

# Description of basement volcanic sequences in Holes U1342A and U1342D on Bowers Ridge in the Bering Sea<sup>1</sup>

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## Abstract

At Ulm Plateau, near the eastern end of the crestral area of Bowers Ridge, basement of lithified volcanoclastic sediment (~42 m) was recovered at Integrated Ocean Drilling Program (IODP) Site U1342 beneath a thin cover (~49 m) of surface sediment. Recovery of basement rock provided an unprecedented opportunity to address the origin and evolution of this enigmatic appendage of the Aleutian arc massif. Contrasting hypotheses have been proposed for the formation of the arc massif of Bowers Ridge, either in the Cretaceous North Pacific Ocean exotic to the Bering Sea or within the Bering Sea during the Eocene formation of the Aleutian arc.

The volcanic sequence recovered from Site U1342 was divided into six major lithologic units: Unit I, vesiculated andesitic lava flow; Unit II, interbedded volcanic sandstone and polymict volcanic conglomerate; Unit III, monomict volcanic conglomerate; Unit IV, interbedded volcanic sandstone and polymict volcanic conglomerate; Unit V, monomict volcanic conglomerate; and Unit VI, polymict volcanic conglomerate. Units III and IV represent hydroclastic volcanoclastic deposits, whereas Units II, IV, and VI are epiclastic volcanoclastic strata.

## Introduction

Bowers Ridge extends northward into the Bering Sea from the midpoint of the Aleutian Ridge and then sweeps westward in a recurving arc back toward the ridge. The dimensions of Bowers Ridge are large. Its curved length is ~800 km, and, where attached to the north side of the Aleutian arc massif, the ridge is nearly 200 km wide. At this junction, the ridge rises ~3500 m above the abyssal floor of the Bering Sea Basin to flatten at a wave-planed summit platform at ~600–1000 m water depth. The ridge's width and height decrease progressively with distance to the west.

Marine geophysical data establish that a ~20–25 km thick core of basement rock constructs the bulk of Bowers Ridge (Cooper et al., 1981, 1987, 1992). Its middle and lower flanks are draped by a mantle of sedimentary deposits as thick as 2 km. The ridge's magnetic, velocity, and gravity characteristics are typical of an arc massif. A sediment-buried trench at the base of the ridge's northern flank implies that the arc-generating subduction zone dipped southward beneath Bowers Ridge.

<sup>1</sup>Kawabata, H., Sato, K., Tatsumi, Y., Scholl, D.W., Takahashi, K., and the Expedition 323 Scientists, 2011. Description of basement volcanic sequences in Holes U1342A and U1342D on Bowers Ridge in the Bering Sea. *In* Takahashi, K., Ravelo, A.C., Alvarez Zarikian, C.A., and the Expedition 323 Scientists, *Proc. IODP, 323*: Tokyo (Integrated Ocean Drilling Program Management International, Inc.).

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Confirming the ridge's arc origin, in 1970 the R/V *Melville* dredged altered volcanoclastic sediment of calc-alkaline affinity from the ridge's upper, northern flank (Scholl et al., 1975; Scholl, 2007). The dredge site is located near Integrated Ocean Drilling Program (IODP) Site U1342. In 2009, west of Site U1342, the R/V *Sonne* dredged similar material from exposed basement also along the ridge's northern flank.

At Site U1342, a total of 41.54 m of basement rock was recovered from the southern side of Ulm Plateau, a subsided, ~800 m deep wave-eroded platform. For the entire Aleutian-Bowers arc massif, no similar vertical sequence of its submerged arc framework exists. The recovered basement is evidently from a former ridge-cresting volcanic edifice demolished by subaerial and wave-base erosion in the late Miocene. Aboard the R/V *JOIDES Resolution*, the now vanished edifice was informally named Whiskey Mountain.

Two contrasting hypotheses have been proposed for the origin and evolution of the Bowers arc massif. The first is that, in the Late Cretaceous, Bowers Ridge formed in the Pacific Basin well to the south of its present location (Ben-Avraham and Cooper, 1981; Seliverstov, 1984). The second conjecture states that Bowers Ridge began to form within the Bering Sea region as an Eocene, in situ construct (Scholl et al., 1975; Scholl, 2007; Ben-Avraham and Cooper, 1981). The age, paleolatitude, geochemical, and petrologic analyses of the unprecedented recovery of a vertical section of basement rock at Site U1342, presumably from an erosionally decapitated and deeply submerged arc volcano, will determine which hypothesis is most correct or that neither is correct.

## Summary of core description

This paper describes the cored volcanic section recovered during IODP Expedition 323 from Holes U1342A and U1342D. In the description, we used the nongenetic terms of volcanic conglomerate and volcanic sandstone (Suthren, 1985) instead of lapilli tuff, tuff breccia, and volcanic breccia. Mineral abundances in the igneous rocks were determined by point counting using 1000 points per thin section.

The volcanic sequence in Cores 323-U1342D-7X through 19X was divided into six major lithologic units as described below. Figure F1 schematically shows the lithology of the material recovered in Cores 323-U1342D-7X through 19X.

Unit I is a vesiculated andesitic lava flow that was recovered in Sections 323-U1342D-7X-1 through 8X-1 (Figs. F2, F3). A comparable lithology appears in

Core 323-U1342D-9X in Hole U1342A (Fig. F4). The andesite contains phenocrysts (~20–30 vol%) of magnetite (Mt), orthopyroxene (Opx), clinopyroxene (Cpx), and plagioclase (Pl) and has a groundmass showing intersertal texture. It also contains ellipsoidal vesicles <7 mm long. This unit has a minimum thickness of 0.9 m. The Unit I/II boundary was not recovered.

Unit II consists of interbedded volcanic sandstones and polymict volcanic conglomerates. These were recovered in Cores 323-U1342D-8X through 10X (Figs. F3, F5, F6). Volcanic clasts in the conglomerates and gravel sandstones are mainly angular to subangular fragments of basalts and andesites. The clasts have various phenocryst assemblages, phenocryst proportions, extent of vesiculation, and groundmass textures. For example, the following clasts are observed: olivine (OL)-Cpx-Pl porphyritic basalt, Cpx-Pl porphyritic basalt, Pl-sparsely phyric basaltic andesite, and aphyric basaltic andesite. Sandstones and the matrix of conglomerates consist of basaltic and andesitic fragments, together with mineral grains of pyroxene, plagioclase, and magnetite. Biogenic material is absent. The bedding planes of this unit have dips of 0° to 10°. The unit has a minimum thickness of 8 m. The base of this unit gradually changes to Unit III, which is monomict volcanic conglomerate.

Unit III is formed by monomict volcanic conglomerates, which are observed in Cores 323-U1342D-10X and 11X (Figs. F6, F7). Clasts in the conglomerates are made up of aphyric basalt, in which there are phenocrysts (<3 vol%) of clinopyroxene and plagioclase and glassy to intersertal groundmass. Clasts are an average of ~1.5 cm in size, with a maximum size of >6 cm. The matrix is basically composed of fine- to medium-sized altered glass of the same basalt as that making up the clasts. The minimum thickness of this unit is 6.5 m. The presence of radial cooling joints in large basaltic clasts and the cognate origin of the clasts and the glassy matrix suggest that this unit is probably hydroclastic volcanoclastics (e.g., Suthren, 1985).

Unit IV consists of interbedded volcanic sandstones and polymict volcanic conglomerates. This unit appears in Cores 323-U1342D-11X through 14X (Figs. F7, F8, F9, F10). The sandstones and the matrix of the polymict conglomerates are composed of various types of volcanic fragments. Because large amounts of reddish sand are included in this unit compared to Unit II, the sandstone and matrix of the conglomerate are dark red to reddish gray in color. Clasts in the conglomerate are angular to subangular basaltic and andesitic pebbles. This unit is characterized by the presence of fault and slump structures. The fault

planes have dips of  $\sim 85^\circ$  and displacements of  $\sim 7$  cm. This unit is 9.5 m thick. There is a sharp contact between the base of this unit and the top of Unit V.

Unit V is comprised of monomict volcanic conglomerates recovered from Core 323-U1342D-14X (Fig. F10). Clasts are angular to subangular vesiculated basalt. The clasts reach 7 cm in size, with an average size of 1 cm. The basalt clasts contain phenocrysts (less than  $\sim 10$  vol%) of completely altered olivine, clinopyroxene, and plagioclase, and exhibit variable vesiculation up to  $\sim 15$  vol%. The matrix consists of very fine fragments of glassy basaltic material, which is the same as the clasts. The minimum thickness of this unit is 1 m. This unit is probably hydroclastic volcanoclastics. The Unit V/VI boundary was not recovered.

Unit VI consists of polymict volcanic conglomerates recovered from Cores 323-U1342D-15X through 19X (Figs. F11, F12, F13, F14, F15). Clasts are angular to subangular and consist of various types of basalts to andesites. The most abundant type of clasts is a highly porphyritic basalt (consisting of  $\sim 30$ – $40$  vol% phenocrysts) with phenocrysts of altered olivine, clinopyroxene, plagioclase, and minor orthopyroxene. The basaltic clasts have variable vesicularities up to  $\sim 15$  vol%. The matrix of the clasts is made up of medium-grained to very coarse grained basaltic and andesitic fragments together with plagioclase and pyroxene grains. Depending on the fraction and size of the clasts, four subunits are recognized. The boundaries between the subunits are gradual. The lower three subunits are characterized by normal grading of clasts. The minimum thickness of this unit is 18 m.

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Transocean, who made the successful recovery of the volcanic sequence by proceeding with the extended core barrel technique rather than employing the rotary core barrel technique within the limited time that could be allocated for basement drilling of  $\sim 24$  h.

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**MS 323-110**

Figure F1. Lithology and core recovery of Cores 323-U1342D-7X through 19X.

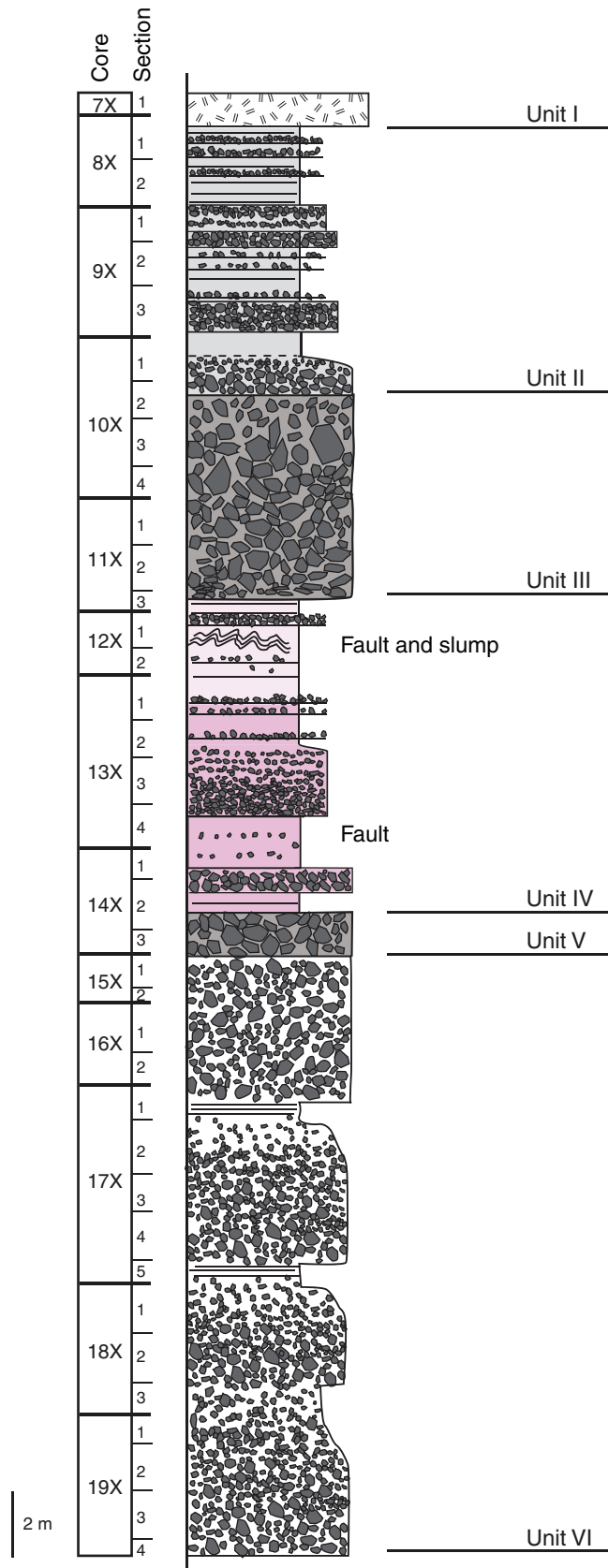


Figure F2. Description of Core 323-U1342D-7X.

