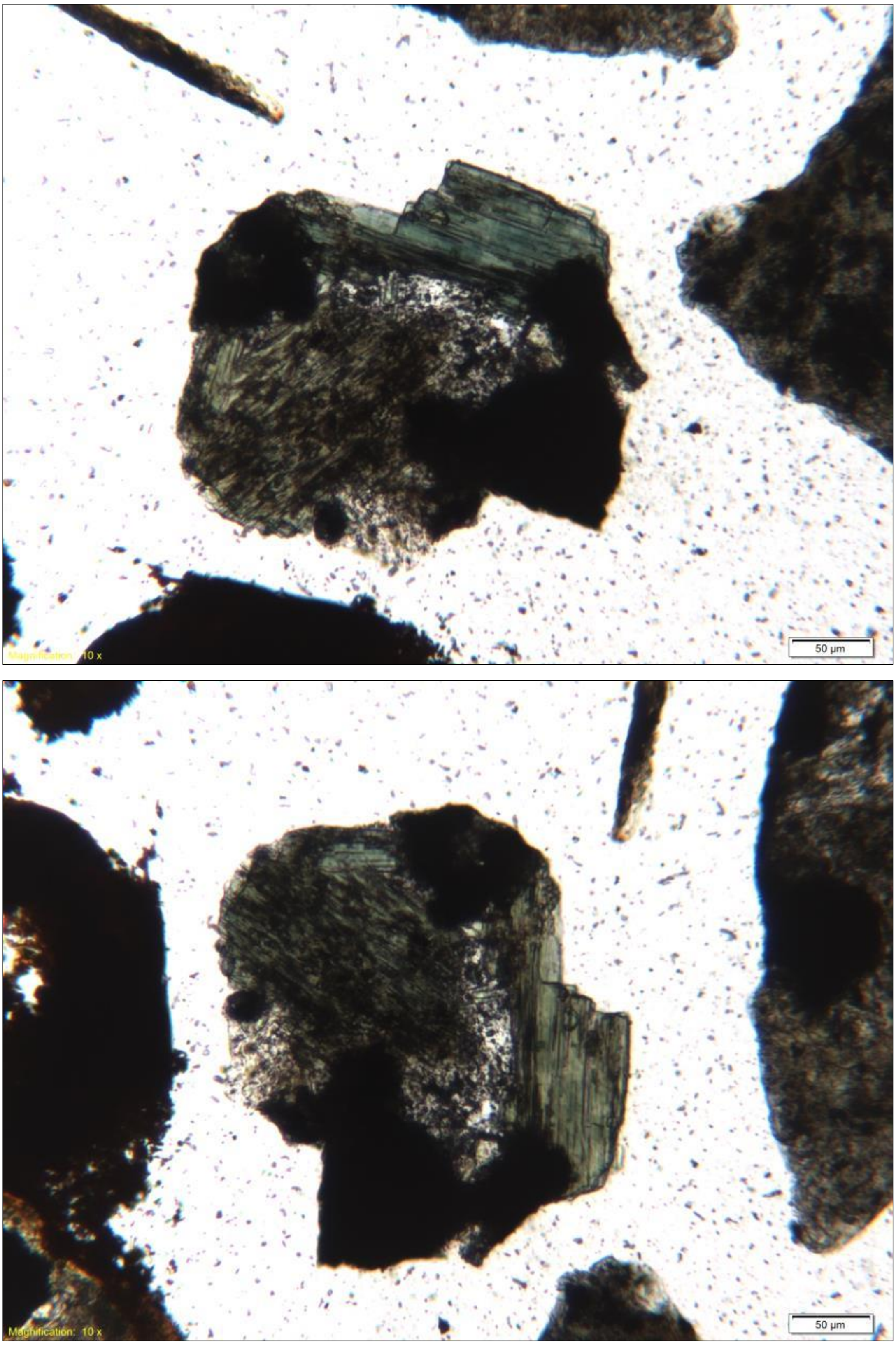


Figure 38. *In the middle, an extensively altered basalt grain with a hornblende crystal (on top and right hand side of grain in the upper and lower figures, respectively). Plane-polarized light in both cases, but sample has been rotated to reveal pleochroism of the hornblende. Well ÞG-3, 2542 m.*

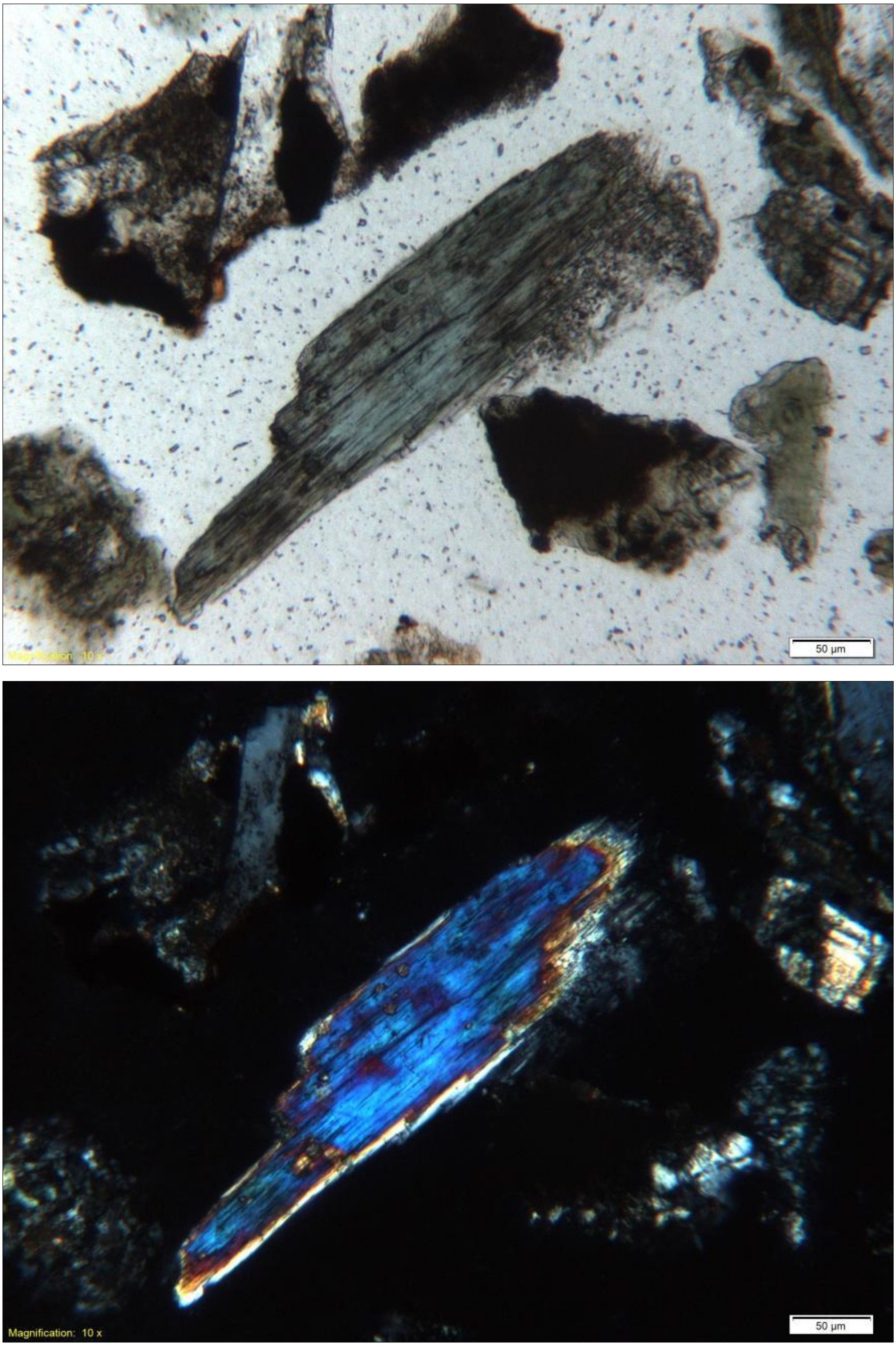


Figure 39. *Hornblende crystal in the middle of the photograph. Well ÞG-6, 2350 m.*

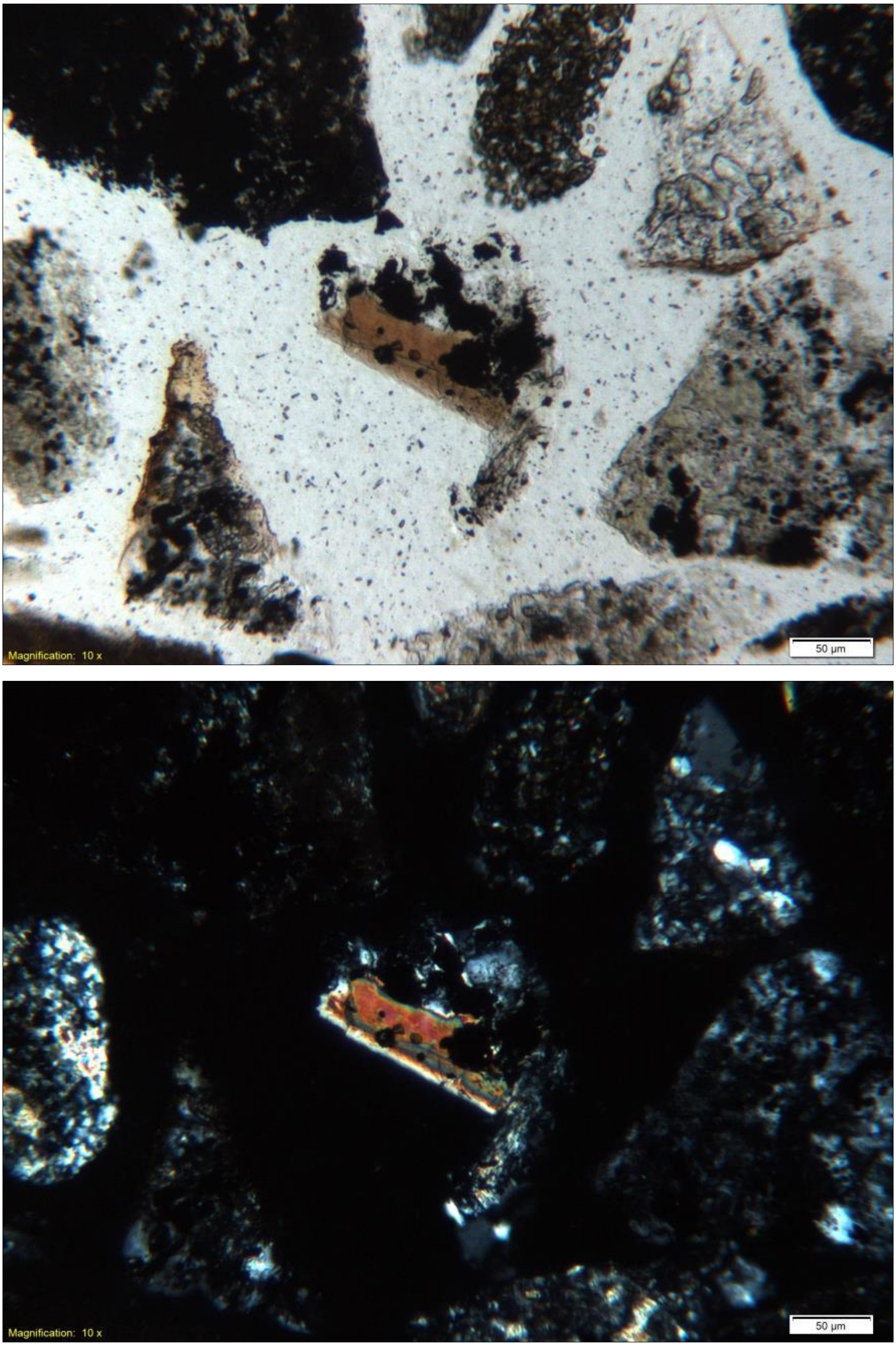


Figure 40. *Biotite (brown grain in the centere) in a sample of rhyolite. Well ÞG-6, 2700 m.*

