Holes U1415F and U1415G[1]

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Chapter contents

Operations

The locations for Integrated Ocean Drilling Program Holes U1415F and U1415G (see Fig. **F8** in the "Expedition 345 summary" chapter [Gillis et al., 2014b]) were selected to test sediment thickness and subseafloor drilling conditions, with the aim of finding a suitable site for establishing a deep hole. Hole operations are summarized in Table **T1** and outlined below. All times are ship local time (UTC – 7 h).

Near-bottom 3.5 kHz pinger and camera survey

At the end of operations in Hole U1415E and while still at that location, we assembled a new bottom-hole assembly (BHA) and lowered the bit to just above the seafloor. The previous problem with the 3.5 kHz pinger was ascribed to dead batteries, so the batteries were charged and the pinger was operational once again. We lowered the camera system with the 3.5 kHz pinger attached and conducted a new survey of the seafloor and near-subbottom in an attempt to locate an area on the bench with thin sediment and little or no rubble in evidence. This survey lasted from 1615 to 2000 h on 26 December 2012 (see Table **T1** and Fig. **F3** in the "Bench site survey" chapter [Gillis et al., 2014a]).

Hole U1415F drilling operations

A new location was selected, the top drive picked up, and a jet-in test was started at 2100 h on 26 December 2012. The seafloor depth for this hole was established as 4857.0 meters below rig floor (mbrf). The bit was jetted into the formation only 1.5 m before the test was terminated. The bit was pulled clear of the seafloor, and the camera system was recovered.

Hole U1415G drilling operations

The drill string was spaced out, and Hole U1415G was spudded at 2355 h on 26 December 2012 without offsetting the ship from the location of Hole U1415F. Rotary core barrel coring continued to 4869.94 mbrf (12.9 meters below seafloor) before being terminated. Core 345-U1415G-1R recovered 0.29 m (2%). Hole conditions were the same as in earlier holes, making it highly risky to attempt making connections with the bit in the hole. The bit was pulled clear of the seafloor at 0445 h on 27 December, ending Hole U1415G.

[1] Gillis, K.M., Snow, J.E., Klaus, A., Guerin, G., Abe, N., Akizawa, N., Ceuleneer, G., Cheadle, M.J., Adrião, Á., Faak, K., Falloon, T.J., Friedman, S.A., Godard, M.M., Harigane, Y., Horst, A.J., Hoshide, T., Ildefonse, B., Jean, M.M., John, B.E., Koepke, J.H., Machi, S., Maeda, J., Marks, N.E., McCaig, A.M., Meyer, R., Morris, A., Nozaka, T., Python, M., Saha, A., and Wintsch, R.P., 2014. Holes U1415F and U1415G. *In* Gillis, K.M., Snow, J.E., Klaus, A., and the Expedition 345 Scientists, *Proc. IODP,* 345: College Station, TX (Integrated Ocean Drilling Program).
doi:10.2204/iodp.proc.345.107.2014
[2] **Expedition 345 Scientists' addresses.**

Igneous petrology

Coring in Hole U1415G recovered five different igneous lithologic intervals from lithologic Unit I (surficial rubble) at Site U1415 (Fig. F1).

Gabbro

Gabbro defines two intervals (Intervals 2 and 4) from Unit I in Hole U1415G. In general, the gabbro is medium-grained equigranular rock. Modally, the gabbro consists of plagioclase (29%–50%) and clinopyroxene (50%–70%), with trace amounts of olivine, orthopyroxene, and oxide. Plagioclase is medium grained and subhedral to euhedral with a tabular-shaped habit. Clinopyroxene is medium grained and anhedral with an interstitial to oikocrystic habit.

Clinopyroxene oikocryst-bearing troctolite

Clinopyroxene oikocryst-bearing troctolite occurs as a single piece recovered from Unit I in Interval 3 (Section 345-U1415G-1R-1) (Fig. F2). The clinopyroxene oikocryst-bearing troctolite is medium-grained equigranular rock, with well-developed magmatic modal layering and foliation. The strong foliation is formed by the alignment of tabular plagioclase. Modally, the rock consists of olivine (20%), plagioclase (76%), and clinopyroxene (4%), with trace oxide minerals. Olivine is fine grained and subhedral to anhedral with an irregular, elongate amoeboid habit. Despite their irregular habit, the long axes of the olivines are subparallel to the foliation, defined by the plagioclase in the troctolitic matrix (Fig. F3). Plagioclase is fine grained and subhedral to euhedral with a tabular habit. Overall, plagioclase shows no obvious zoning. Clinopyroxene occurs as large anhedral oikocrysts (as large as 15 mm) that contain a distinctive population of subhedral to euhedral, lath-shaped, partially resorbed plagioclase chadacrysts (Fig. F2). The plagioclase chadacrysts have random orientations within the oikocryst in sharp contrast to the surrounding strongly foliated plagioclase fabric. Olivine is conspicuous by its absence as a chadacryst in the oikocrysts.