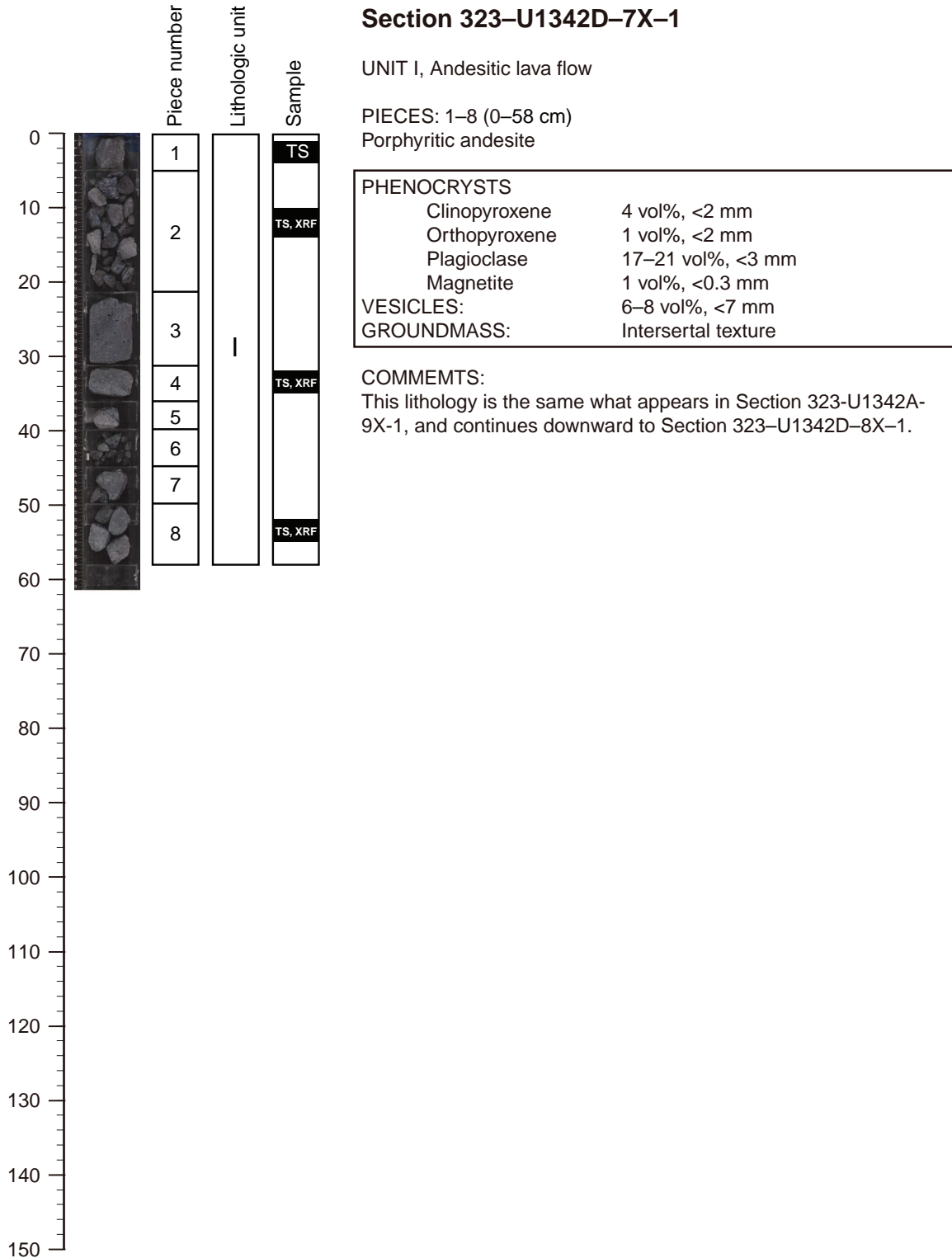




Figure F3. Description of Core 323-U1342D-8X. (Continued on next page.)

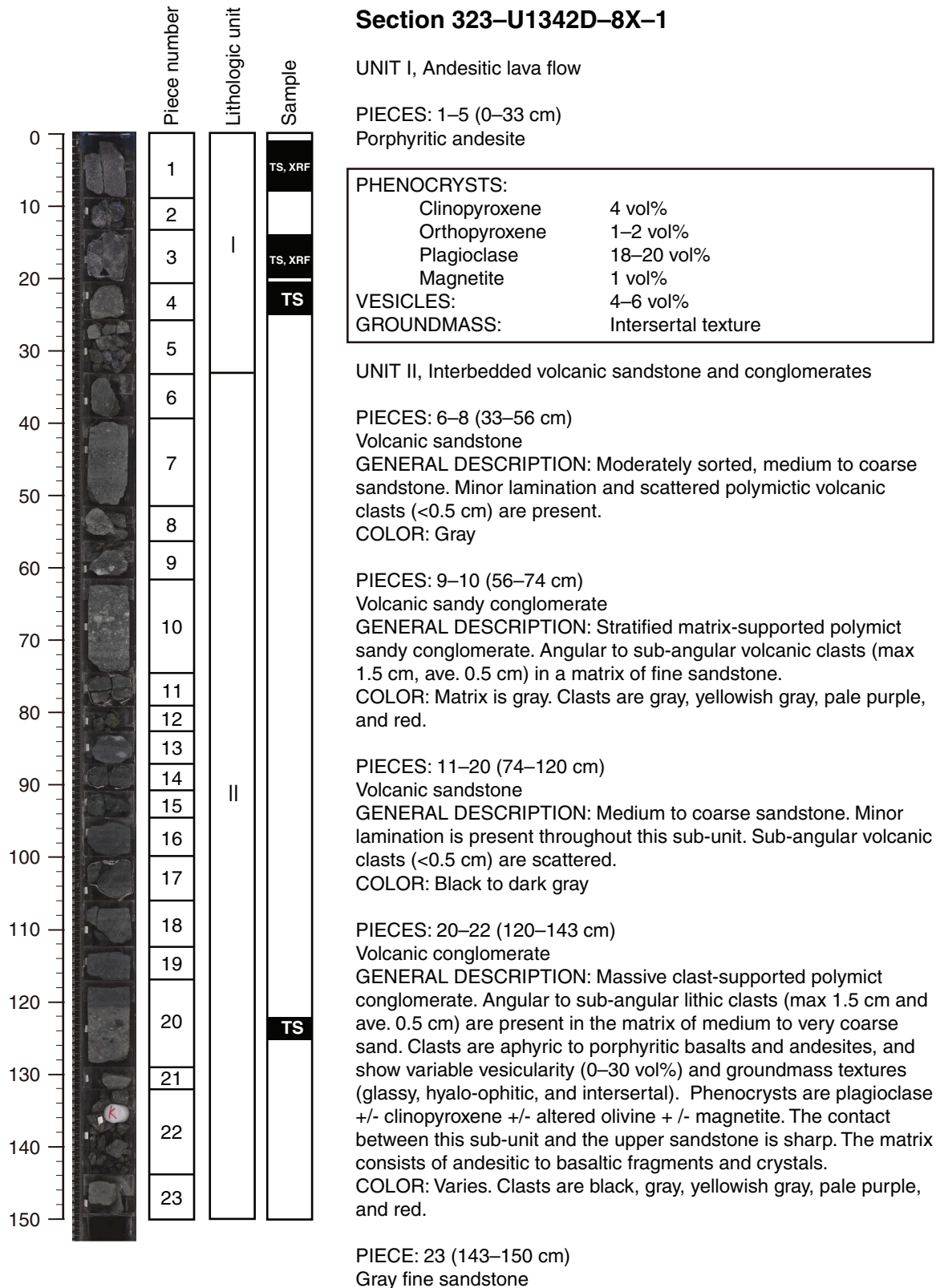


Figure F3 (continued).

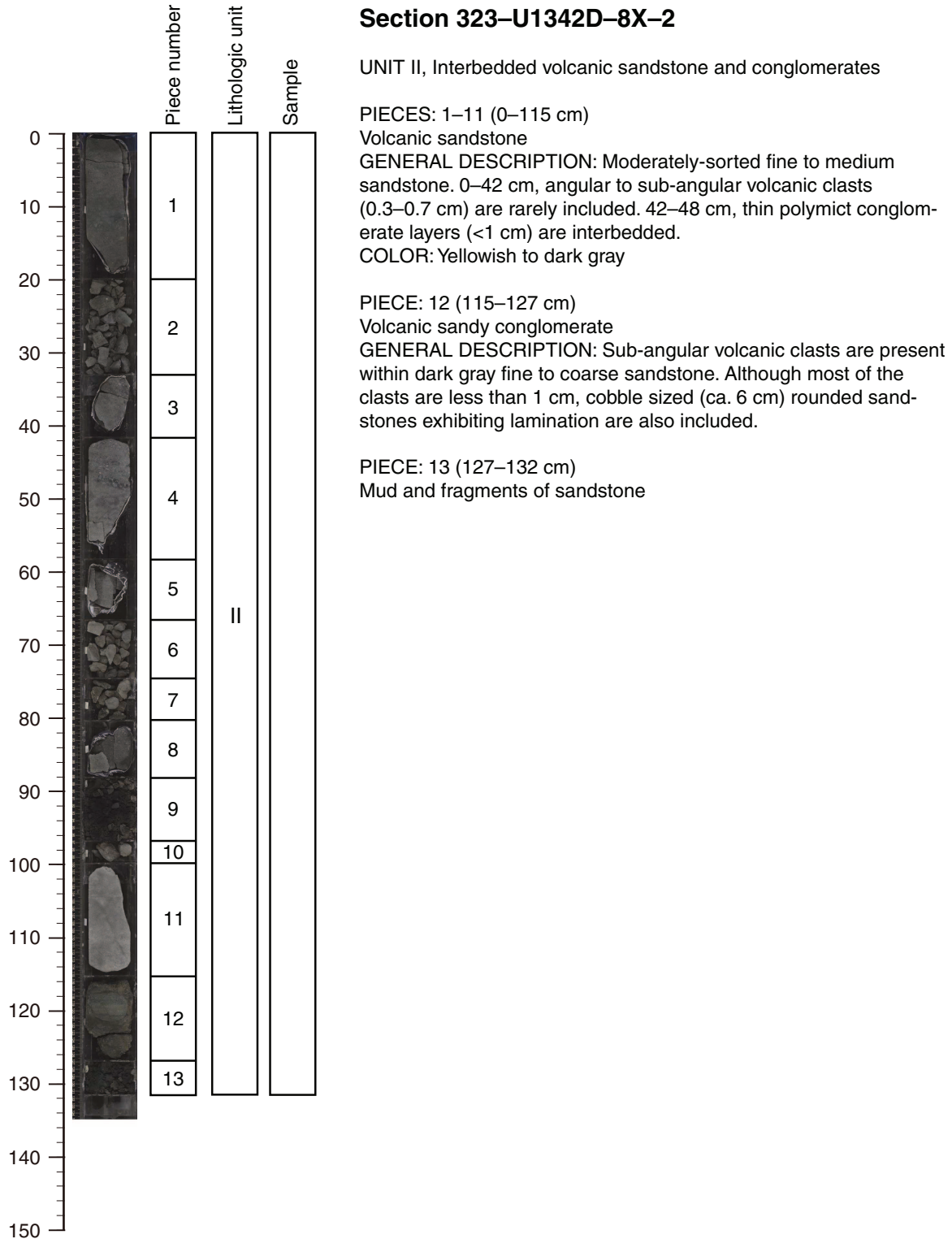


Figure F4. Description of Core 323-U1342A-9X.

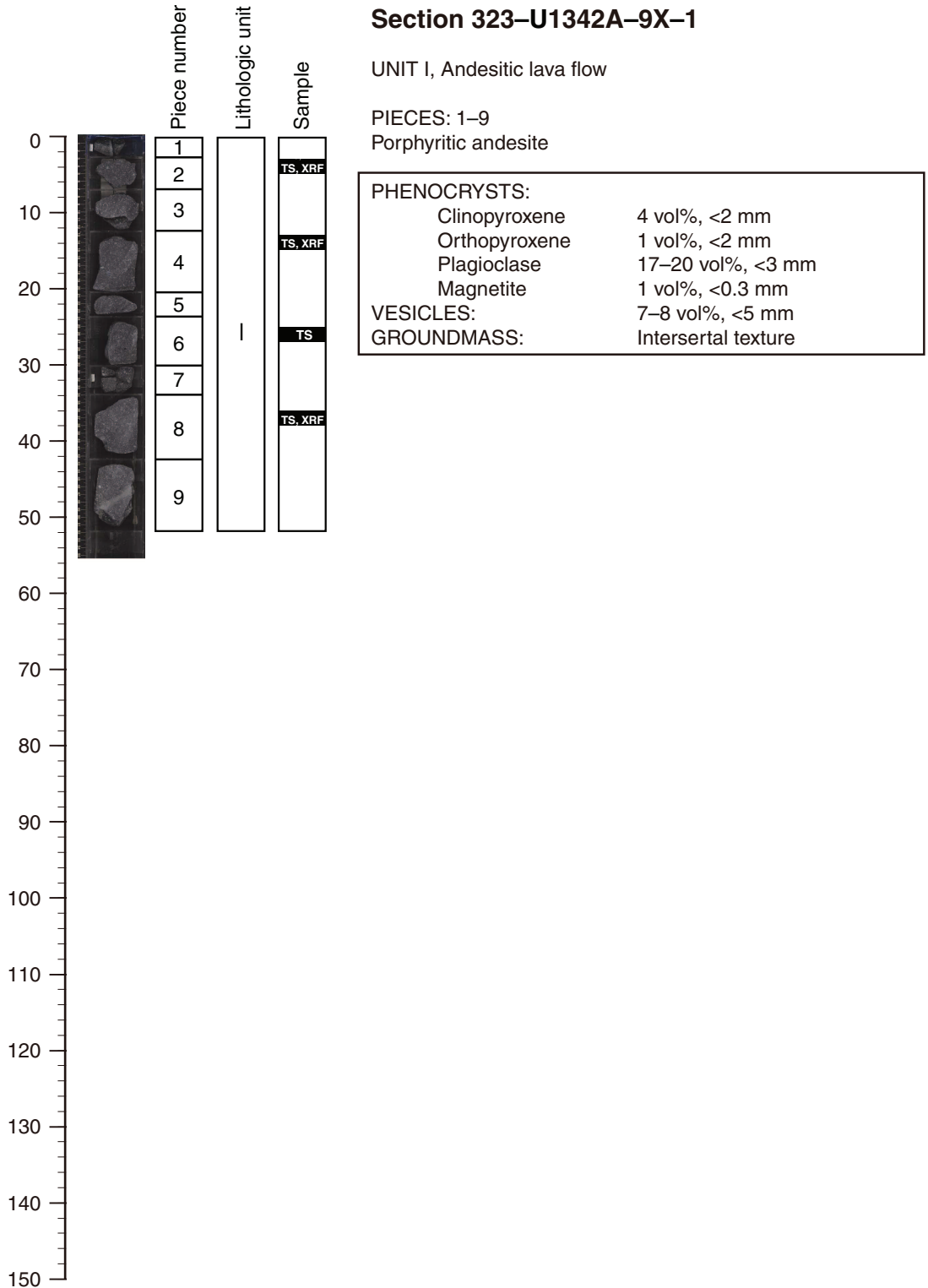




Figure F5. Description of Core 323-U1342D-9X. (Continued on next two pages.)