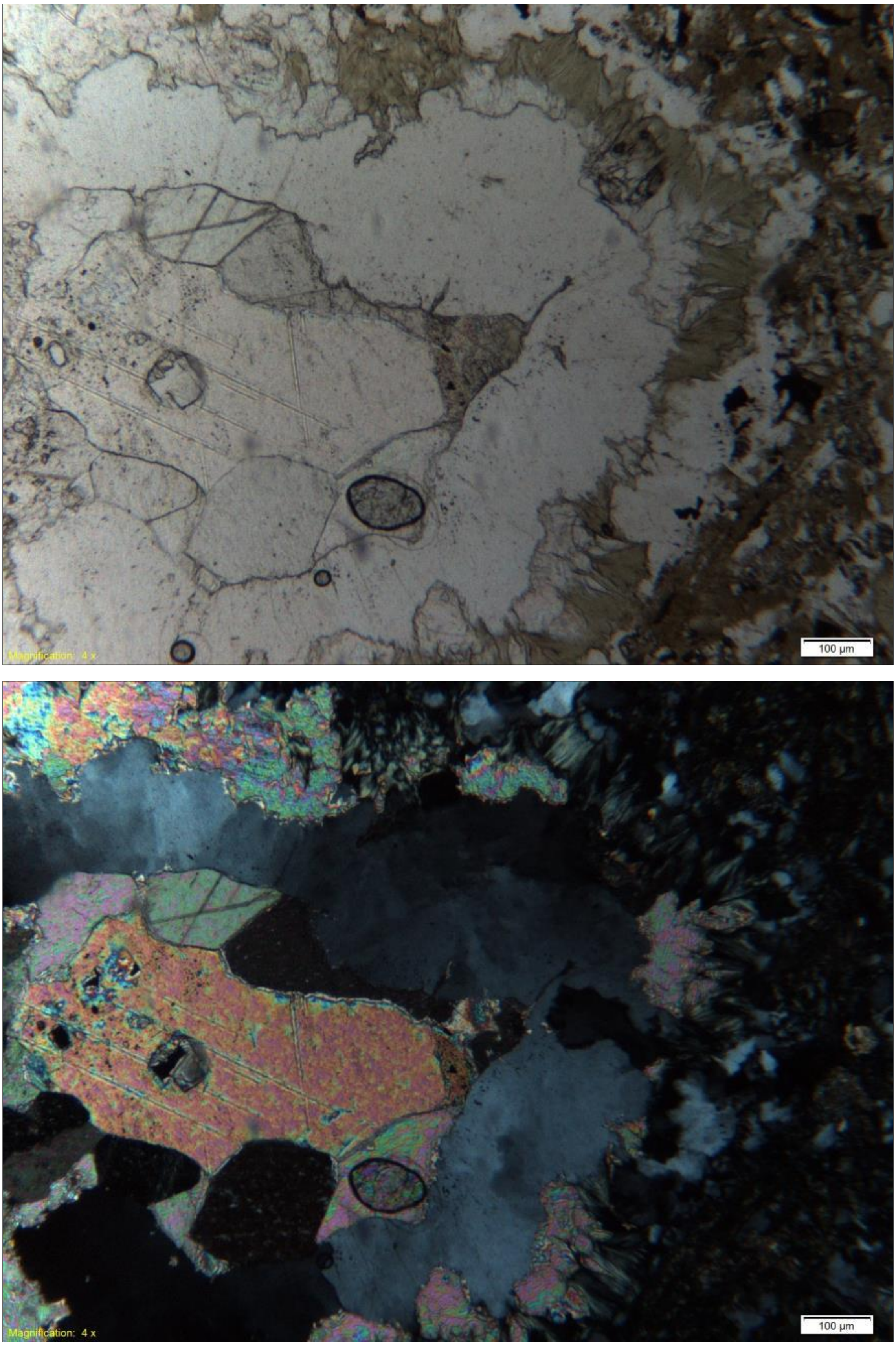


Figure 41. *Calcite, quartz and mixed-layer clay filling a vesicle. Well ÞG-6, 130 m.*

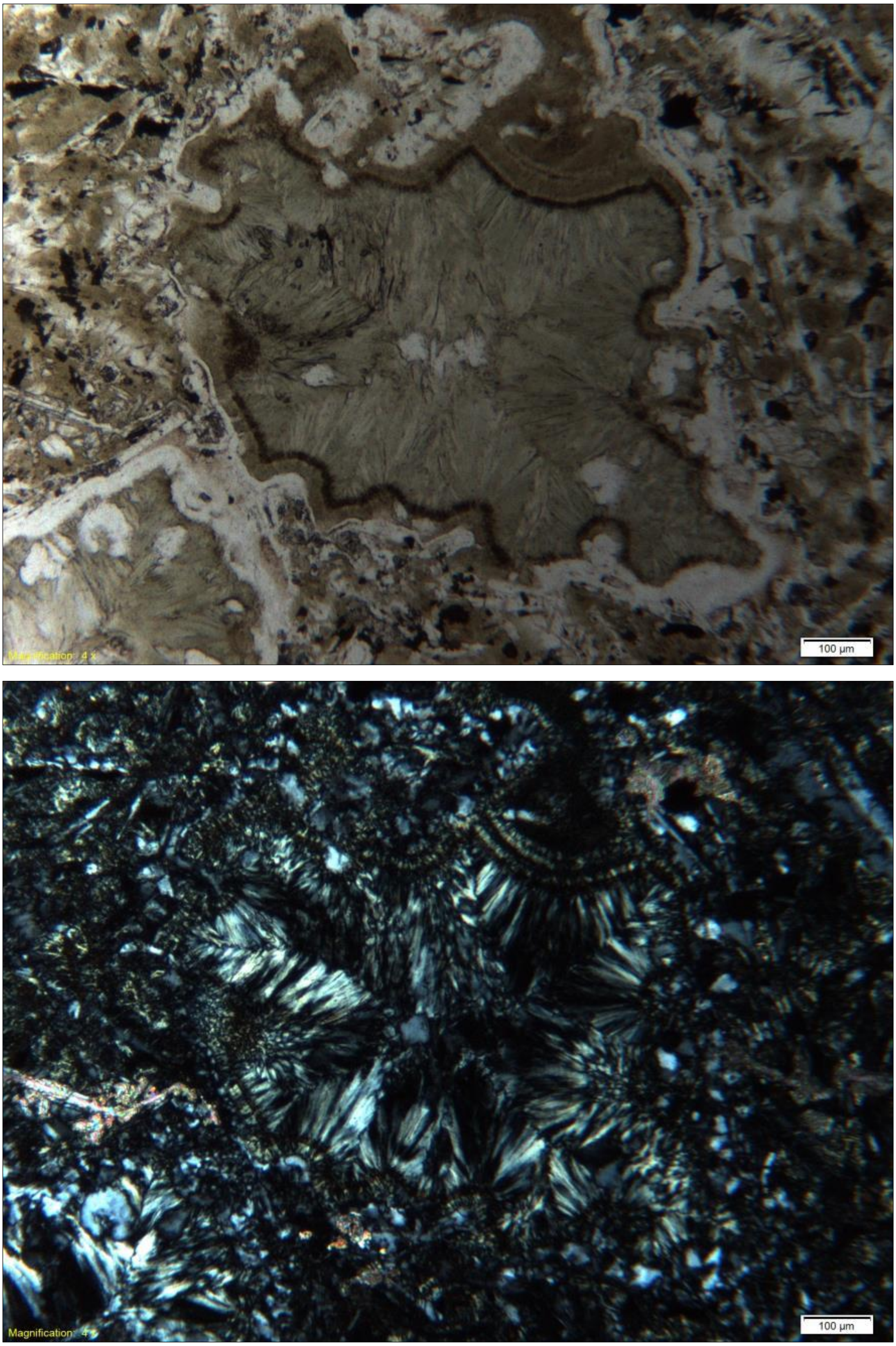


Figure 42. *Mixed-layer clay filling a vesicle. Well ÞG-6, 130 m.*

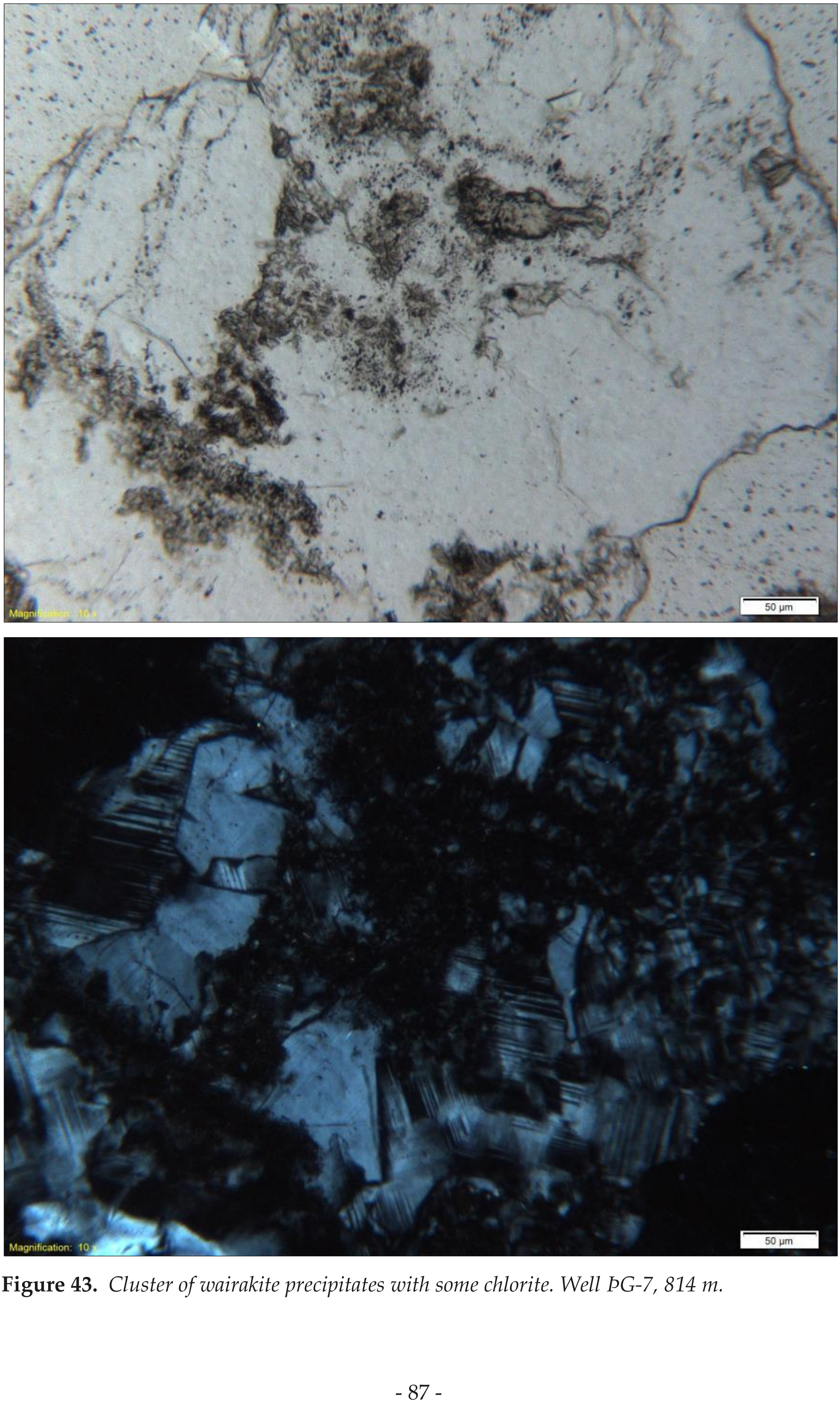


Figure 43. *Cluster of wairakite precipitates with some chlorite. Well ÞG-7, 814 m.*