Olivine gabbro

Olivine gabbro defines one interval from Unit I. The olivine gabbro is a medium-grained equigranular granular rock. Modally, the olivine gabbro consists of olivine (10%), plagioclase (60%), and clinopyroxene (30%), with trace amounts of oxide. Olivine is fine grained and euhedral to subhedral with a subequant habit. Plagioclase is medium grained and subhedral to euhedral with a lath-shaped habit. Clinopyroxene is medium to coarse grained and anhedral with an oikocrystic habit.

Orthopyroxene-bearing olivine gabbro

Orthopyroxene-bearing olivine gabbro defines Interval 4 in Unit I. The orthopyroxene-bearing olivine gabbro is a medium-grained equigranular granular rock. Modally, the orthopyroxene-bearing olivine gabbro consists of olivine (10%), plagioclase (70%), clinopyroxene (17%), and orthopyroxene (3%), with trace amounts of oxide. Olivine is fine grained and euhedral to subhedral with a subequant habit. Plagioclase is medium grained and euhedral to subhedral with a tabular habit. Clinopyroxene is medium grained and anhedral with an irregular interstitial habit. Orthopyroxene is subhedral with a prismatic habit.

Orthopyroxene-bearing gabbro

Orthopyroxene-bearing gabbro defines Interval 5 in Unit I. The orthopyroxene-bearing gabbro is a medium-grained equigranular granular rock displaying a strong magmatic foliation (Fig. F4). Modally, the orthopyroxene-bearing gabbro consists of plagioclase (60%), clinopyroxene (36%), and orthopyroxene (4%). Plagioclase is medium grained and subhedral with a tabular habit defining a magmatic foliation. Clinopyroxene is medium grained and subhedral to anhedral with a prismatic habit. Orthopyroxene is subhedral to euhedral with a prismatic to poikilitic habit.

Metamorphic petrology

Background alteration

The lithologies in Unit I consist mainly of slightly altered gabbro and olivine gabbro. Samples exhibit metamorphism over greenschist to subgreenschist facies and show a broad range of alteration intensities, but because they are not in situ, patterns of alteration cannot be established. Primary mineral replacement ranges from 10% to 60%. Most of the secondary minerals are visible to the naked eye; some particularly fine grained minerals were identified only in thin section.

In the recovered gabbroic rock, pyroxene is slightly to moderately altered to pale green amphibole along rims and cleavage planes. Olivine is replaced by serpentine in seams parallel to the magmatic foliation but with little development of corona textures. Serpentine was subsequently altered to clay minerals in some grains. Orthopyroxene is altered to bright green chlorite-smectite aggregates. In most of the rocks, plagioclase is slightly altered to prehnite and secondary plagioclase. Plagioclase is also replaced by chlorite in rims surrounding relict olivine. Alteration within vein halos is more intense but with the same mineralogy as the dominant alteration.

Veins

Three of the five recovered pieces contain veins. Veins are mostly thin (<1–2 mm wide) and isolated and are dominated by subgreenschist facies minerals including clay minerals, quartz, actinolite, and minor prehnite. Vein shapes are regular and characterized by sharp contacts with the host rock (Fig. F5). Alteration of mafic minerals is more complete in vein halos (2–5 mm wide); within vein halos olivine is completely altered to serpentine and clay. Plagioclase is very fresh and does not appear more altered within vein halos. See also **"Alteration veins."**

Metamorphic conditions

The alteration observed in Hole U1415G is variable, as would be expected in rocks from discontinuous intervals. The dominant alteration was at subgreenschist to greenschist facies conditions. The alteration predominantly affects pyroxene and olivine; primary plagioclase is largely unaltered except where in contact with relict olivine or in vein halos.

Structural geology

All core pieces from Holes U1415F and U1415G are relatively small (maximum length = 6 cm), were not cored or oriented, and comprise a surficial rubble unit (lithologic Unit I).

Magmatic structures

The earliest history of the rock in Hole U1415G is constrained by magmatic fabrics preserved in the recovered gabbroic rock. No magmatic layering was observed, possibly because of the small size of the pieces. One gabbro piece exhibits planar moderate plagioclase SPO (Sample 345-U1415G-1R-1 [Piece 5]; Fig. F6A). Two olivine gabbro pieces exhibit moderate to strong plagioclase and olivine SPO (Sample 1R-1 [Pieces 1 and 3]; Fig. F6B). All cut pieces of sufficient size show moderate to strong magmatic foliation; consequently, 100% of the core has magmatic foliation.