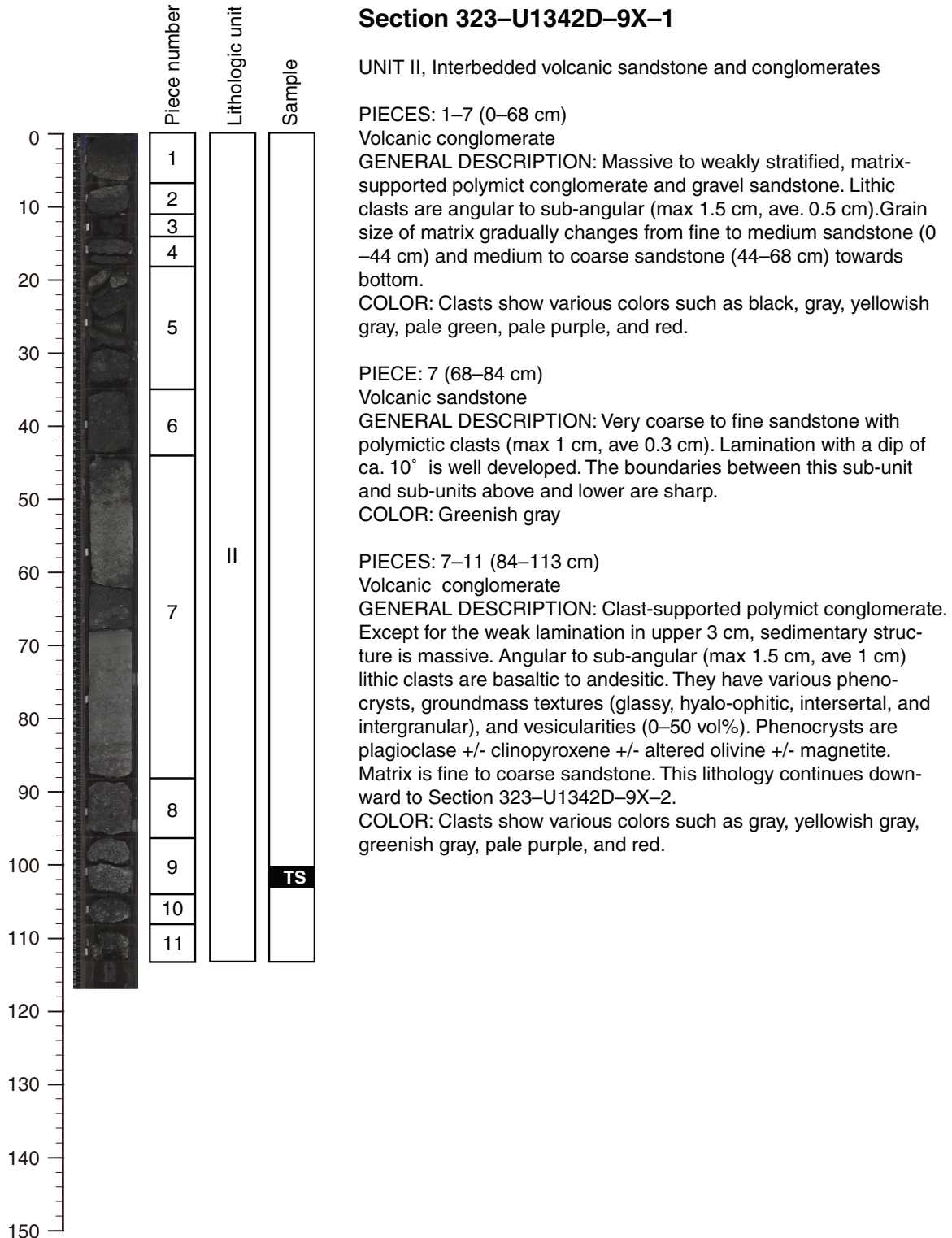


Figure F5 (continued). (Continued on next page.)

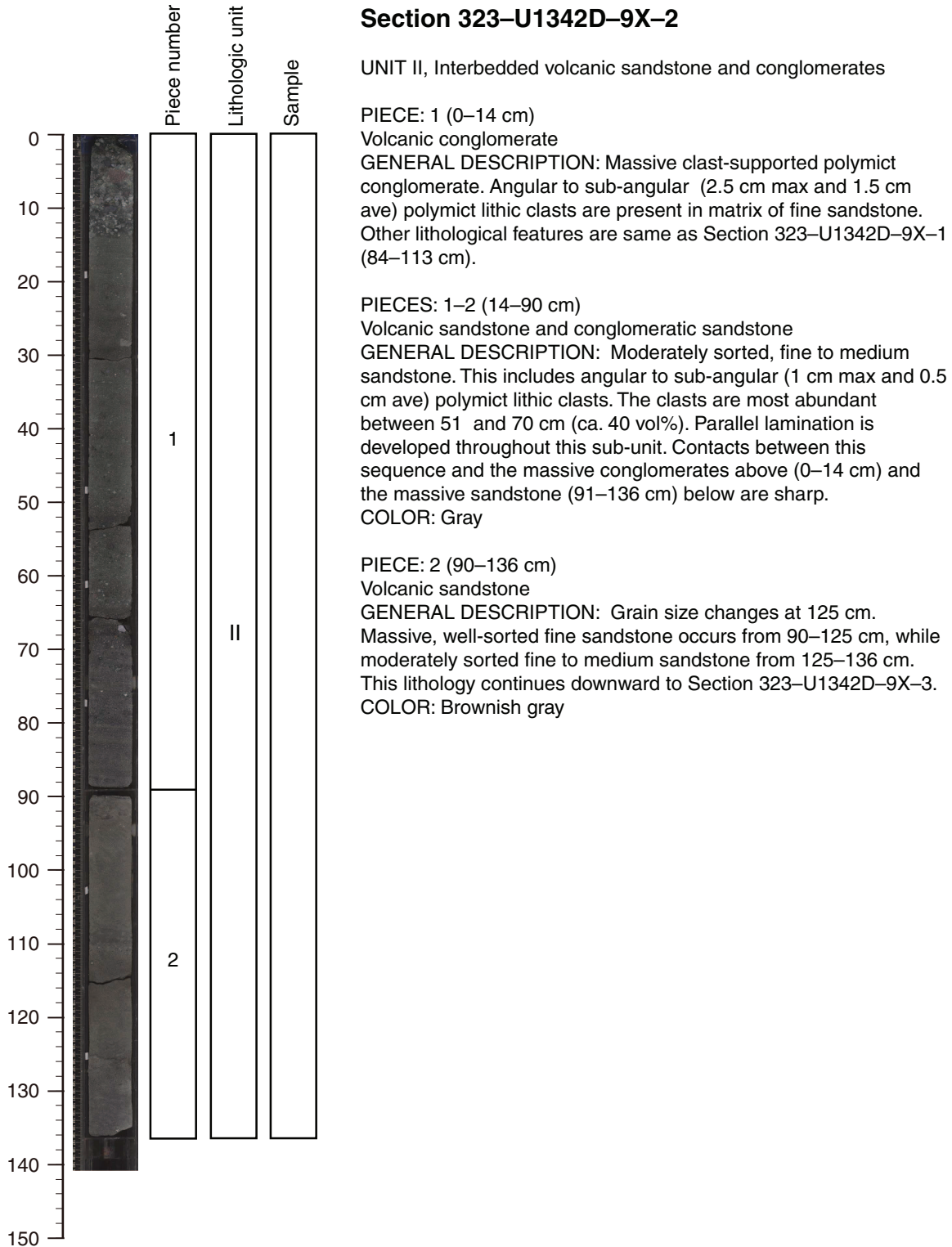
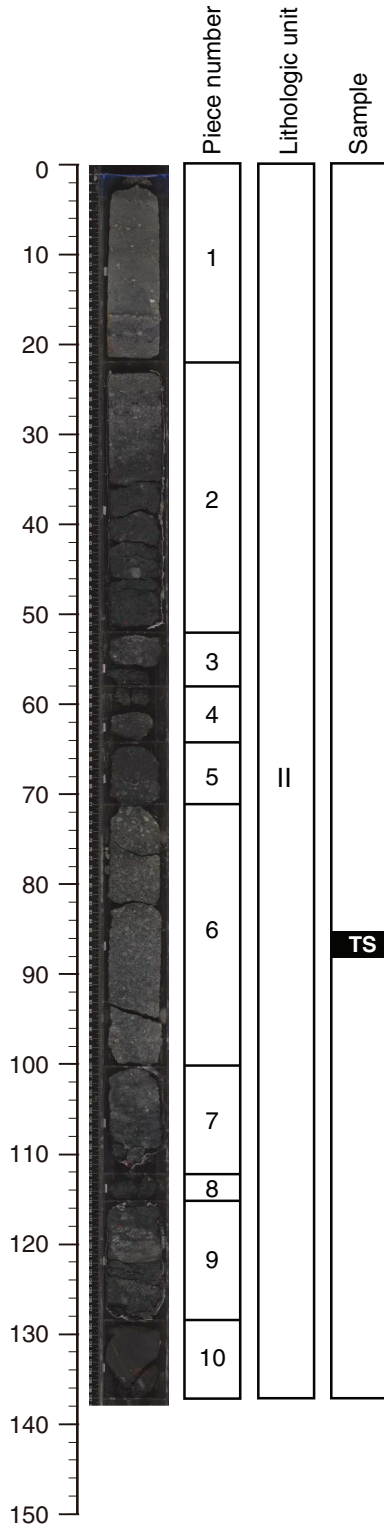


Figure F5 (continued).



**Section 323-U1342D-9X-3**

UNIT II, Interbedded volcanic sandstone and conglomerates

PIECE: 1 (0-16 cm)

Volcanic sandstone with lithic clasts

GENERAL DESCRIPTION: Weakly stratified, very coarse to fine-grained sandstone with scattered lithic clasts. The clasts are angular to sub-angular and <1 cm in size. The contact between this sub-unit and the lower conglomerate is sharp.

COLOR: Yellowish gray

PIECES: 1-9 (16-128 cm)

Volcanic conglomerate

GENERAL DESCRIPTION: Massive clast-supported polymict conglomerate. In the upper 5 cm thin coarse to very coarse sandstone layers are interbedded. Angular to sub-angular lithic clasts (max 2 cm and ave 0.4 cm) are in a matrix of very coarse to medium-grained sandstone. Clasts have various phenocrysts, groundmass textures (glassy, hyalo-ophitic, and intersertal), and vesicularities (0-30 vol%). Phenocrysts are plagioclase +/- clinopyroxene +/- altered olivine +/- magnetite.

COLOR: Clasts show various colors such as gray, yellowish gray, greenish gray, pale purple, and red.

PIECE: 10 (129-137 cm)

Volcanic sandstone

GENERAL DESCRIPTION: Massive medium sandstone. This lithology continues downward to Section 323-U1342D-10X-1.

COLOR: Dark gray

Figure F6. Description of Core 323-U1342D-10X. (Continued on next three pages.)