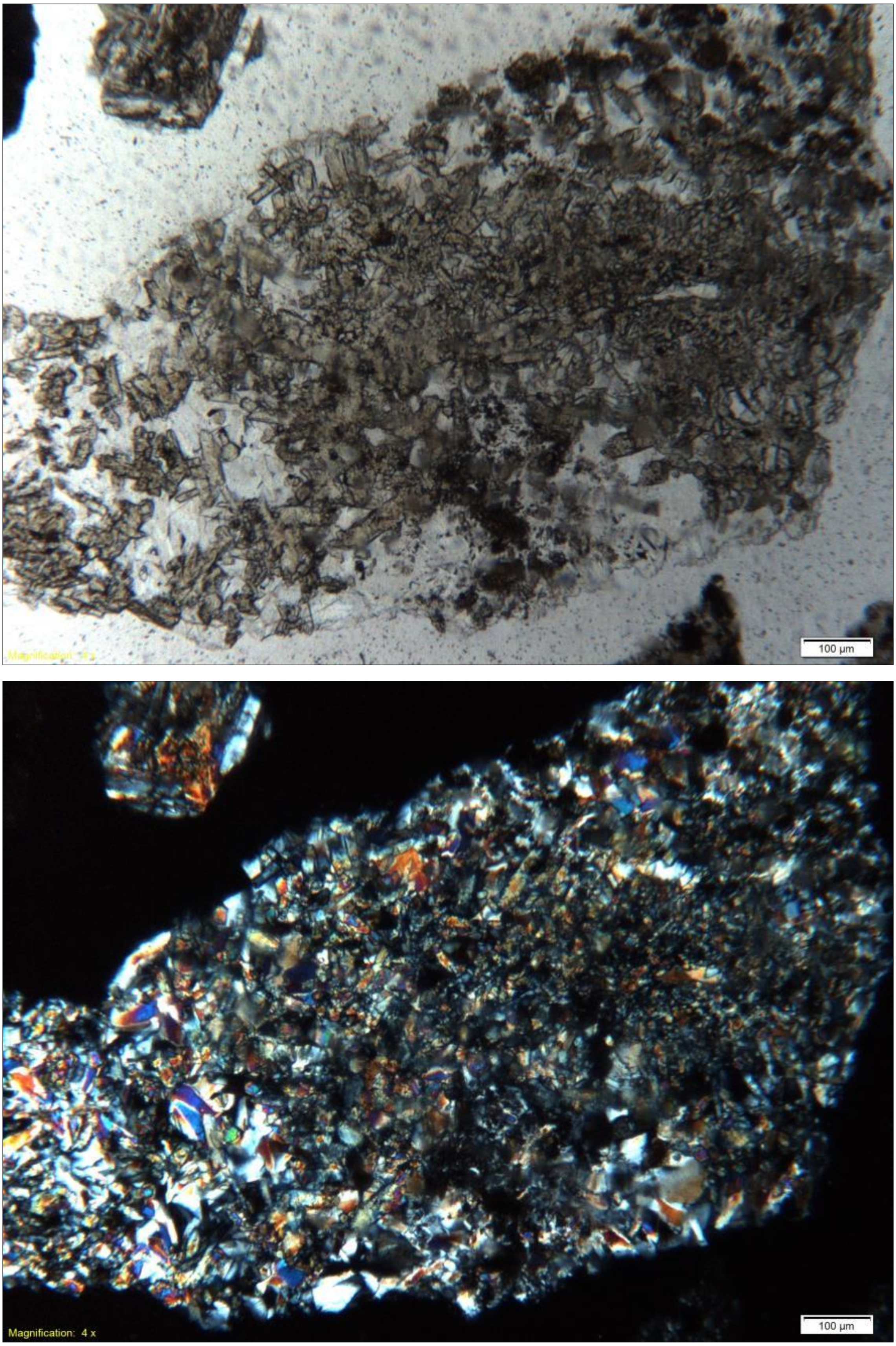


Figure 44. *Precipitates composed of a mixture of epidote and wairakite. Well ÞG-7, 1986 m.*

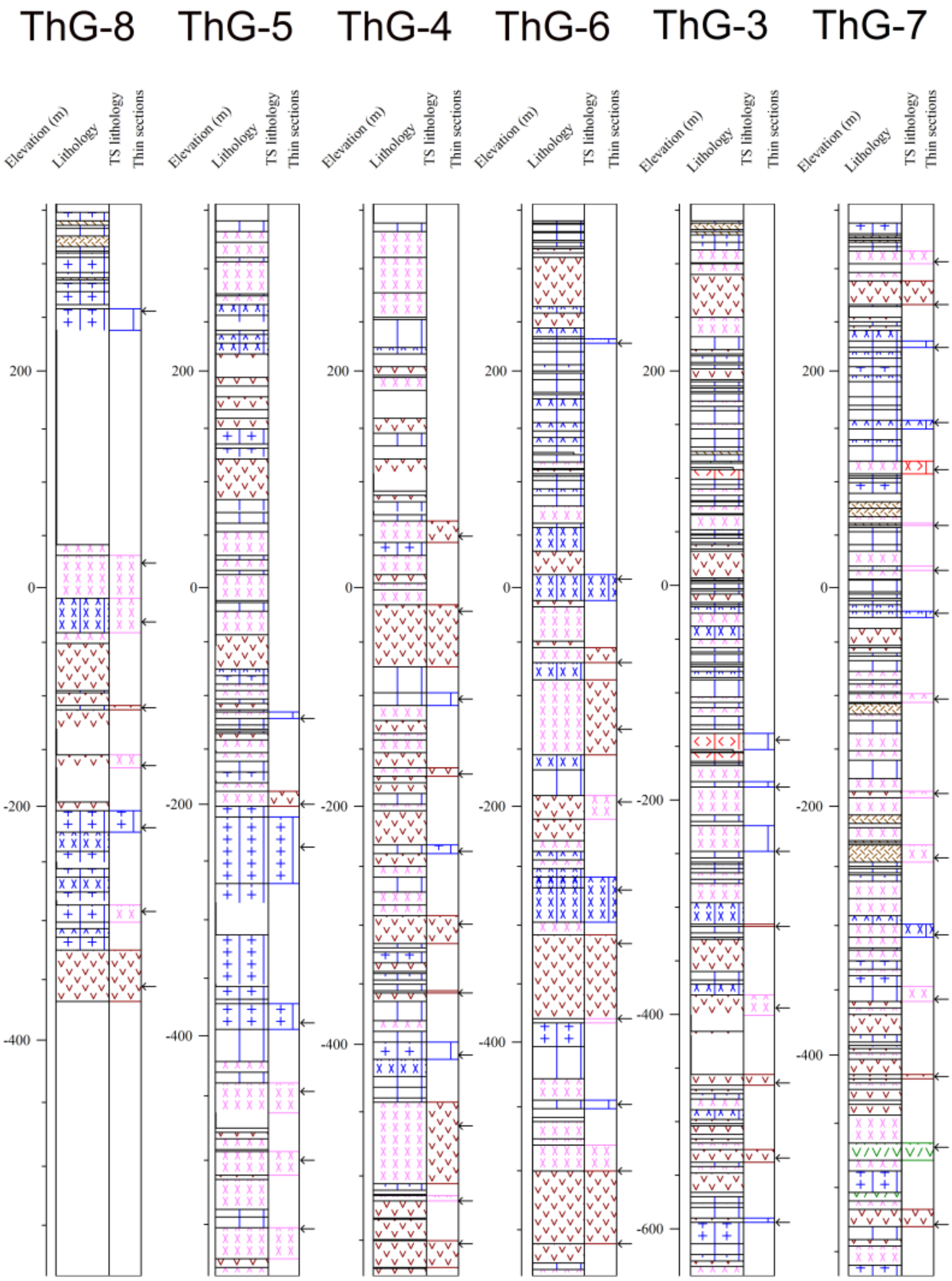


Figure 45. *Comparison of lithology from logging of cuttings and as determined in thin sections in all the wells, 0–1000 m MD. The arrows indicate the depth of thin section samples. The boundaries used for formations determined in thin section are the same as determined by logging. The depth scales show elevation relative to sea level.*

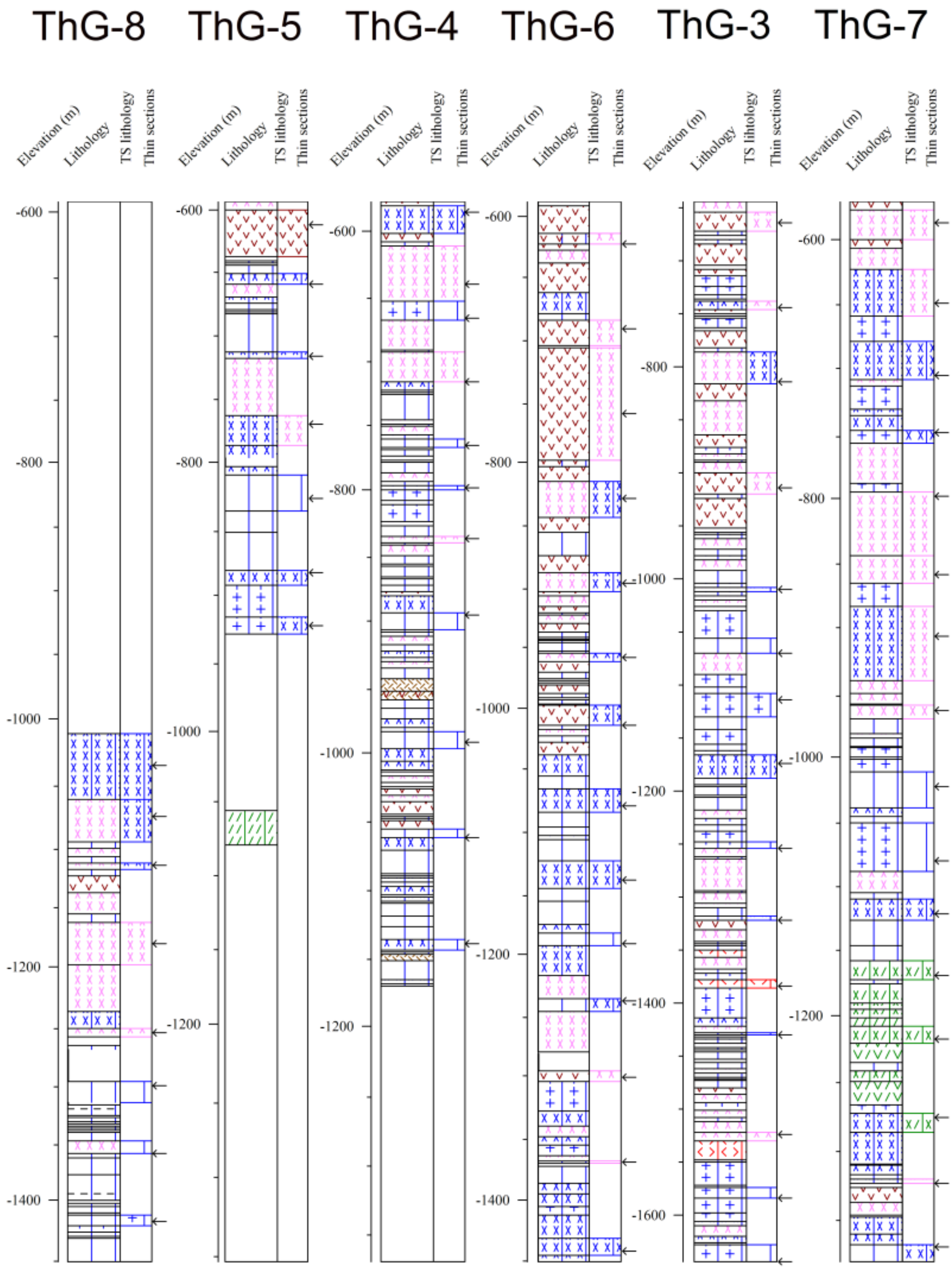


Figure 46. *Comparison of lithology from logging of cuttings and as determined in thin sections in all the wells, 1000–2000 m MD. The arrows indicate the depth of thin section samples. The boundaries used for formations determined in thin section are the same as determined by logging. The depth scales show elevation relative to sea level.*