Thin section observations show that the magmatic foliation is defined by both the preferred orientation and shape anisotropy of the plagioclase crystals. The plagioclase crystals are often tabular and 1–5 mm in length, have shape aspect ratios as high as 5:1, and show traces of [010] albite twin planes running parallel to the long axes of the crystals. Microstructural observations in thin section show that plagioclase crystals in the gabbro (Sample 345-U1415G-1R-1, 21–26 cm [Piece 5]) exhibit minor deformation twinning and gently curved grain boundaries with 120° grain junctions; the latter indicates significant grain boundary annealing. Olivine gabbro hosted in Sample 1R-1, 10–16 cm (Piece 3) (Table T2), has strong plagioclase SPO and moderate olivine SPO defined by sometimes tabular, partially skeletal olivine crystals (Fig. F6B) that show minor undulose extinction and incipient subgrain development. Plagioclase crystals show rare deformation twinning, common annealed grain boundaries, and, in patchy regions, equilibrated clusters of polygonal plagioclase with 120° grain junctions (Fig. F6C). The plagioclase SPO appears to wrap at least partly around the clinopyroxene oikocrysts (Fig. F6D), whereas plagioclase crystals within the oikocryst are smaller with a higher shape aspect ratio (as high as 8:1) than those outside the grain and have no preferred orientation. Both of these observations and the relatively minor crystal-plastic deformation present in both plagioclase and olivine crystals suggest that foliation development occurred under hypersolidus conditions by compaction and/or shearing. Plagioclase crystals in clinopyroxene oikocrysts occur in glomerocrystic clusters (Fig. F6E). These clusters may be preserved by growth of the clinopyroxene, albeit with some dissolution, and thus record the geometry of plagioclase nucleation and crystal accumulation at an early stage of crystal mush formation.

Crystal-plastic deformation

A planar, weakly foliated zone of subsolidus crystal-plastic deformation is noted over a thin interval (<1 cm) in one piece (Sample 345-U1415G-1R-1, 10–16 cm [Piece 3]). No other structurally continuous subsolidus crystal-plastic deformation was observed in the recovered section.

Cataclastic deformation

Macroscopically, all recovered pieces show no brittle deformation. Minor open fractures are apparent from microstructural observations, with no apparent offset and very low density (<1 fracture per 10 cm).

Alteration veins

Alteration veins are present in four of the five pieces recovered in Hole U1415G (i.e., ~80% of recovered pieces). When present, vein density is always low and is less than a few veins per 10 cm of recovery. All veins are very thin (maximum thickness = 0.02 cm). Accordingly, alteration veins represent no more than

0.1% of the volume of the cores. Vein length generally exceeds the width of the core (6 cm), although vein terminations (vein tips) are frequently observed. Their contact with the host gabbroic rocks is generally clear with no alteration halos. Alteration veins are, in most cases, curved. Very few planar veins are observed; they form networks of crosscutting veins with no marked preferred orientation.

In thin section, the same mineral assemblages (varying combinations of amphibole, chlorite, serpentine, zoisite, prehnite, zeolite, serpentine, and clay) are observed as alteration vein-filling material. Alteration veins cut primary igneous minerals that are, as a rule, much larger than the width of individual veins. Undeformed veins are more common than cataclastic/deformed veins. In some veins, alteration minerals show no preferred orientation (mosaic textures), whereas in others, alteration minerals (usually prehnite) are fibrous with the orientation of the fibers typically perpendicular to the vein walls.

Details specific to structural features were illustrated with comments and sketches in STRUCTUR in **"Supplementary material."**

Temporal evolution

Temporal evolution of structures recovered in Hole U1415G is, from oldest to youngest,

- Intrusion of fine- and coarse-grained gabbroic rocks;
- Magmatic foliation development and limited crystal-plastic deformation in the crystal mush and annealing of plagioclase;
- Very localized subsolidus crystal-plastic deformation;
- Vein formation; and
- Open fracture formation associated with late, brittle faulting.

References

Gillis, K.M., Snow, J.E., Klaus, A., Guerin, G., Abe, N., Akizawa, N., Ceuleneer, G., Cheadle, M.J., Adrião, Á., Faak, K., Falloon, T.J., Friedman, S.A., Godard, M.M., Harigane, Y., Horst, A.J., Hoshide, T., Ildefonse, B., Jean, M.M., John, B.E., Koepke, J.H., Machi, S., Maeda, J., Marks, N.E., McCaig, A.M., Meyer, R., Morris, A., Nozaka, T., Python, M., Saha, A., and Wintsch, R.P., 2014a. Bench site survey. *In* Gillis, K.M., Snow, J.E., Klaus, A., and the Expedition 345 Scientists, *Proc. IODP,* 345: College Station, TX (Integrated Ocean Drilling Program). **doi:10.2204/iodp.proc.345.103.2014**

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Figure F1. Rock types recovered from lithologic Unit I in Hole U1415G based on macroscopic description. For clarity, only the principal rock names are shown without any modifiers.