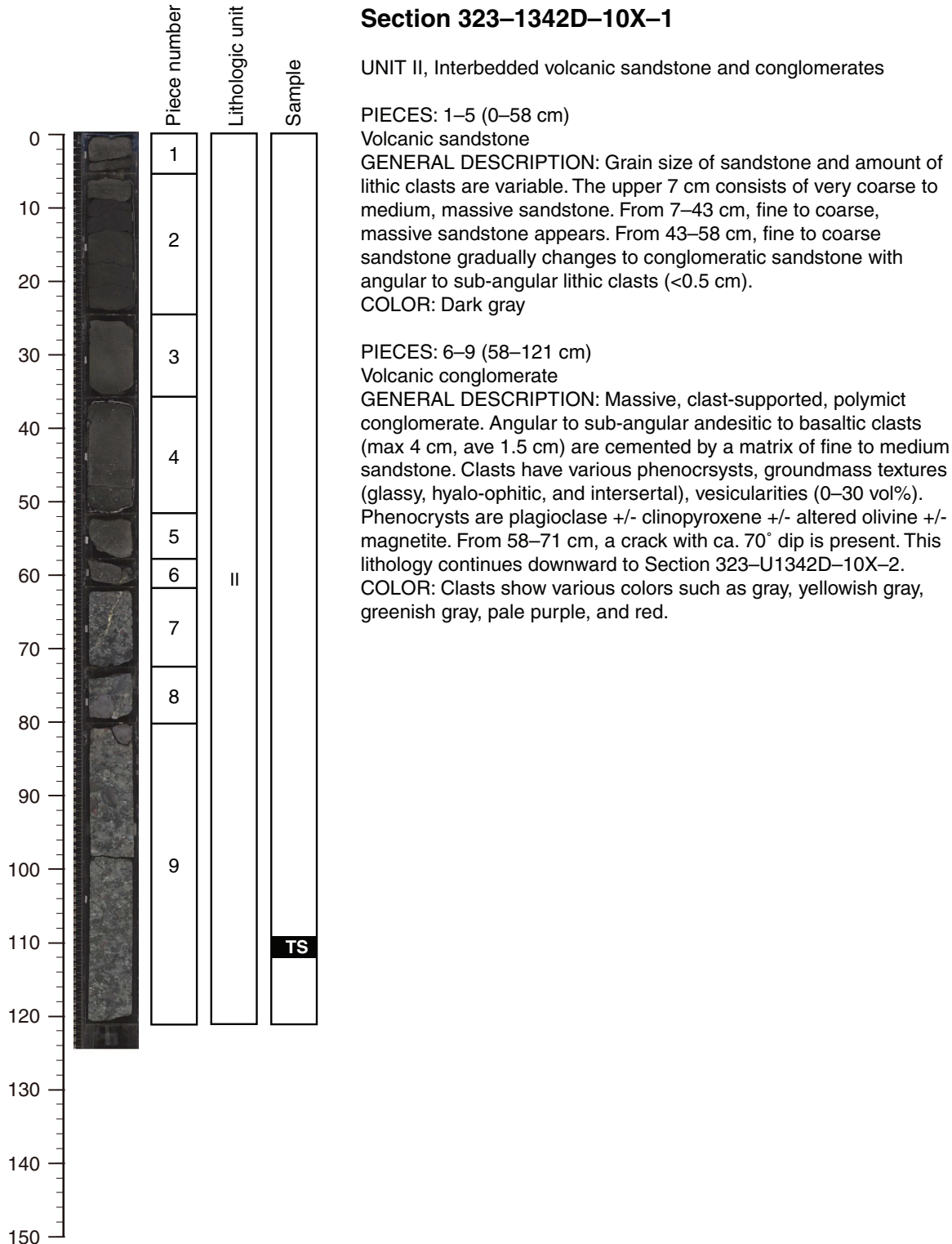


Figure F6 (continued). (Continued on next page.)

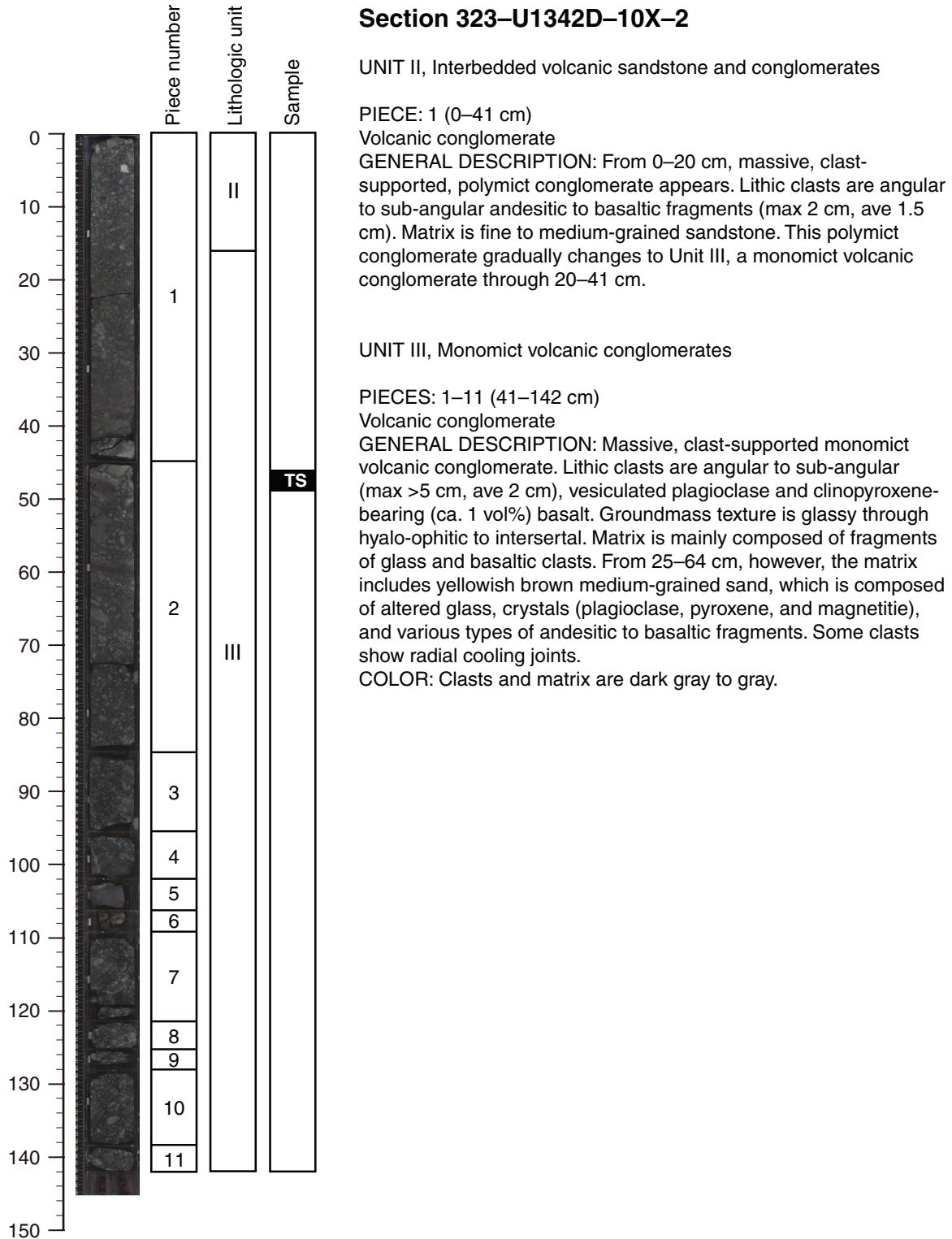


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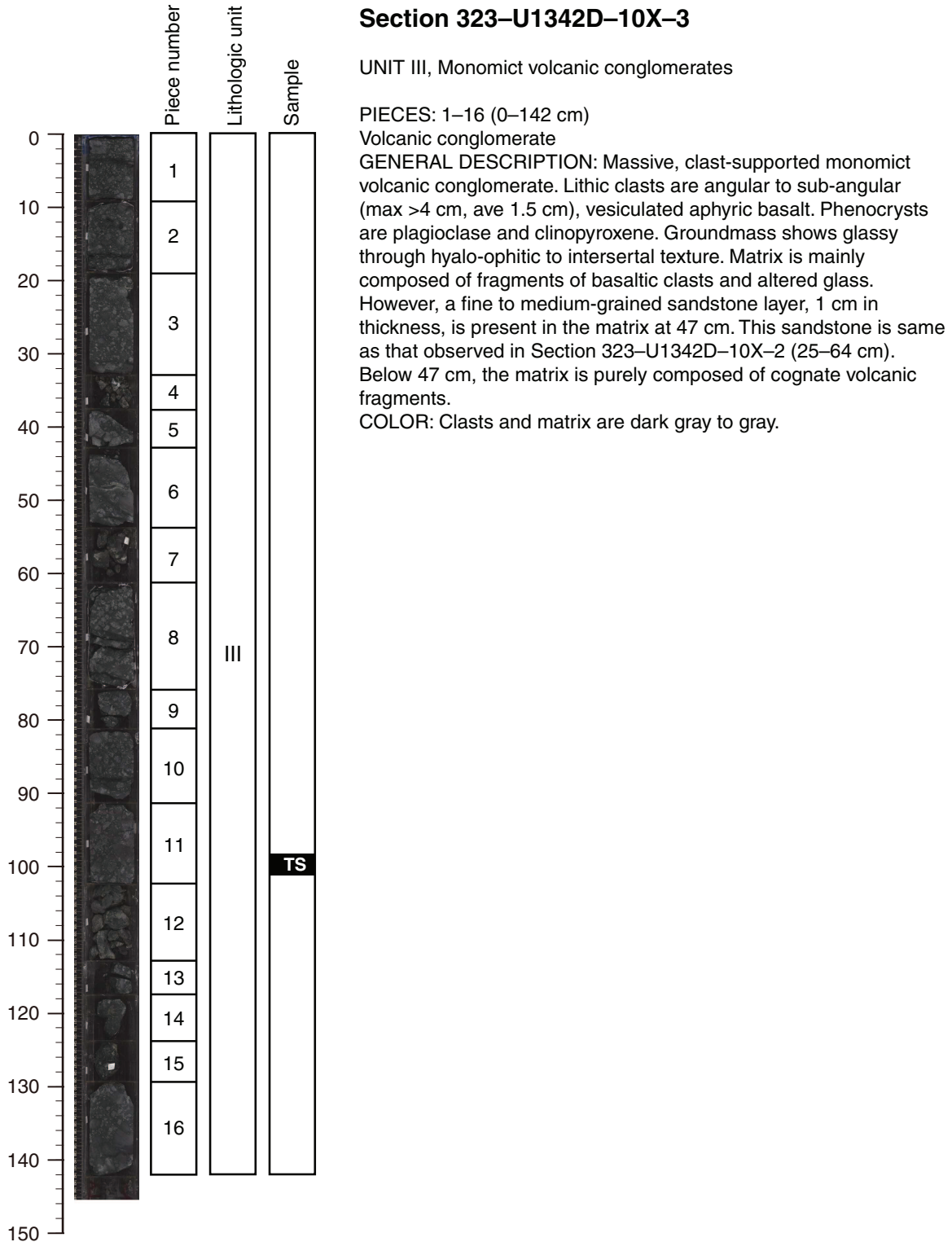




Figure F6 (continued).

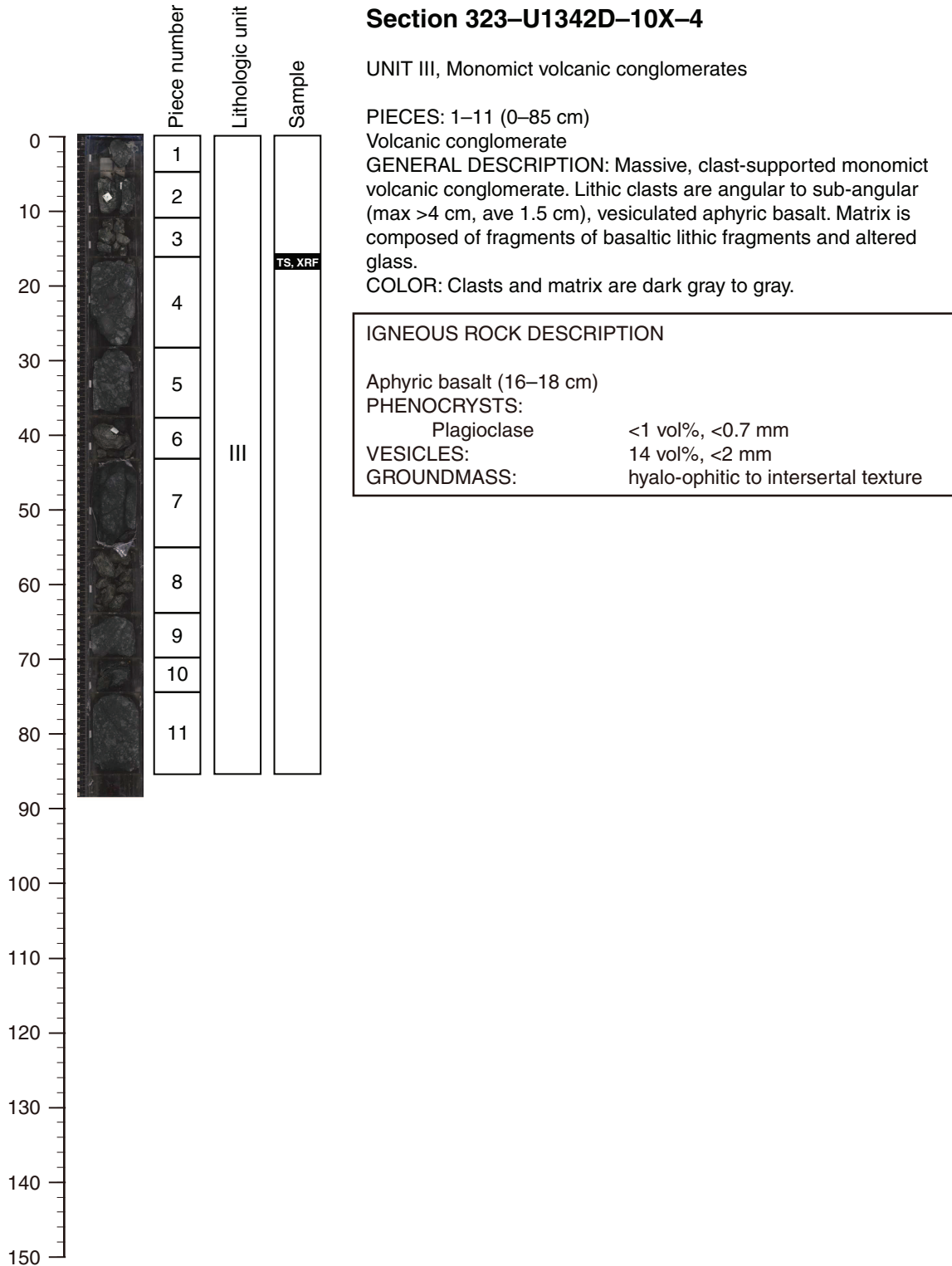


Figure F7. Description of Core 323-U1342D-11X. (Continued on next two pages.)