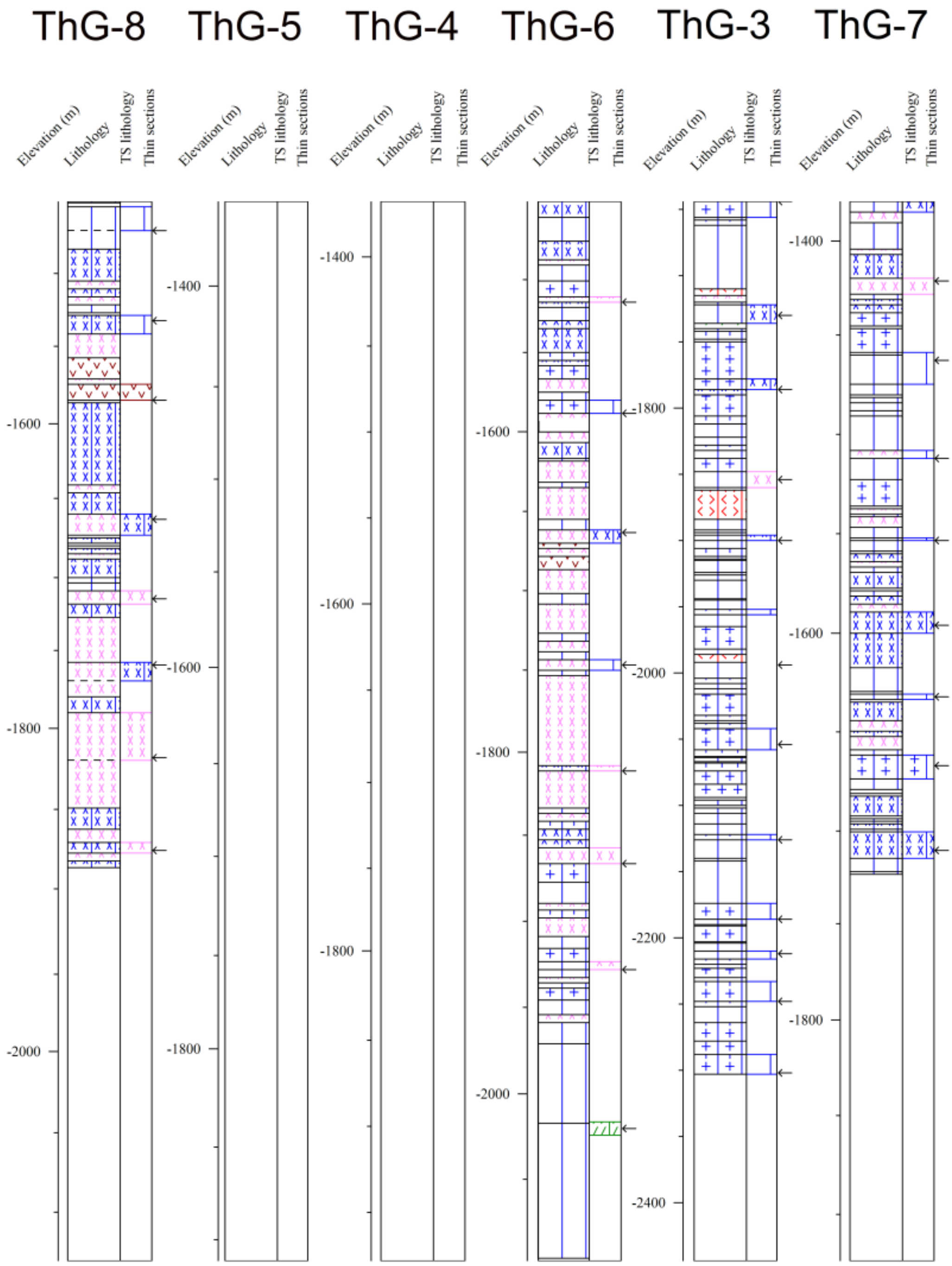


Figure 47. *Comparison of lithology from logging of cuttings and as determined in thin sections in all the wells, 2000–2800 m MD. The arrows indicate the depth of thin section samples. The boundaries used for formations determined in thin section are the same as determined by logging. The depth scales show elevation relative to sea level.*

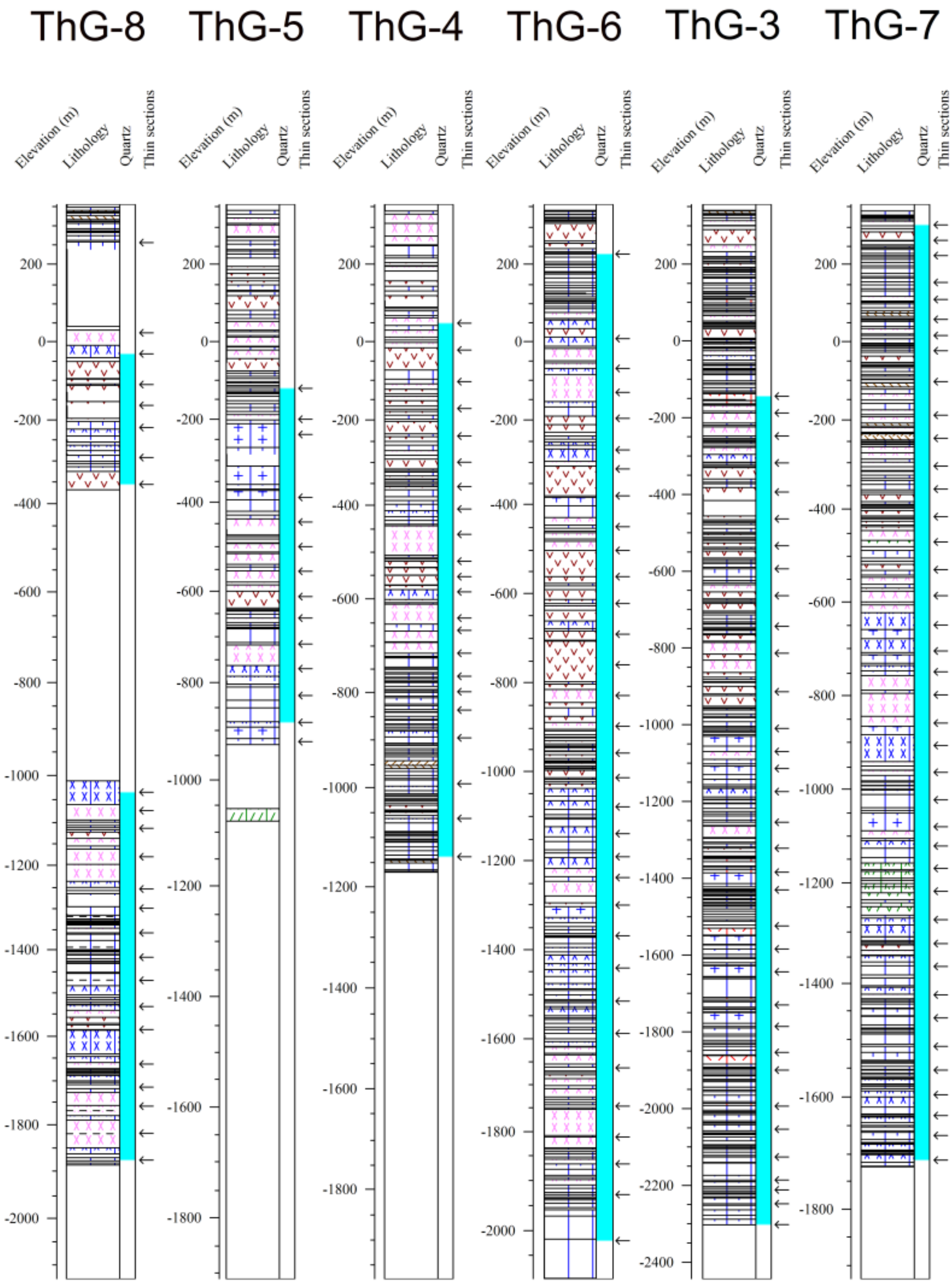


Figure 48. *Distribution of quartz shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

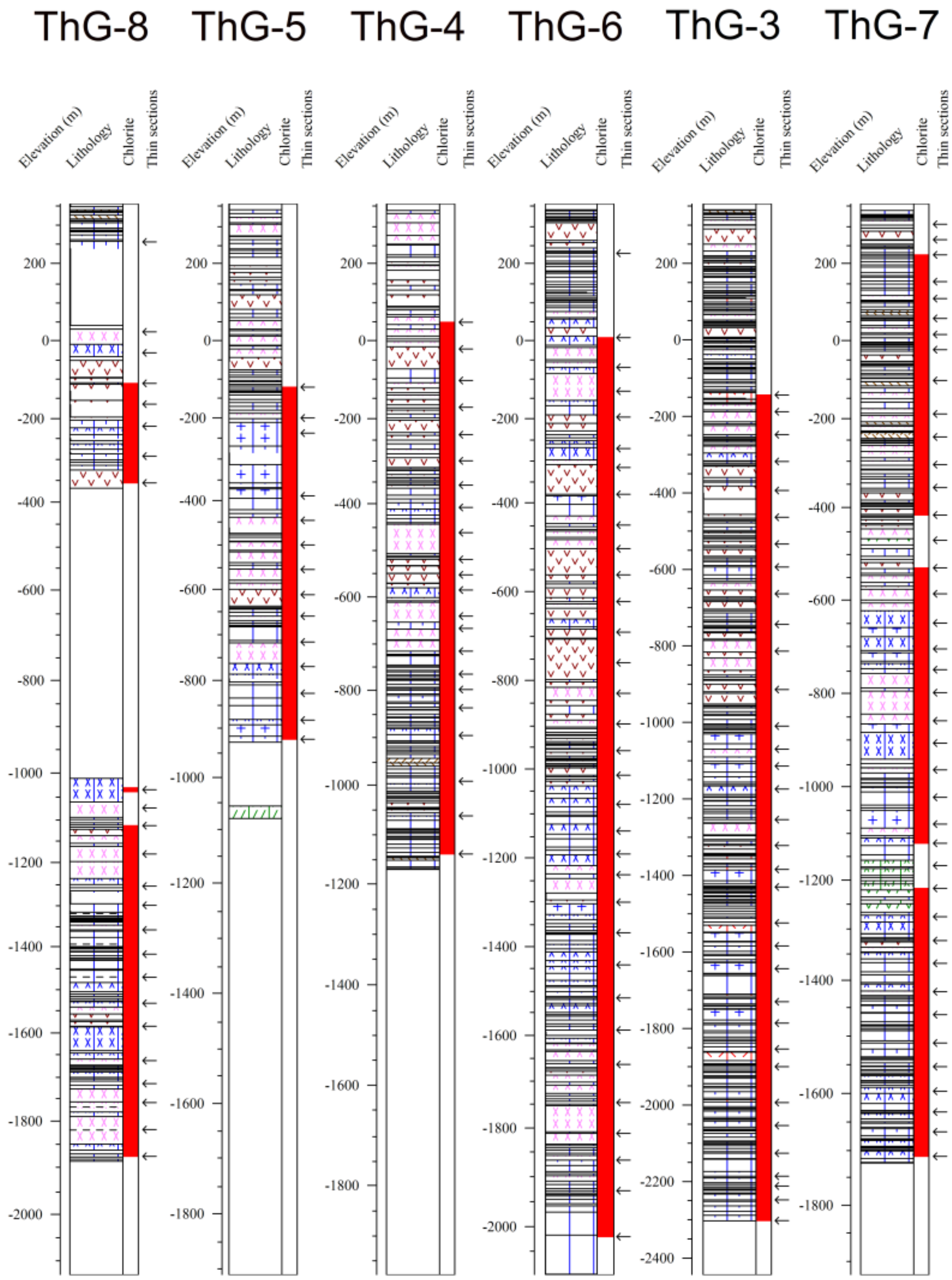


Figure 49. *Distribution of chlorite shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