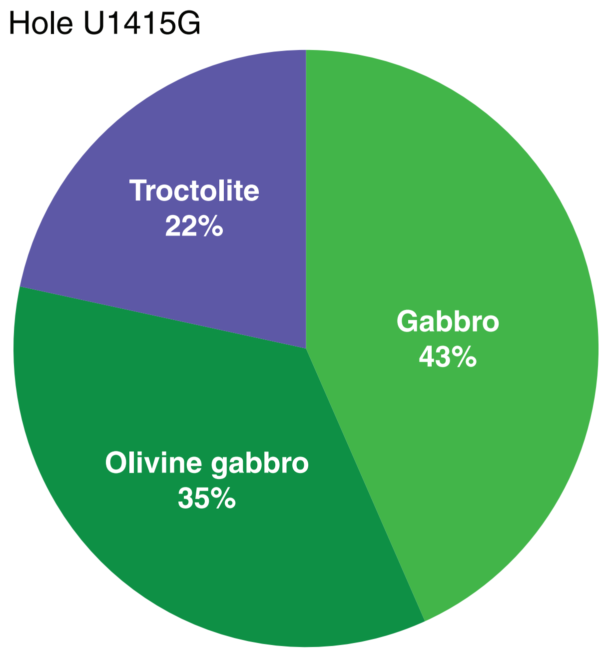

Figure F2. Clinopyroxene oikocryst-bearing troctolite (Sample 345-U1415G-1R-1, 10–16 cm [Piece 3]). **A.** The oikocryst is located in the upper right corner of the core piece (arrow). **B.** Plane-polarized light. **C.** Under crossed polars.