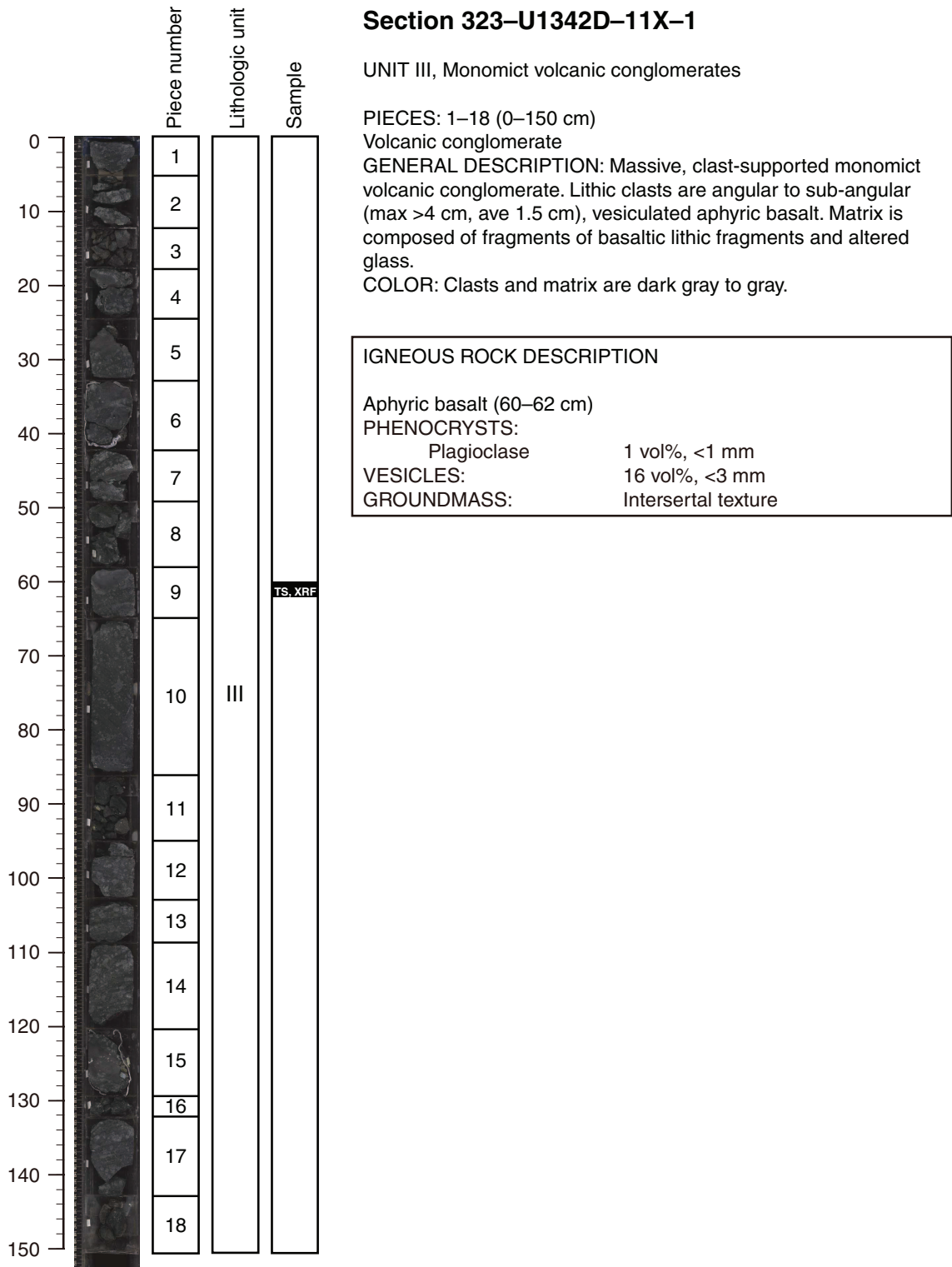


Figure F7 (continued). (Continued on next page.)

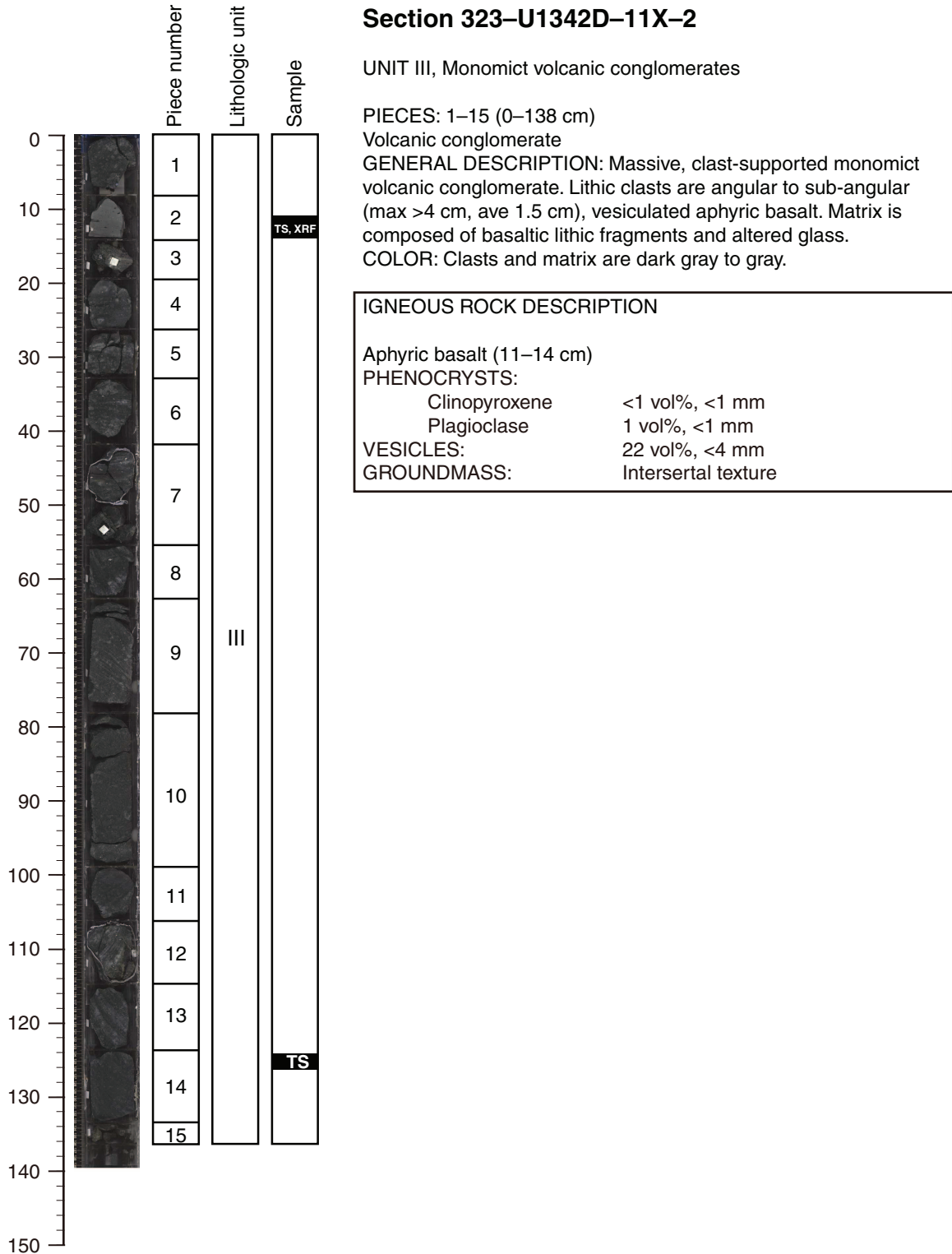


Figure F7 (continued).

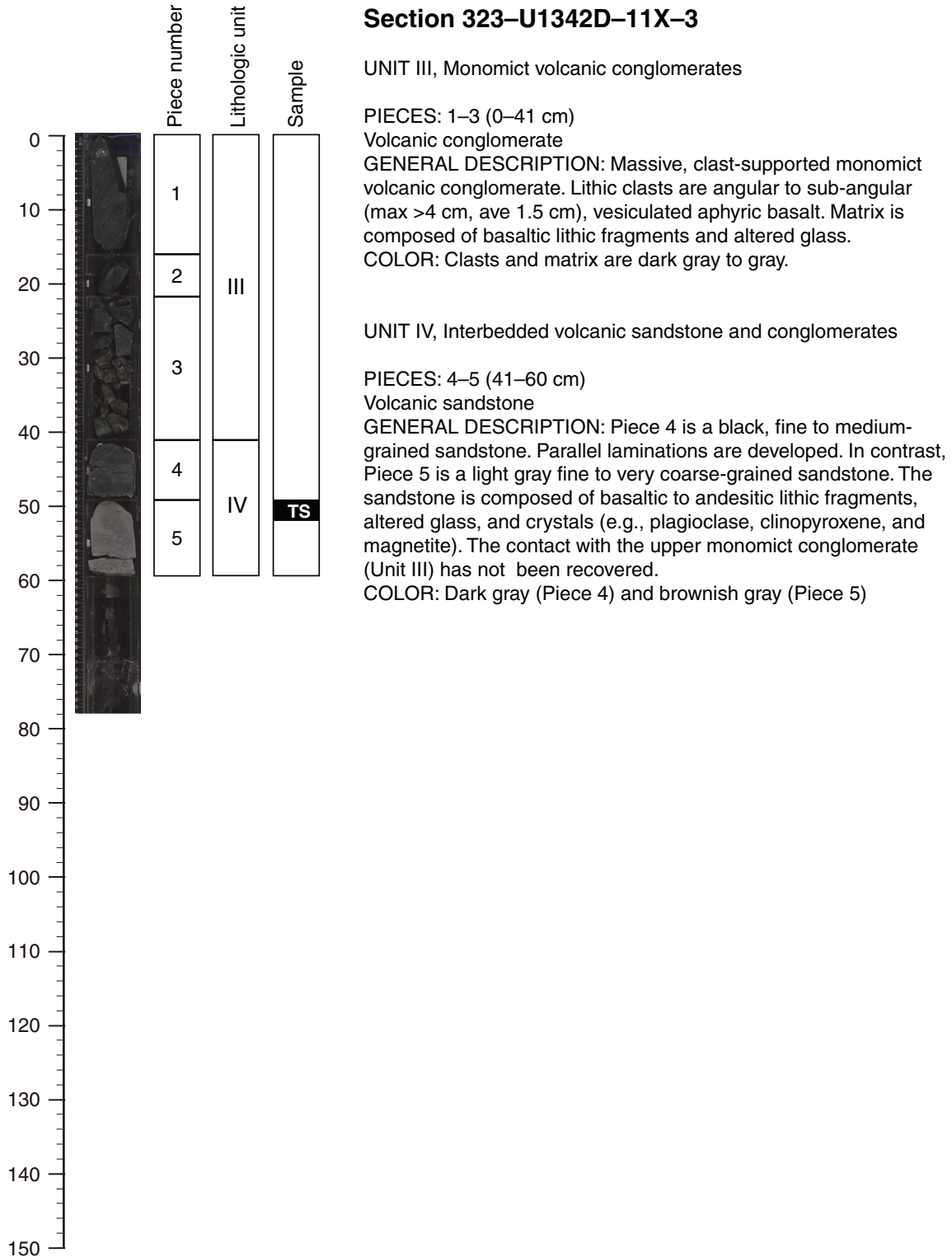


Figure F8. Description of Core 323-U1342D-12X. (Continued on next page.)