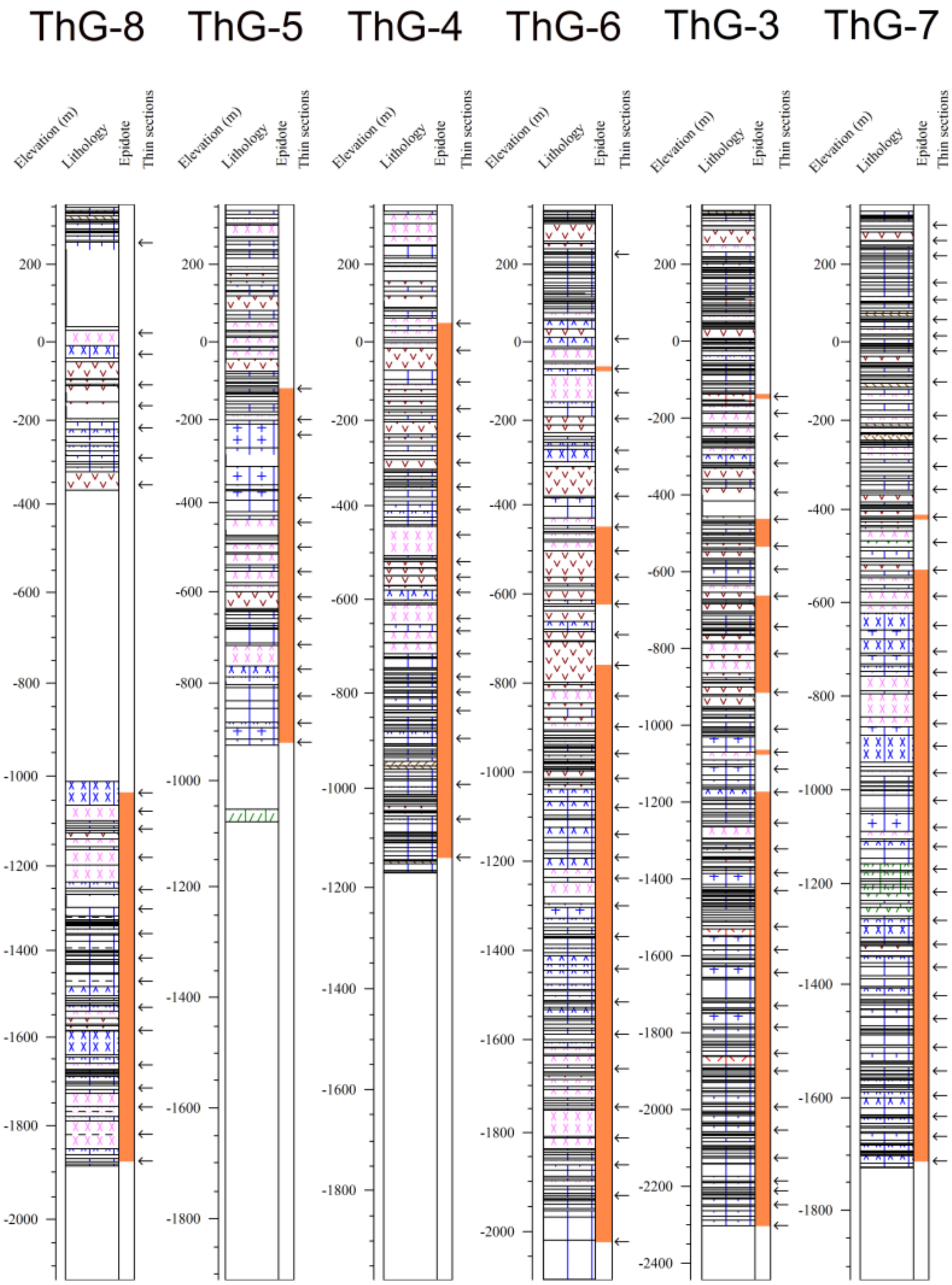


Figure 50. *Distribution of epidote shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

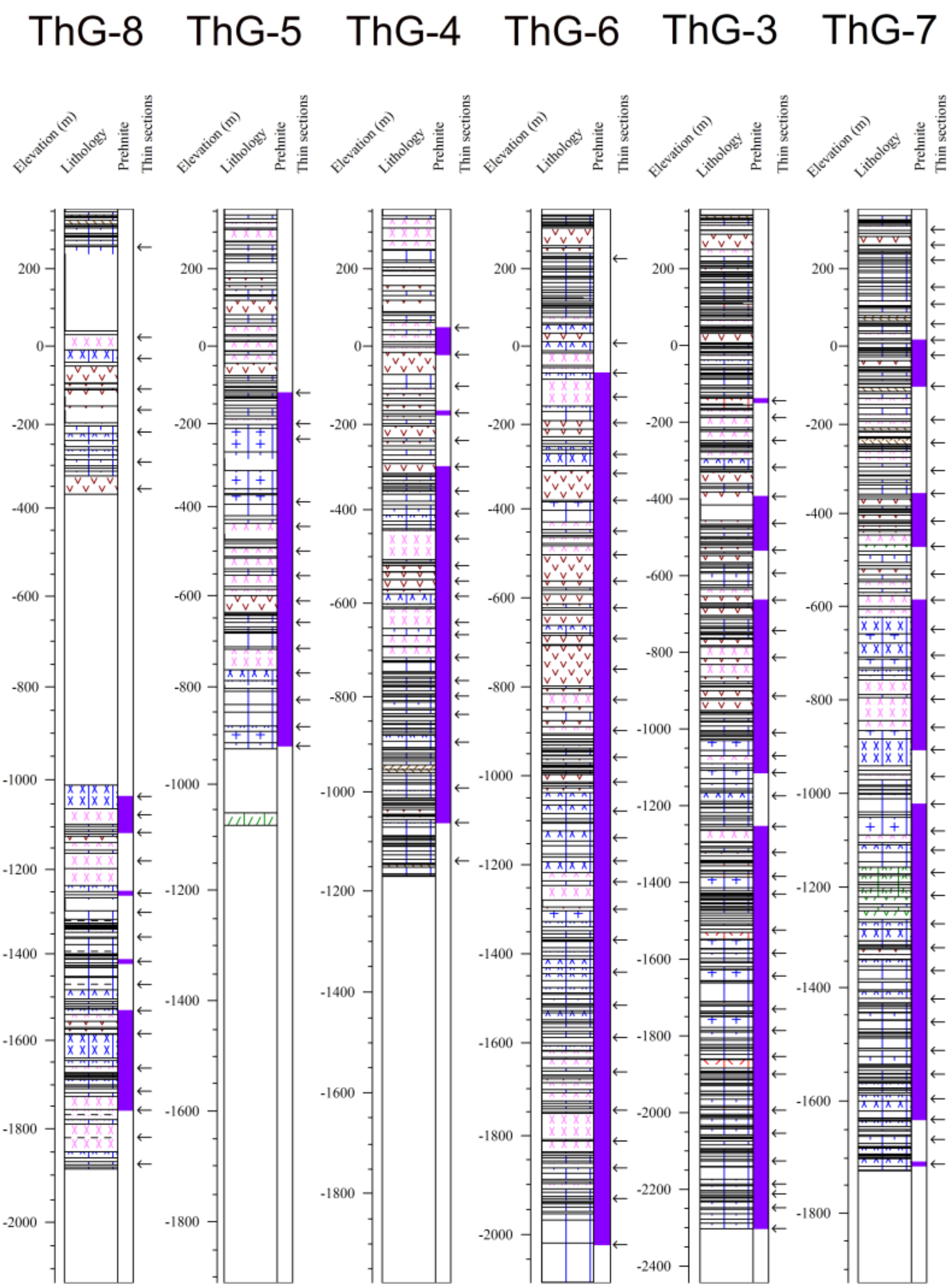


Figure 51. *Distribution of prehnite shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

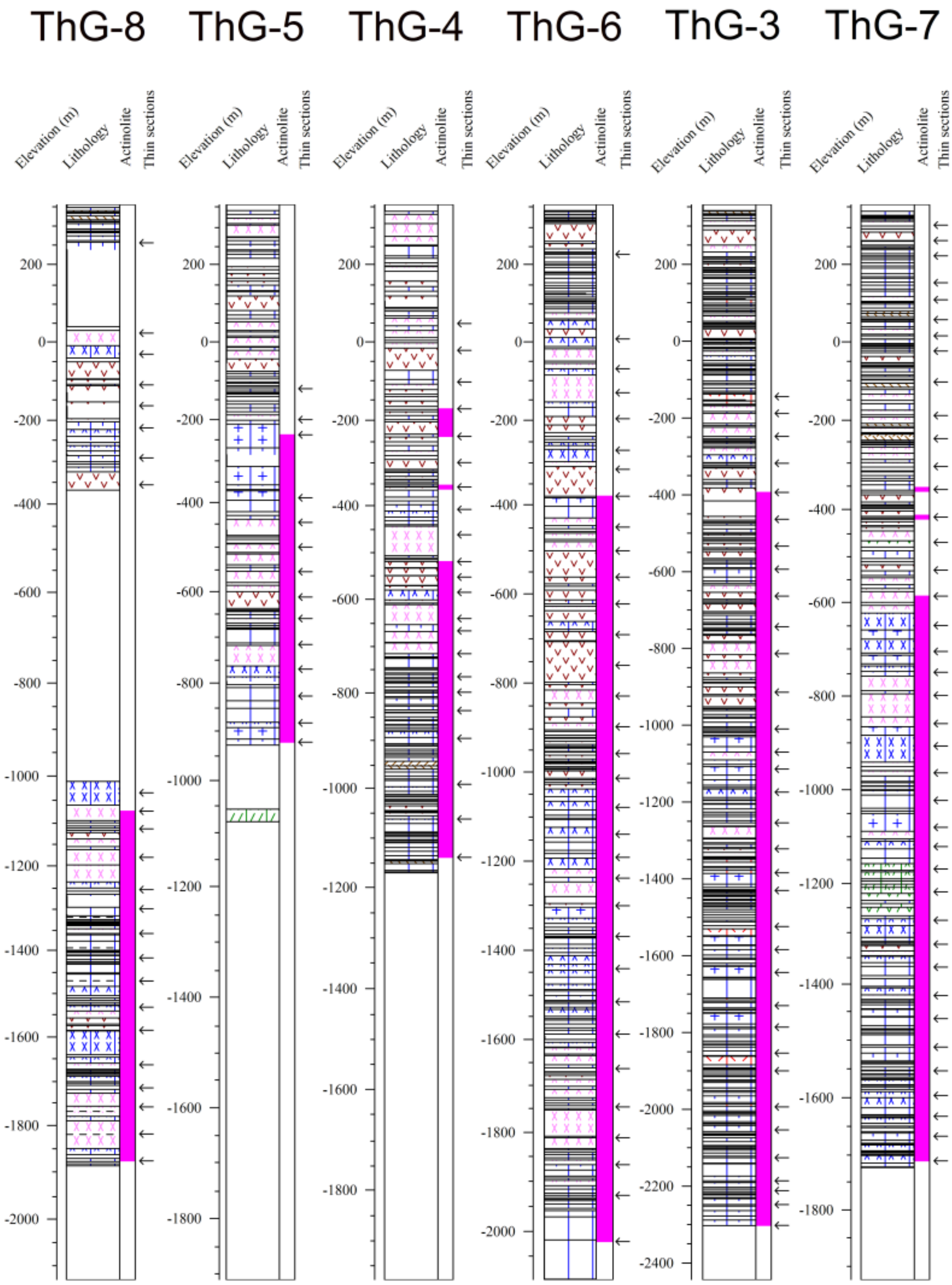


Figure 52. *Distribution of actinolite shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