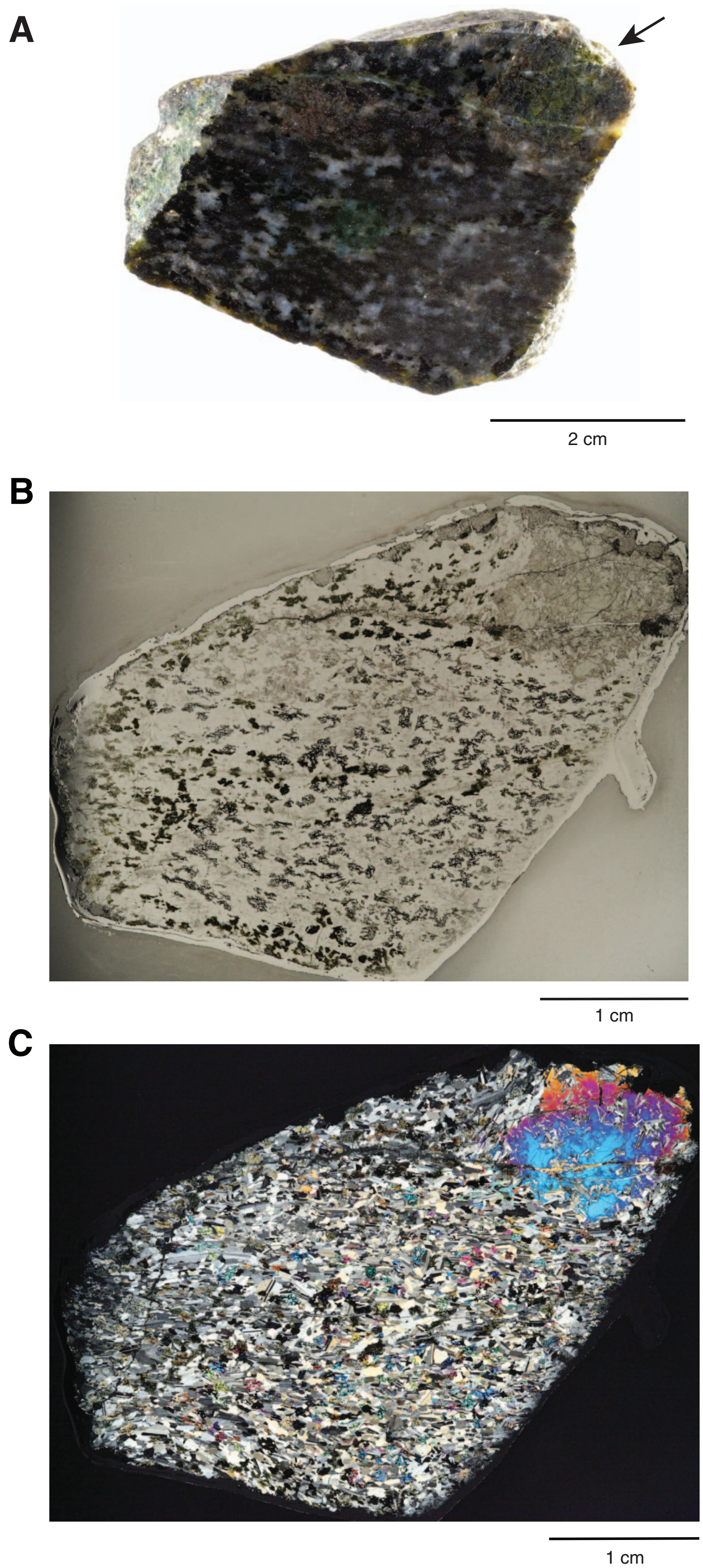

Figure F3. Typical occurrence of anhedral, irregularly shaped olivine (Ol) and subhedral tabular plagioclase (Pl) in clinopyroxene oikocryst-bearing troctolite (Thin Section 6; Sample 345-U1415G-1R-1, 10–16 cm [Piece 3]). Note the well-developed magmatic foliation caused by parallel alignment of plagioclase and olivine, as well as 120° triple junctions between plagioclase grains (yellow arrows in B), implying well-equilibrated textures. **A.** Plane-polarized light. **B.** Under crossed polars.