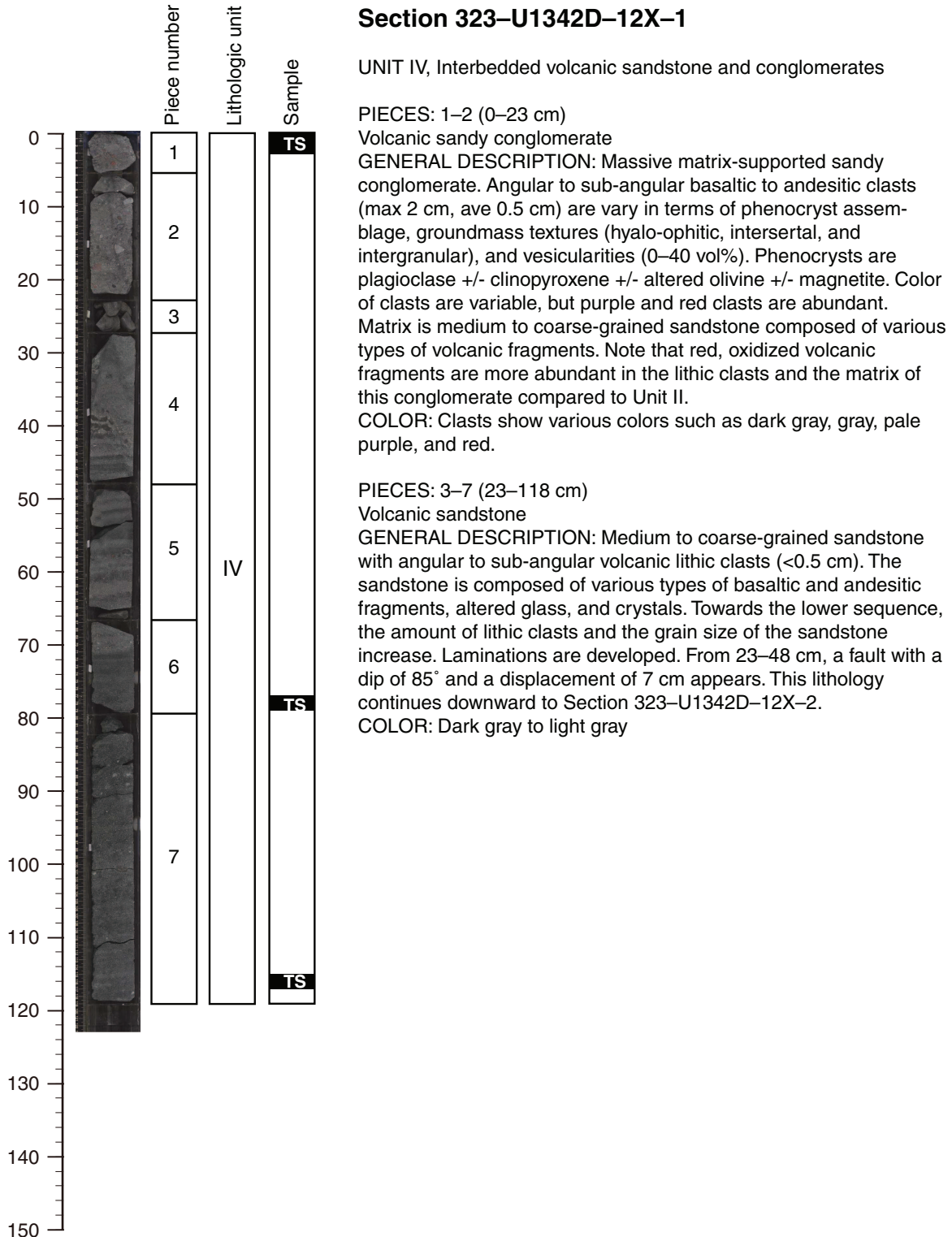
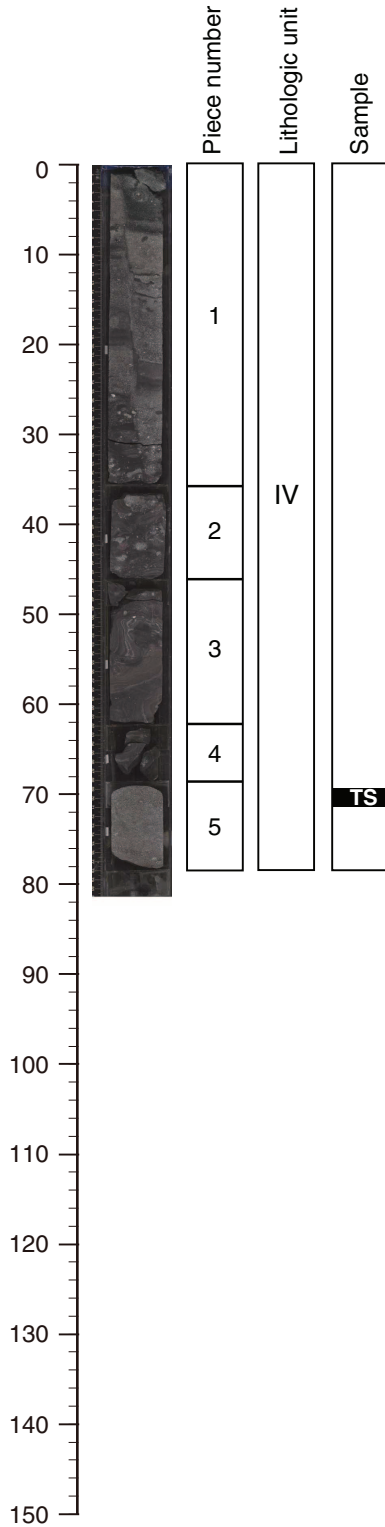


Figure F8 (continued).



**Section 323-U1342D-12X-2**

UNIT IV, Interbedded volcanic sandstone and conglomerates

PIECES: 1-4 (0-69 cm)

Volcanic sandstone

GENERAL DESCRIPTION: Very fine to coarse-grained sandstone.

Polymict clasts (max 2 cm, ave 1 cm) make up less than 5%.

From 0-35 cm, a fault with a dip of 85° and a displacement of 6 cm appears. From 48-68 cm, a slump structure is developed in dark gray sandstone with polymictic volcanic lithic clasts.

COLOR: Black to dark brown

PIECE: 5 (69-78 cm)

Volcanic sandstone

GENERAL DESCRIPTION: Moderately sorted, fine to medium-grained sandstone. The sandstone is composed of volcanic lithic fragments (sub-angular), altered glass, and crystals such as plagioclase, clinopyroxene, and magnetite. Weak parallel laminations are developed.

COLOR: Pale reddish gray



Figure F9. Description of Core 323-U1342D-13X. (Continued on next three pages.)

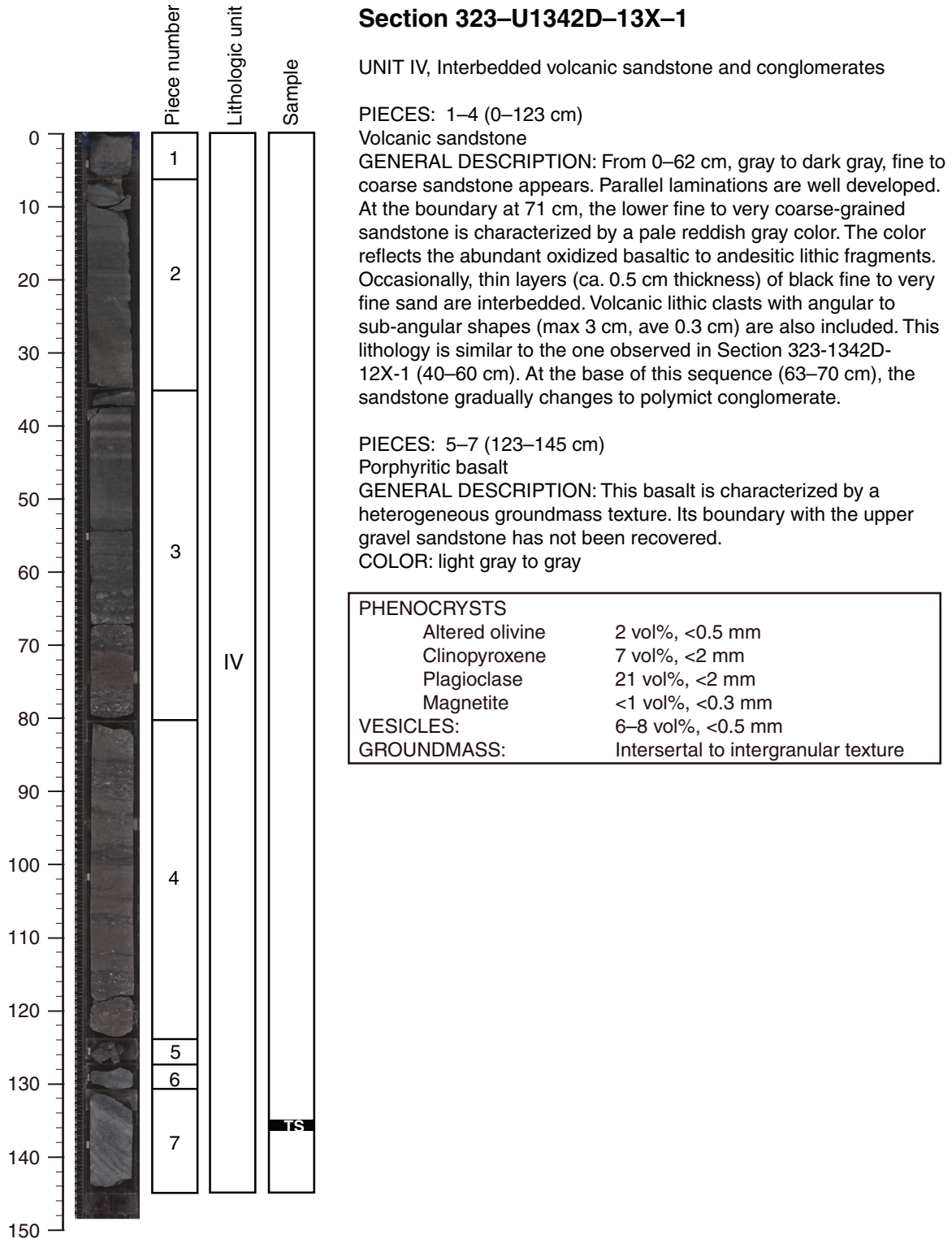


Figure F9 (continued). (Continued on next page.)

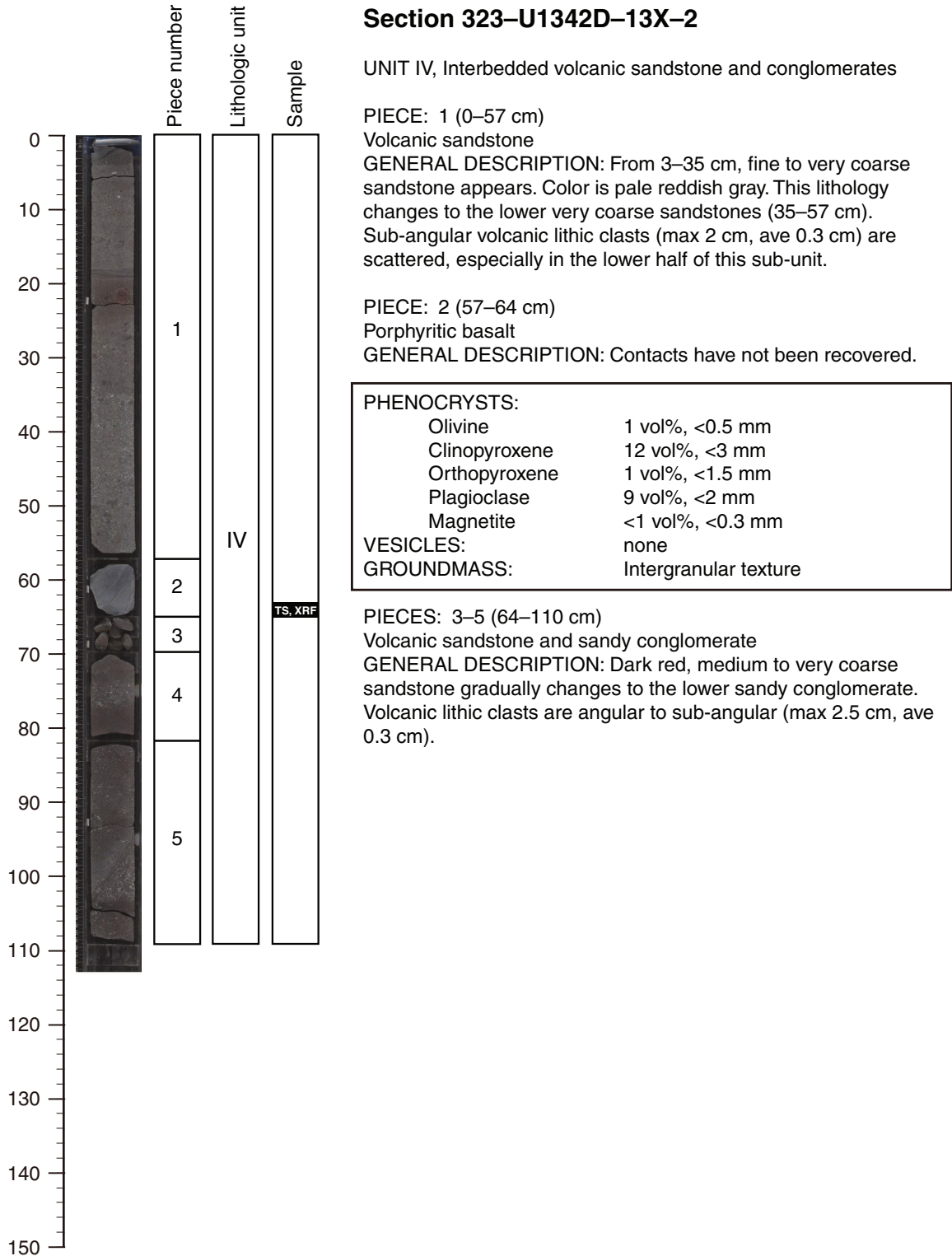


Figure F9 (continued). (Continued on next page.)