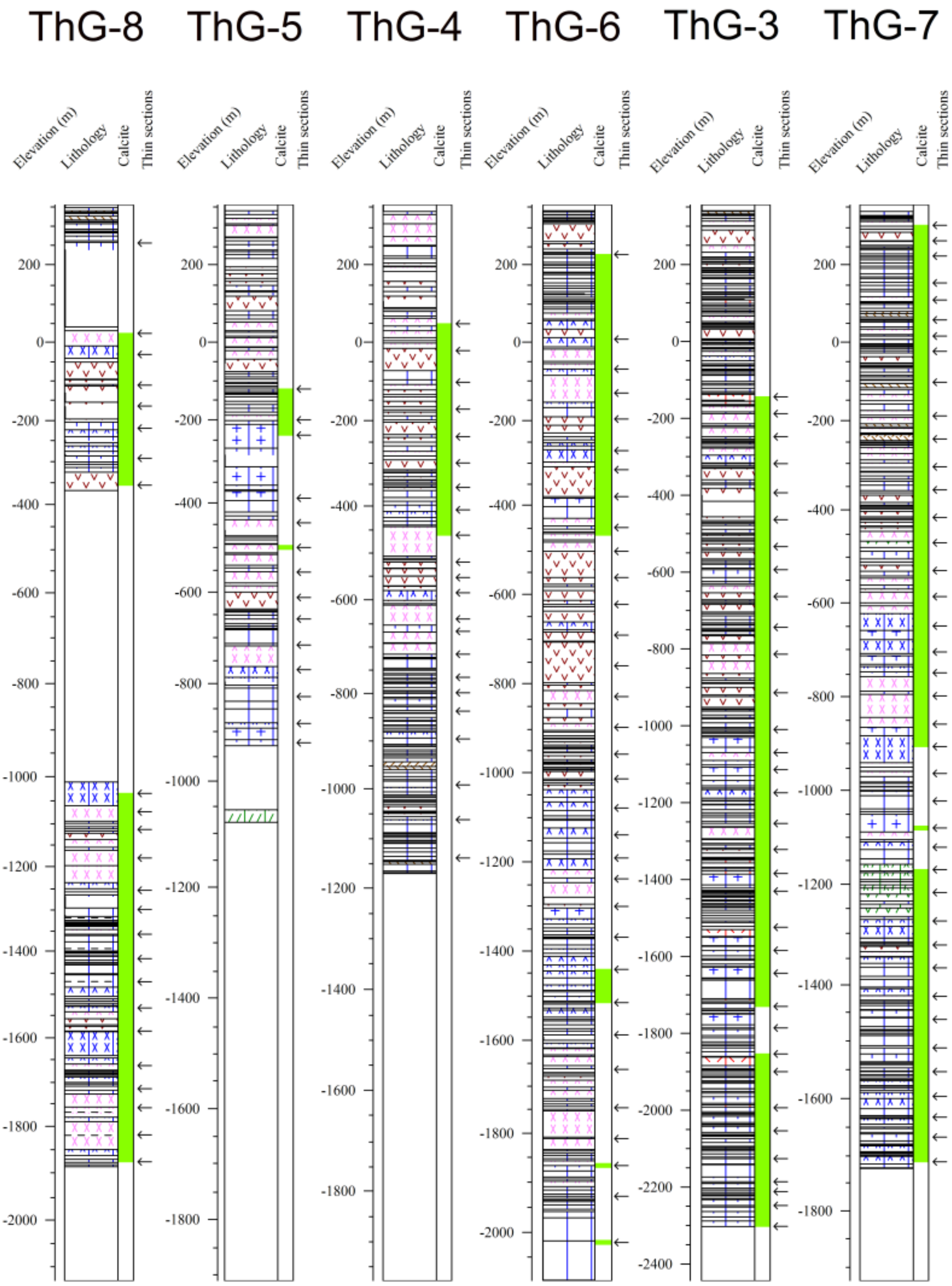


Figure 53. *Distribution of calcite shown next to stratigraphic columns for the wells. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

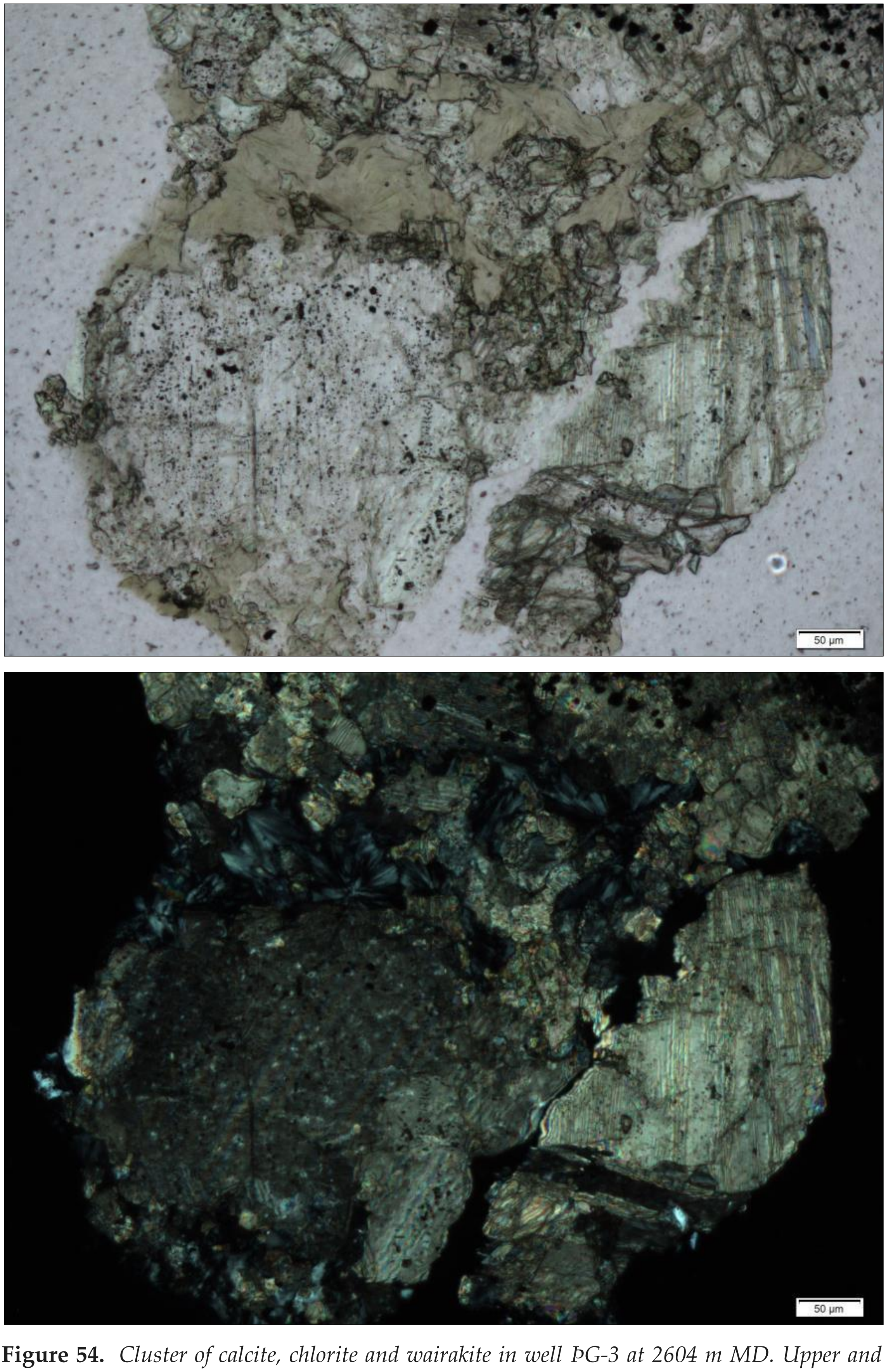


Figure 54. *Cluster of calcite, chlorite and wairakite in well ÞG-3 at 2604 m MD. Upper and lower panel plane-polarized light and cross-polarized light, respectively.*