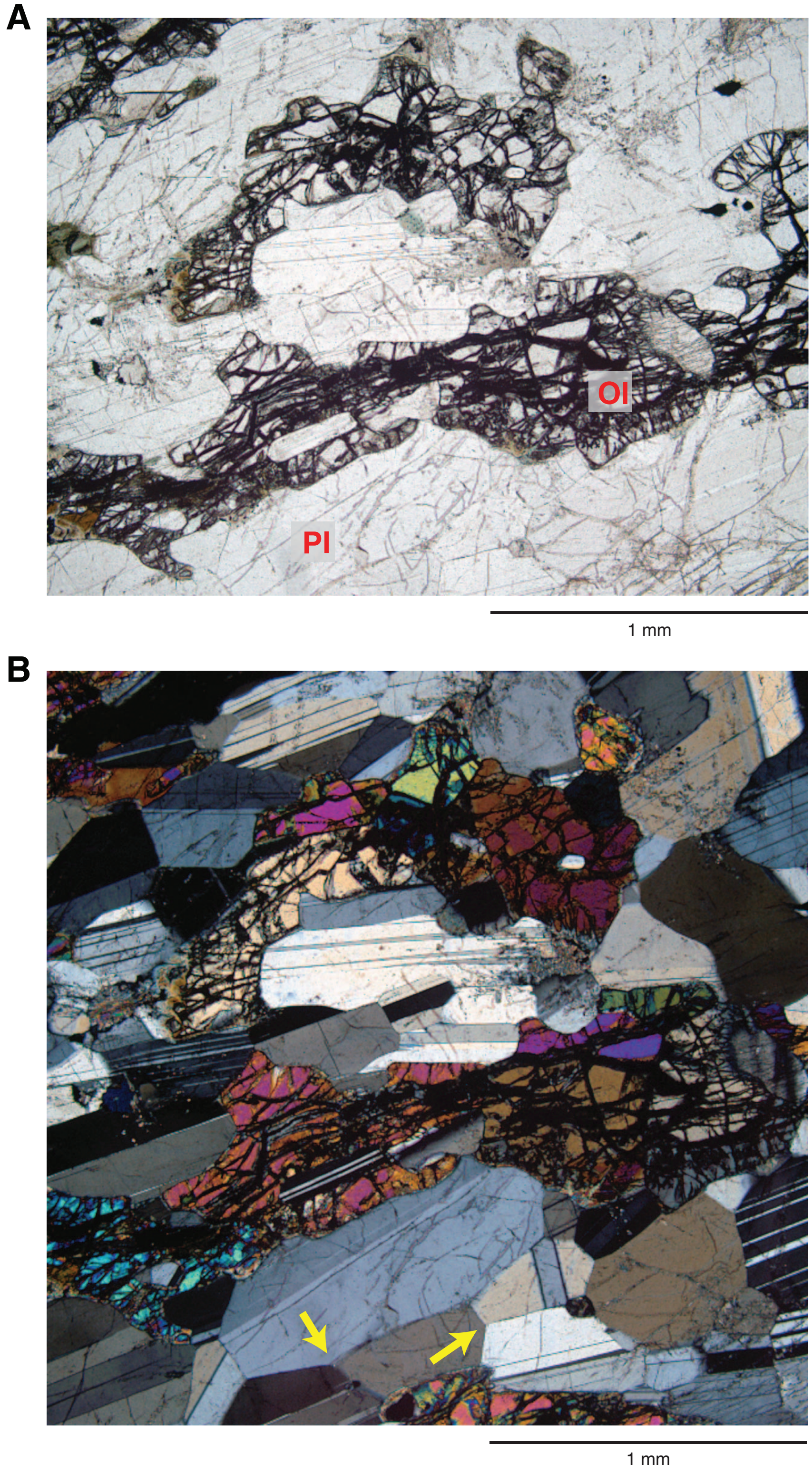

Figure F4. Orthopyroxene-bearing gabbro (Thin Section 5; Sample 345-U1415G-1R-1, 21–26 cm [Piece 5]). Dark-colored minerals in B are pyroxenes consisting both of clinopyroxene (36%) and orthopyroxene (4%). Note the well-developed magmatic foliation defined by subparallel plagioclase (arrows in C). **A.** Core close-up. **B.** Plane-polarized light. **C.** Under crossed polars.

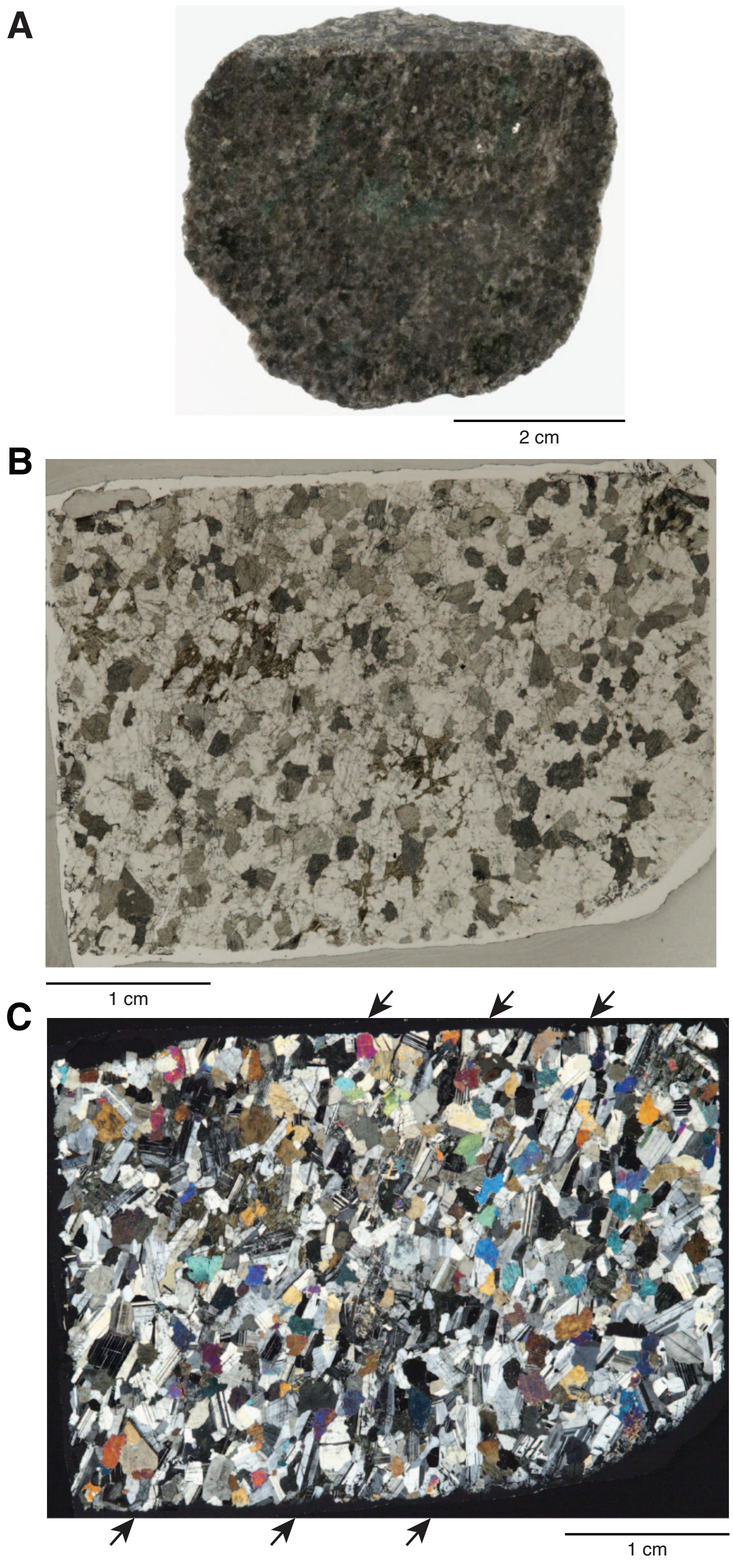

Figure F5. Clinopyroxene oikocryst-bearing troctolite in which a chlorite and quartz vein cuts a relatively fresh clinopyroxene oikocryst that is slightly altered to amphibole along fractures and cleavage planes (Thin Section 6; Sample 345-U1415G-1R-1, 0–6 cm [Piece 3]; under crossed polars). Qtz = quartz, Chl = chlorite, Cpx = clinopyroxene, Amph = amphibole.