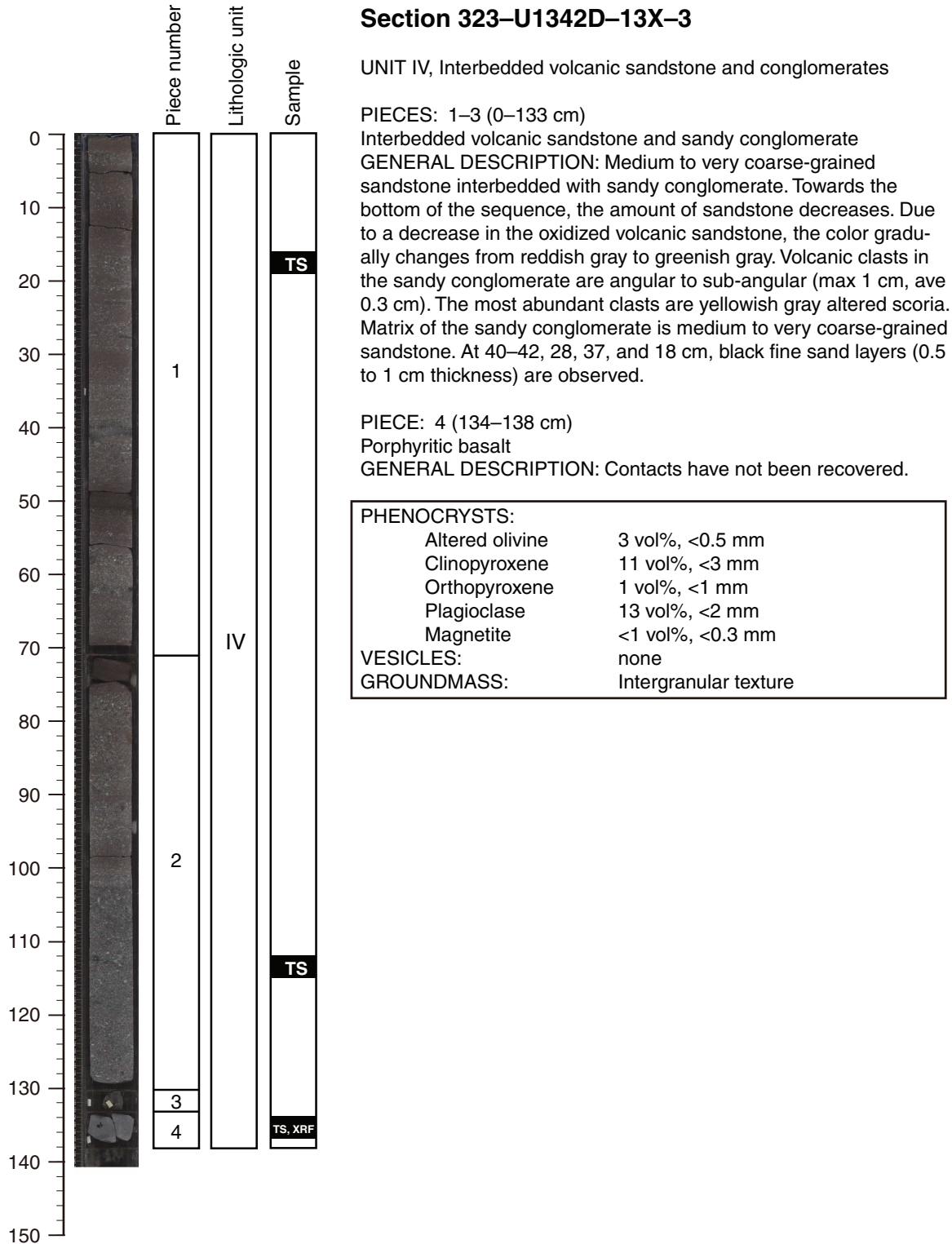
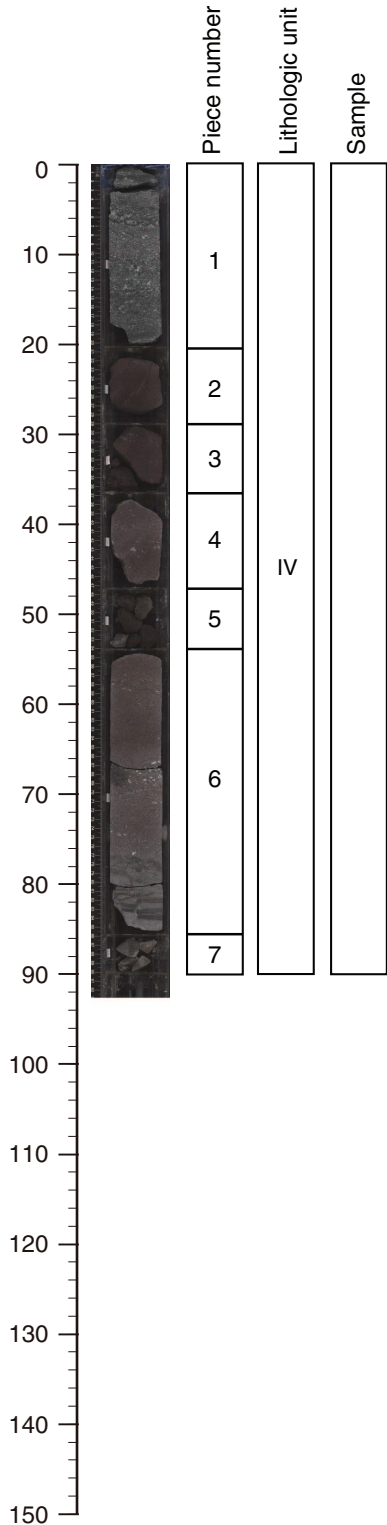


Figure F9 (continued).



**Section 323-U1342D-13X-4**

UNIT IV, Interbedded volcanic sandstone and conglomerates

PIECE: 1 (0-20 cm)

Volcanic sandy conglomerate

GENERAL DESCRIPTION: Polymict sandy conglomerate, showing similar lithology to that in Section 323-1342D-13X-3 (100-130 cm). Volcanic lithic clasts are angular to sub-angular (max 1 cm, ave 0.3 cm). Most abundant clasts are yellowish gray vesiculated basalt. Matrix is medium to very coarse-grained sandstone. Contact between this sequence and the lower reddish sandstone is at 20 cm.

COLOR: Greenish gray

PIECES: 1-7 (20-86 cm)

Volcanic sandstone

GENERAL DESCRIPTION: Fine to medium-grained sandstone with weak parallel laminations. Color gradually changes from reddish gray to pale reddish gray reflecting the change in the amount of oxidized volcanic fragments. From 77-90 cm, very fine (black) to medium (gray) sandstone with parallel laminations is faulted. The fault plane has a dip of 75°, and a displacement of ca. 1 cm. Polymict volcanic lithic clasts (max 1.5 cm, ave 0.3 cm) are scattered within the sandstone. This lithology continues downward to Section 323-1342D-14X-1.

COLOR: Reddish gray to pale reddish gray

Figure F10. Description of Core 323-U1342D-14X. (Continued on next two pages.)

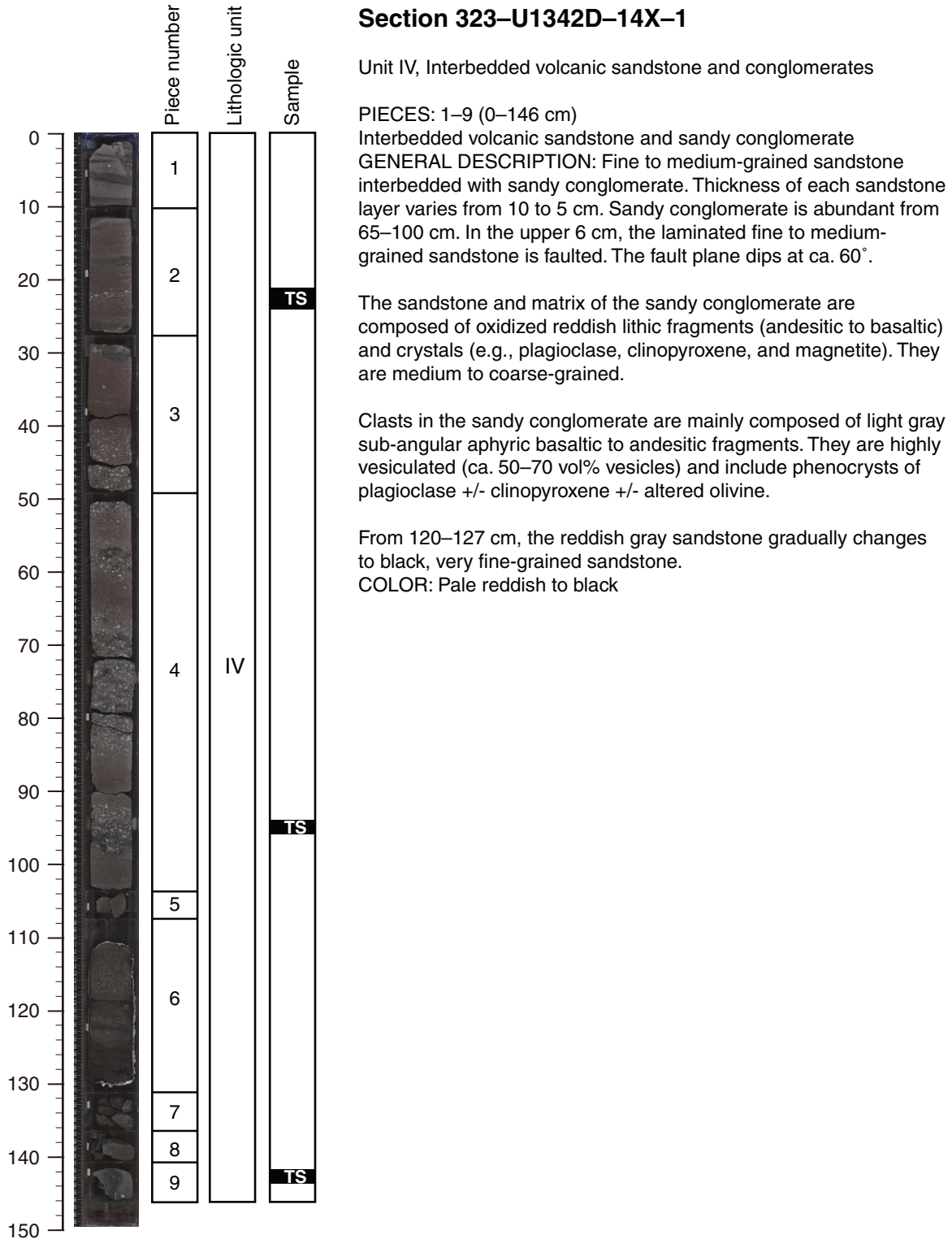


Figure F10 (continued). (Continued on next page.)

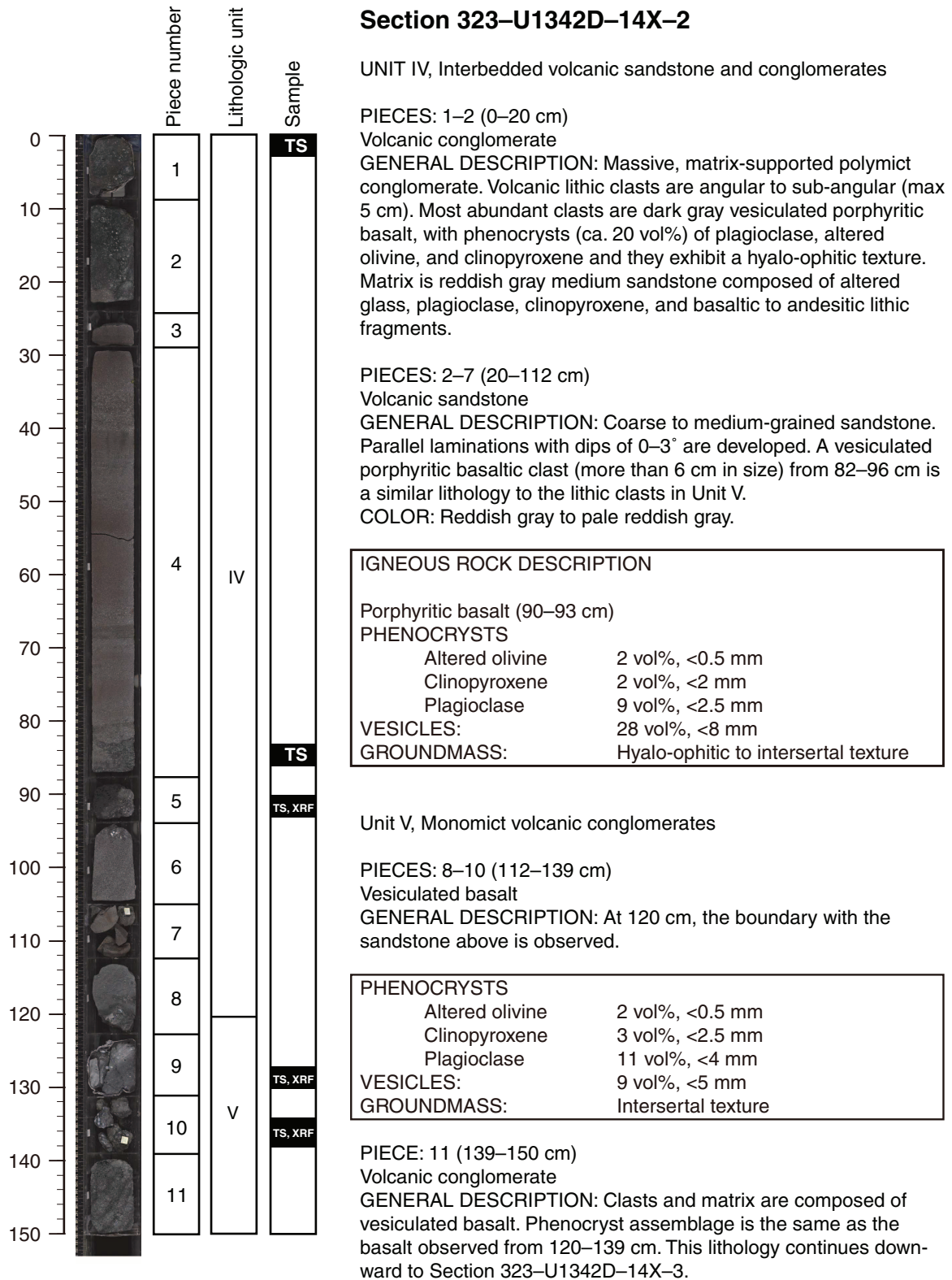




Figure F10 (continued).