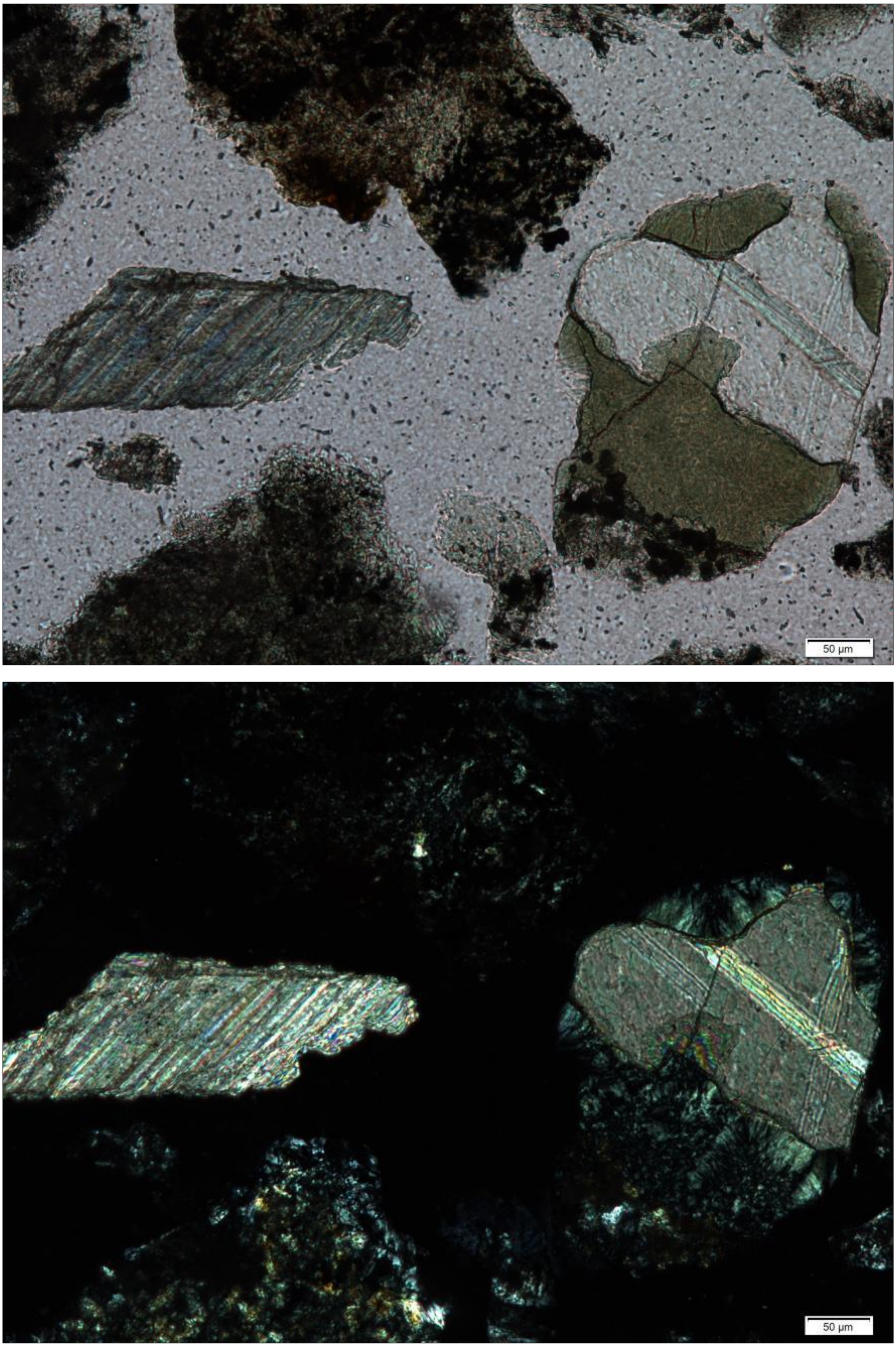


Figure 55. *Highly altered glassy basalt at 2490 m MD in well ÞG-7. A single calcite grain can be seen on the left and another intergrown with actinolite on the right. Upper and lower panel plane-polarized light and cross-polarized light, respectively.*

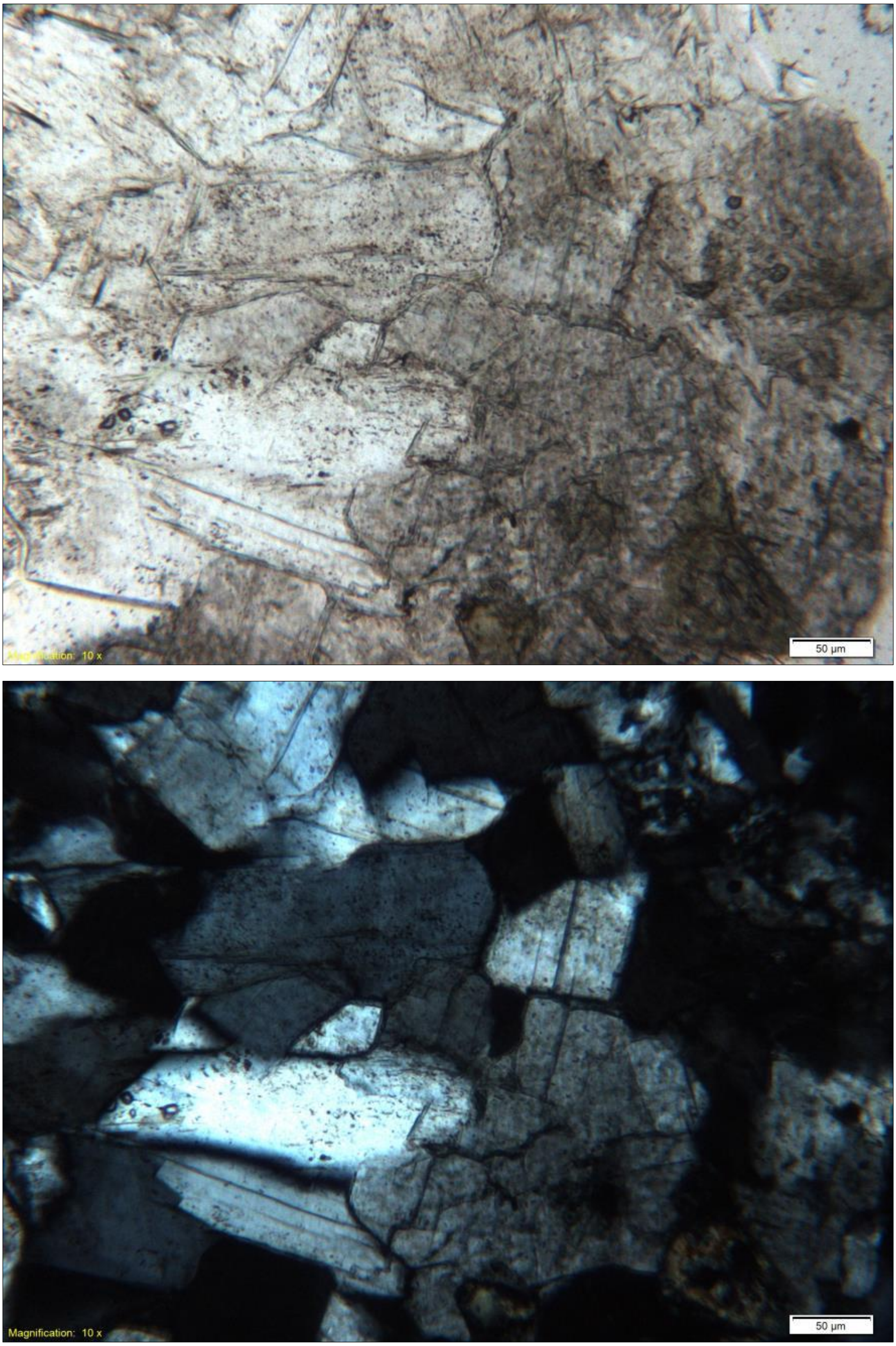


Figure 56. *Laumontite precipitates in well ÞG-8 at 2300m MD. Upper and lower panel plane-polarized and cross-polarized light, respectively.*

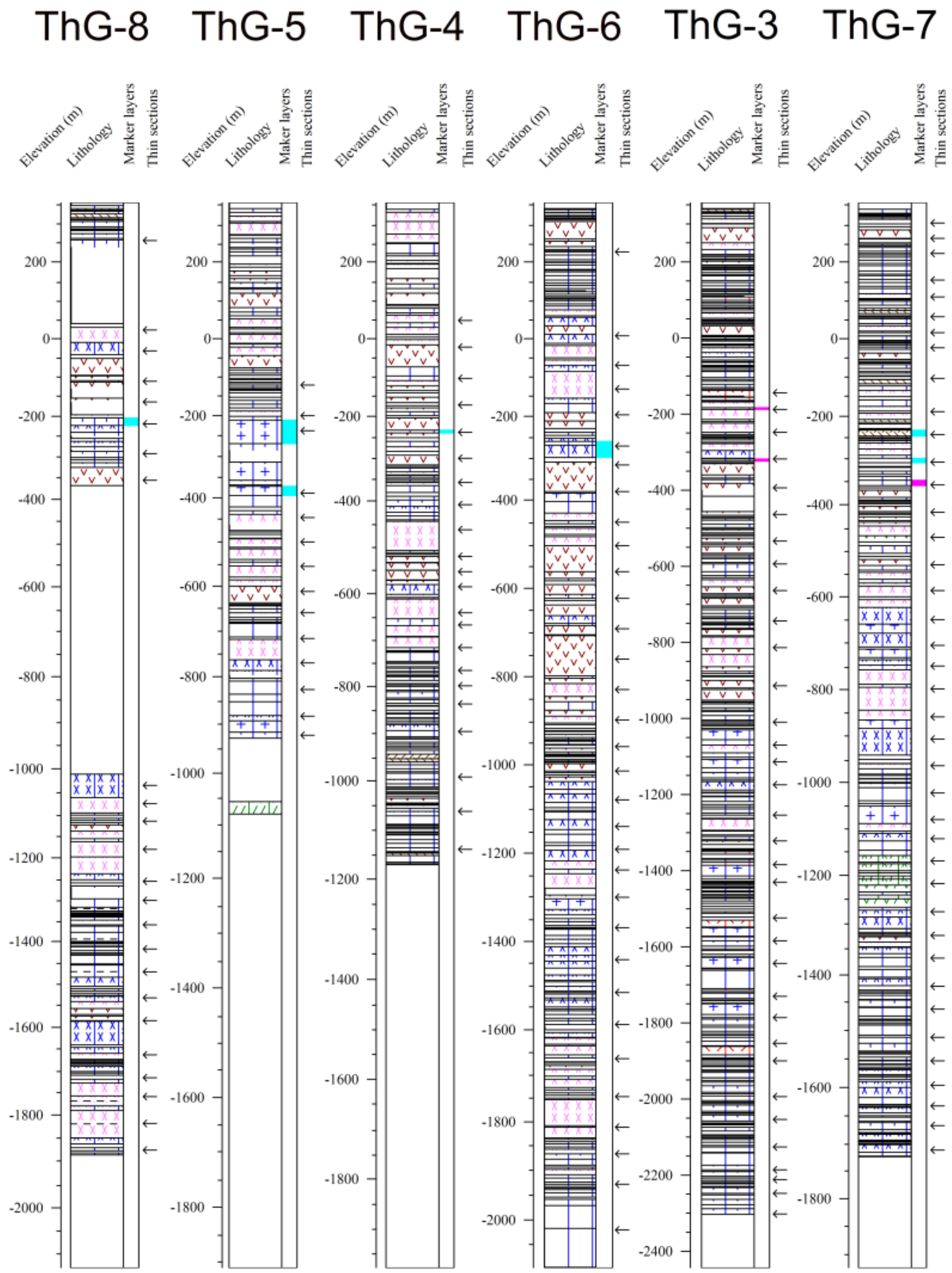


Figure 57. *The depth of marker layers shown in comparison to stratigraphic columns for all the wells. Blue indicates likely marker layer and red possible marker layer. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