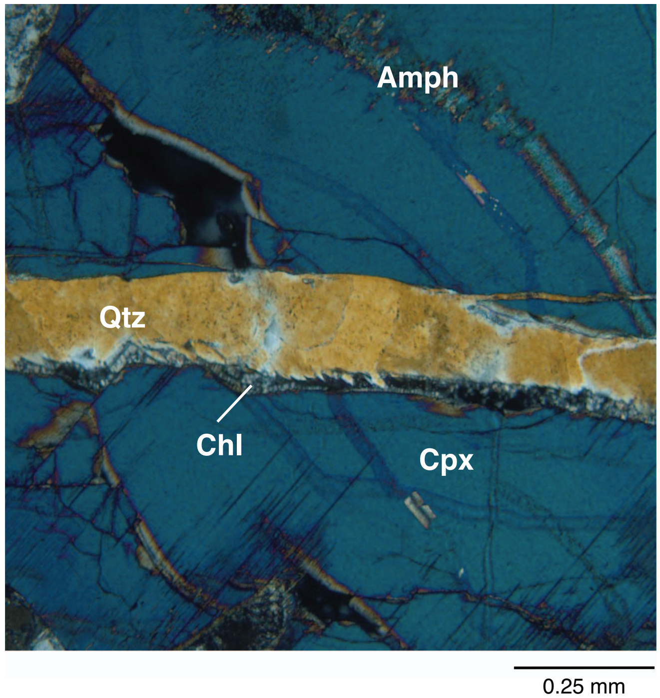

Figure F6. **A.** Plagioclase shape-preferred orientation (SPO) defining magmatic foliation in orthopyroxene-bearing olivine gabbro (Sample 345-U1415G-1R-1, 21–26 cm [Piece 5]; under crossed polars). **B–E.** Sample 345-U1415G-1R-1, 10–16 cm (Piece 3). B. Moderate to strong plagioclase SPO and moderate olivine SPO defined by tabular, partially skeletal olivine crystals (clinopyroxene oikocryst-bearing troctolite; red arrow; plane-polarized light). Red box (tick mark shows upward direction) indicates location of image in C. C. Plagioclase SPO with equilibrated clusters of polygonal plagioclase with 120° grain junctions. D. Plagioclase SPO foliation wrapping around a 1.5 cm diameter clinopyroxene oikocryst. Plagioclase crystals within the oikocryst are smaller, more elongate, and relatively sparse compared to those outside the oikocryst; no olivine crystals are present within the oikocryst. Red box (tick mark shows upward direction) indicates location of image in E. E. Glomerocrystic arrangement of the plagioclase crystals within a large clinopyroxene oikocryst (under crossed polars).