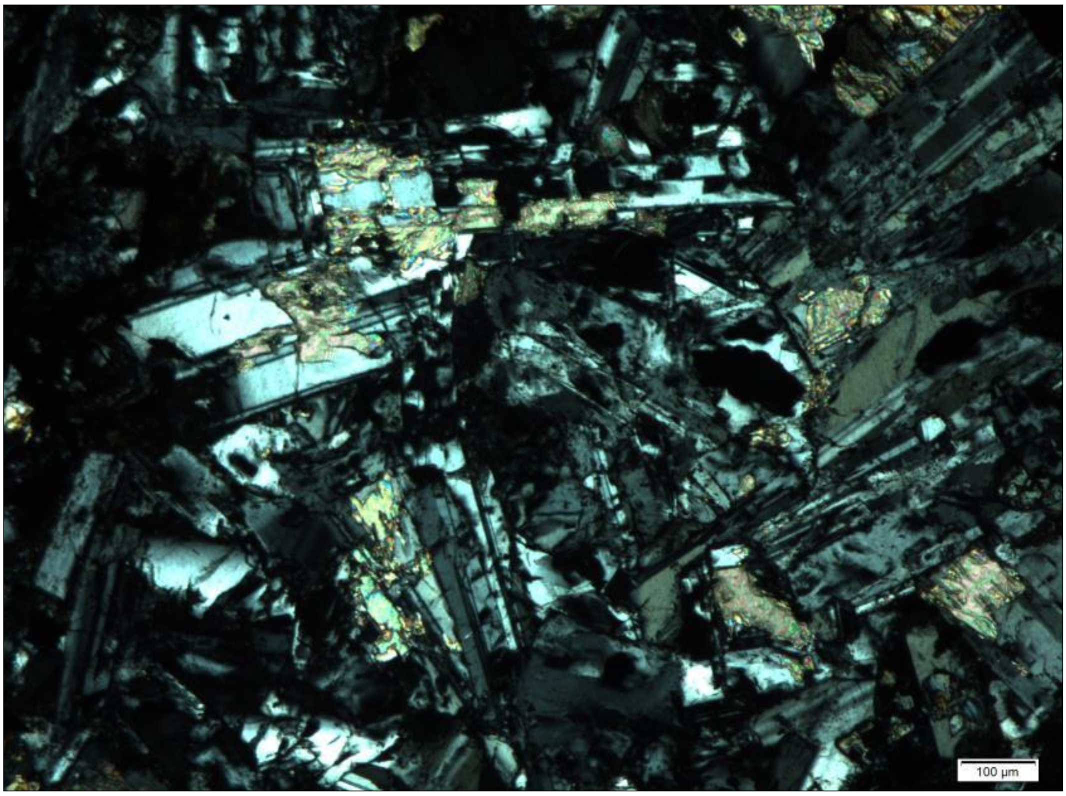


Figure 58. *Plagioclase-rich layer at 582 m MD in well ÞG-8. Some calcite alteration of the plagioclase can be seen. Crossed polarizers.*

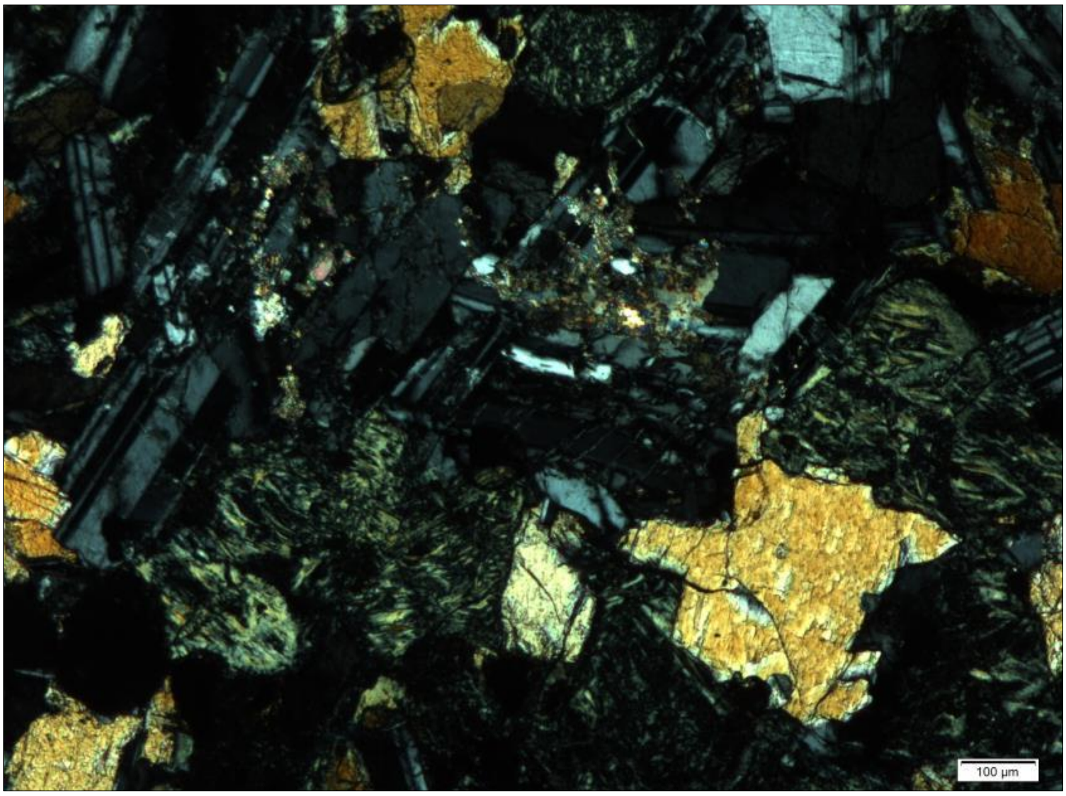


Figure 59. *Plagioclase-rich layer at 640 m MD in well ÞG-6. In addition to plagioclase, some pyroxene and olivine (replaced by mixed-layer clay). Crossed polarizers.*

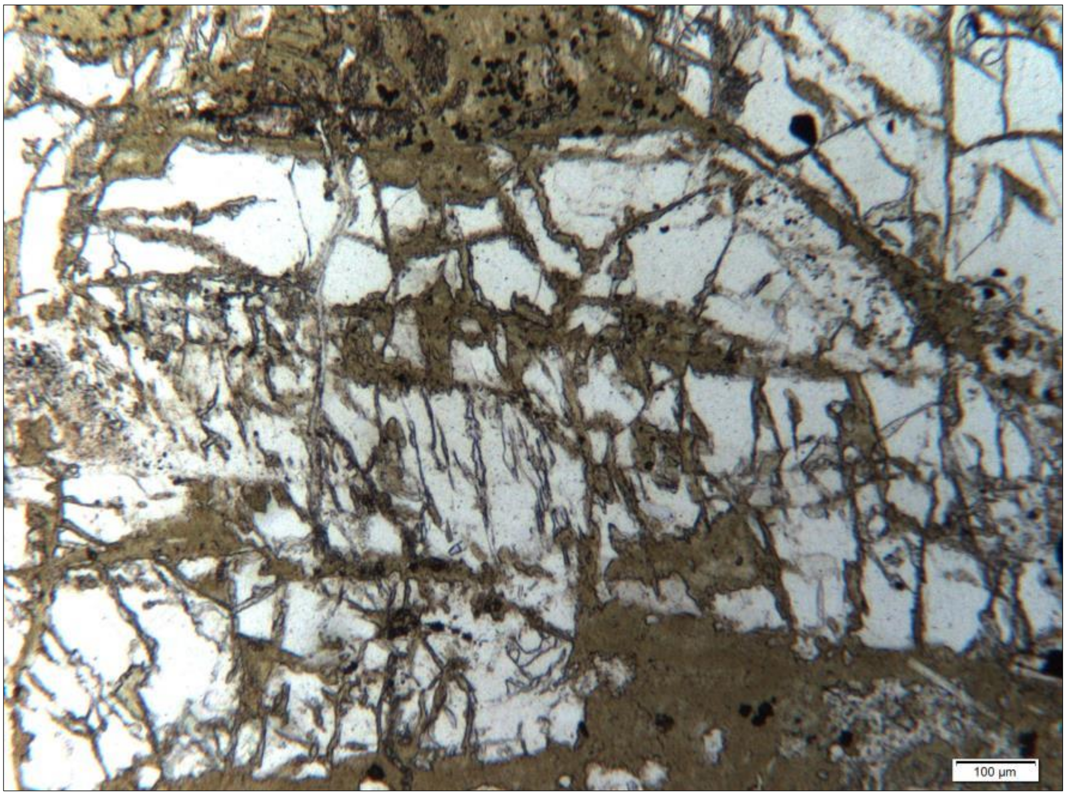


Figure 60. *Plagioclase-rich layer at 600 m MD in well ÞG-5. Altered plagioclase grains with abundant chlorite and calcite. Plane polarized light.*

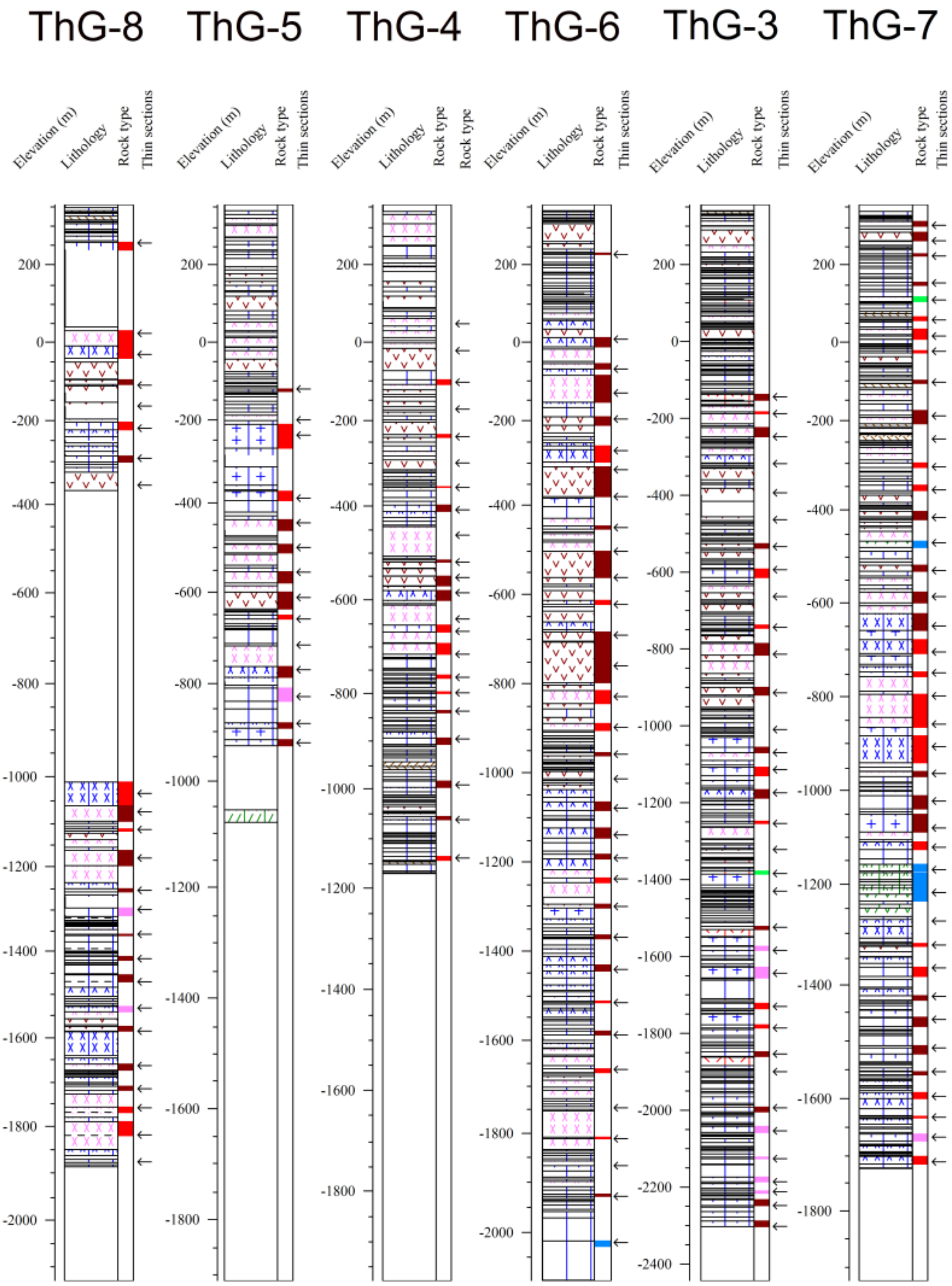


Figure 61. *Types of basalt found in the Theistareykir wells (red, olivine tholeiite; brown, tholeiite). Also indicated are silicic igneous rocks (blue) and intermediate (green). Suspected intrusions are marked with magenta. The depth scales show elevation relative to sea level, and the arrows indicate thin section depths.*

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