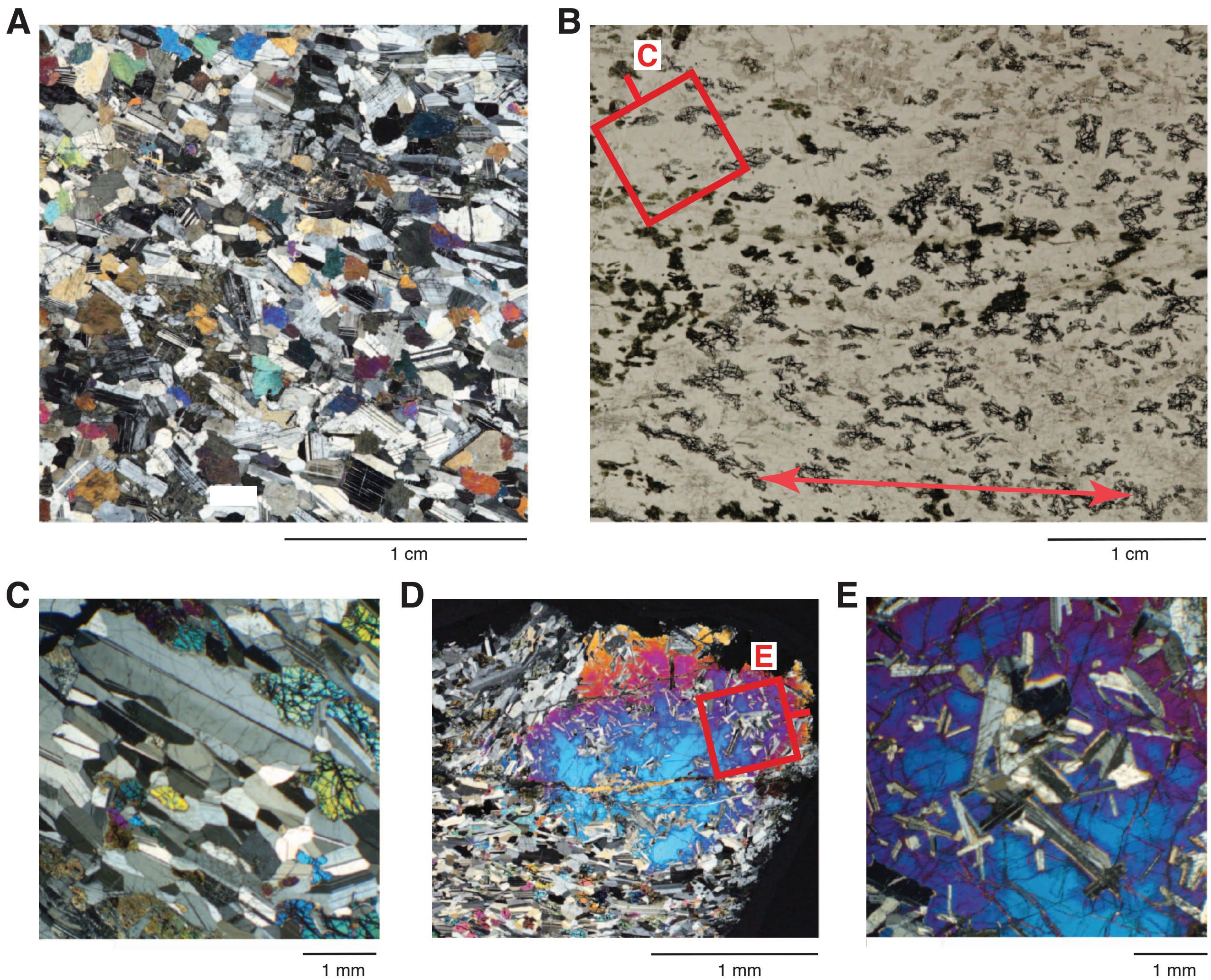

Table T1. Operations summary, Holes U1415F and U1415G.

Hole U1415F (jet-in test only; no coring):
Latitude: 2°15.1394′N
Longitude: 101°32.6261′W
Time at site (h): 19.0 (0215 h, 26 December–2115 h, 26 December 2012)
Seafloor (drill pipe measurement below rig floor, m DRF): 4857.0
Distance between rig floor and sea level (m): 11.2
Water depth (drill pipe measurement from sea level, mbsl): 4845.8
Total penetration (drilling depth below seafloor, m DSF): 1.5

Hole U1415G (RCB coring):
Latitude: 2°15.1390′N
Longitude: 101°32.6263′W
Time on site (h): 7.5 (2115 h, 26 December–0445 h, 27 December 2012)
Seafloor (drill pipe measurement below rig floor, m DRF): 4857.0
Distance between rig floor and sea level (m): 11.2
Water depth (drill pipe measurement from sea level, mbsl): 4845.8
Total penetration (drilling depth below seafloor, m DSF): 12.9
Total depth (drill pipe measurement from rig floor, m DRF): 4869.9
Total length of cored section (m): 12.9
Total core recovered (m): 0.29
Core recovery (%): 2
Drilled interval (m): 0
Total number of cores: 1 RCB

Core	Depth (mbsf) Top of cored interval	Depth (mbsf) Bottom of cored interval	Interval cored (m)	Core recovered (m)	Curated length (m)	Recovery (%)	Date (2012)	Time UTC (h)
345-U1415G-								
1R	0.0	12.9	12.9	0.29	0.26	2	27 Dec	0710
		Total:	12.9	0.29	0.26	2		

Local ship time was UTC – 7 h. DRF = drilling depth below rig floor, DSF = drilling depth below seafloor. R = rotary core barrel (RCB) system.

Table T2. Details and explanations for thin sections with two domains, Hole U1415G.

Core, section, interval (cm)	Thin section number	Lithologic interval	Rock name	Rock comment	Nature of domains	Contact	Number of domains	Igneous domain	Domain lithology name
345-U1415G-									
1R-1W, 10–16 (Piece 3)	6 (image)	3	Clinopyroxene oikocryst-bearing troctolite		Two or more lithologies	Sutured	2	1	Troctolite
								2	Clinopyroxene oikocryst