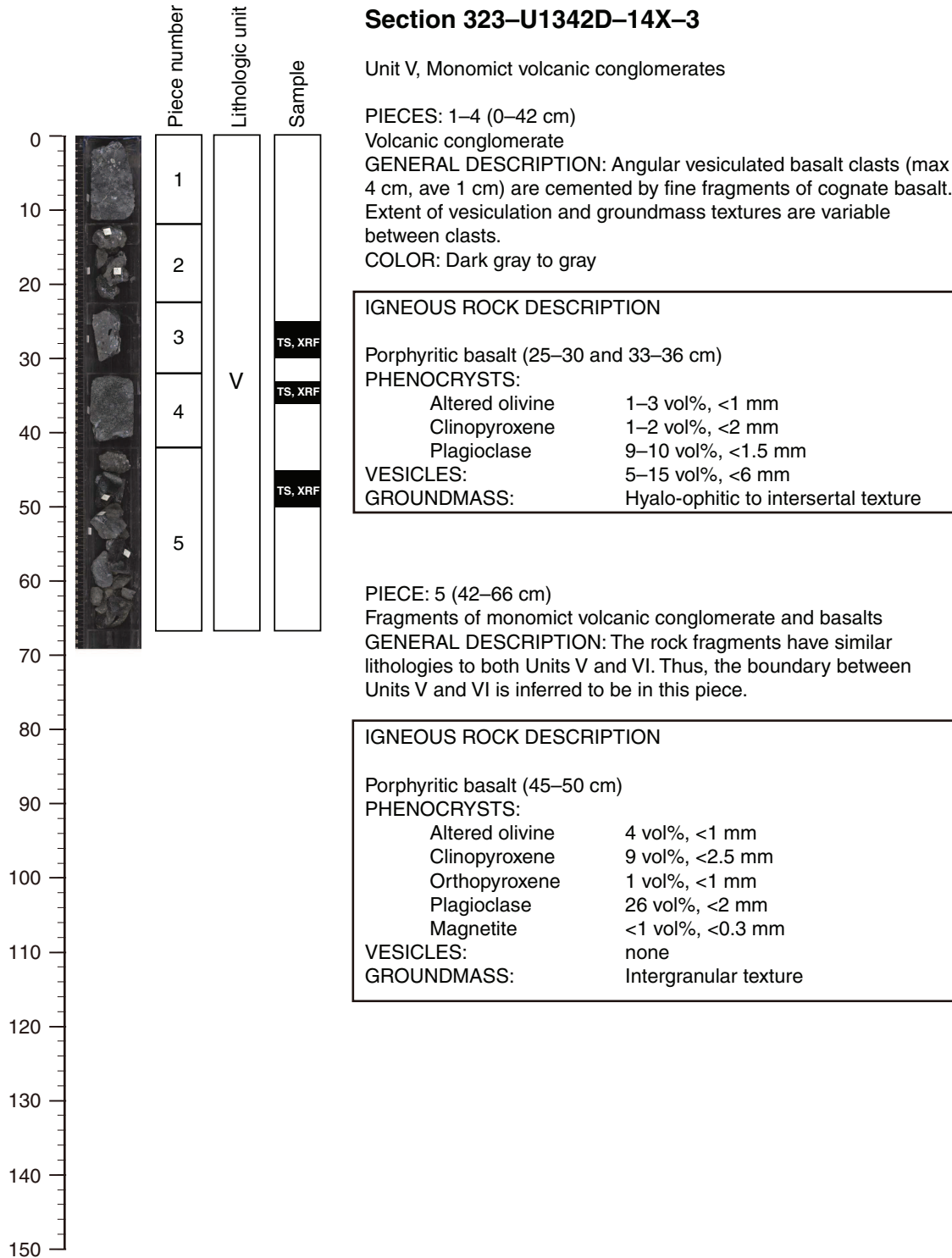


Figure F11. Description of Core 323-U1342D-15X. (Continued on next page.)

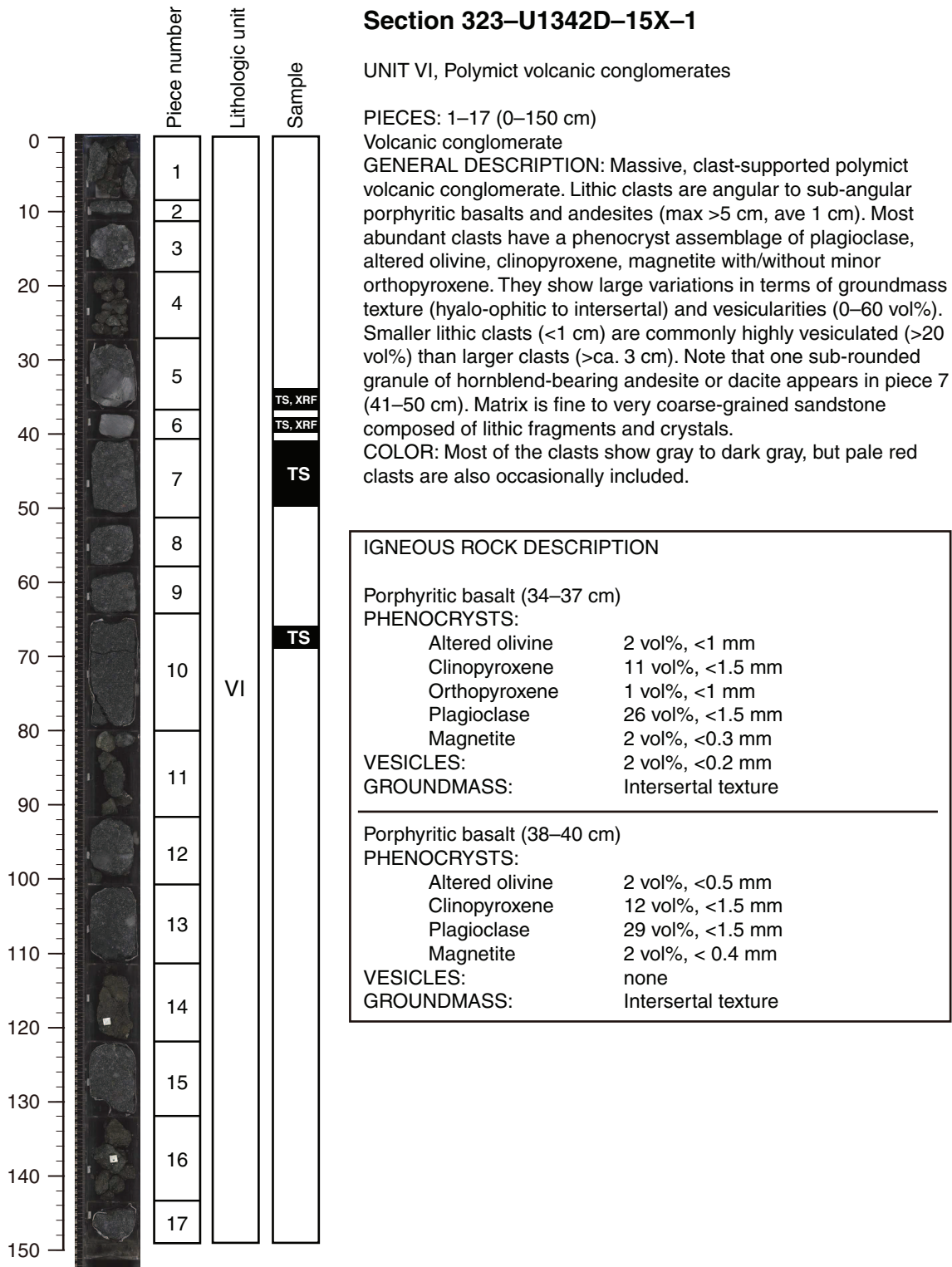


Figure F11 (continued).

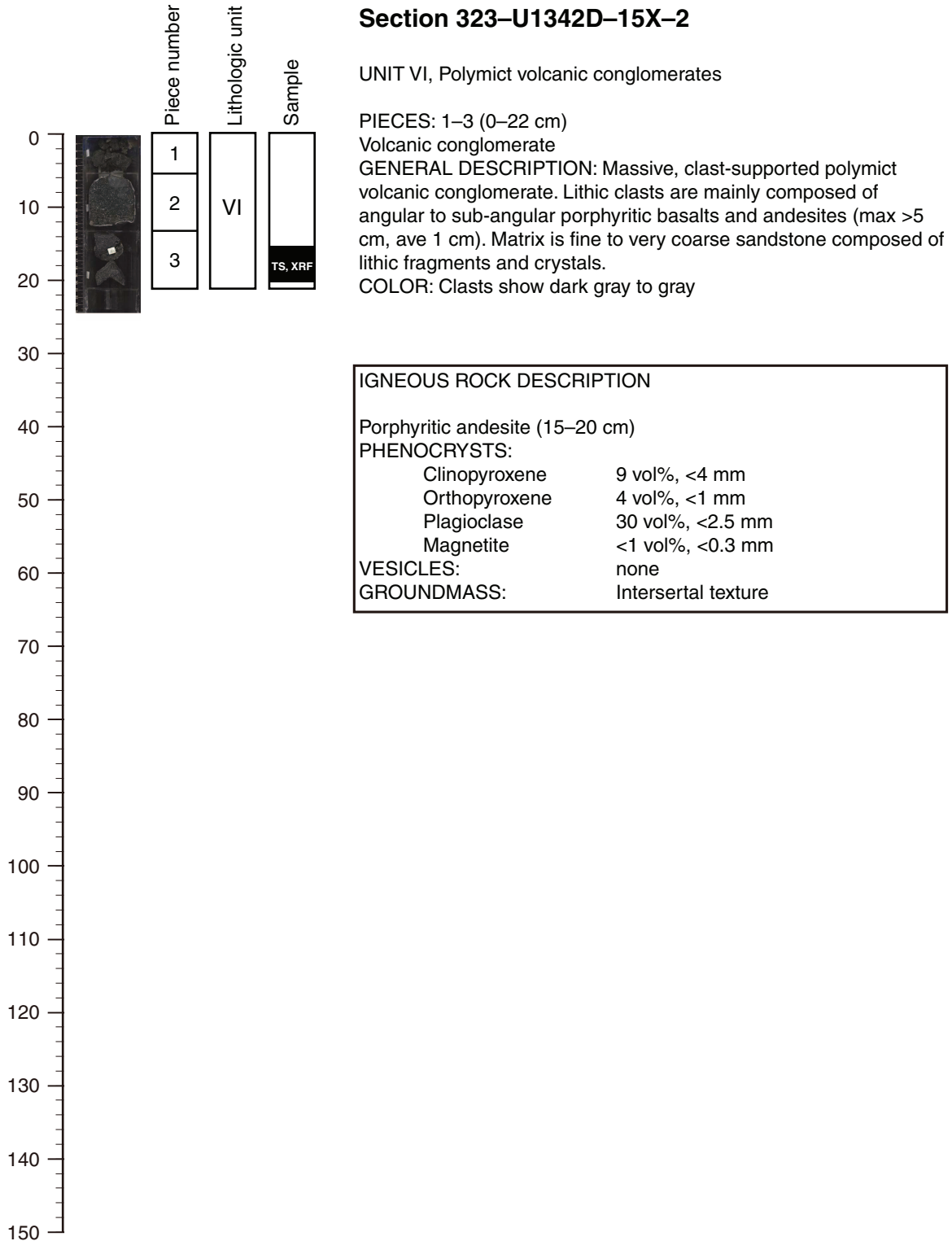


Figure F12. Description of Core 323-U1342D-16X. (Continued on next page.)

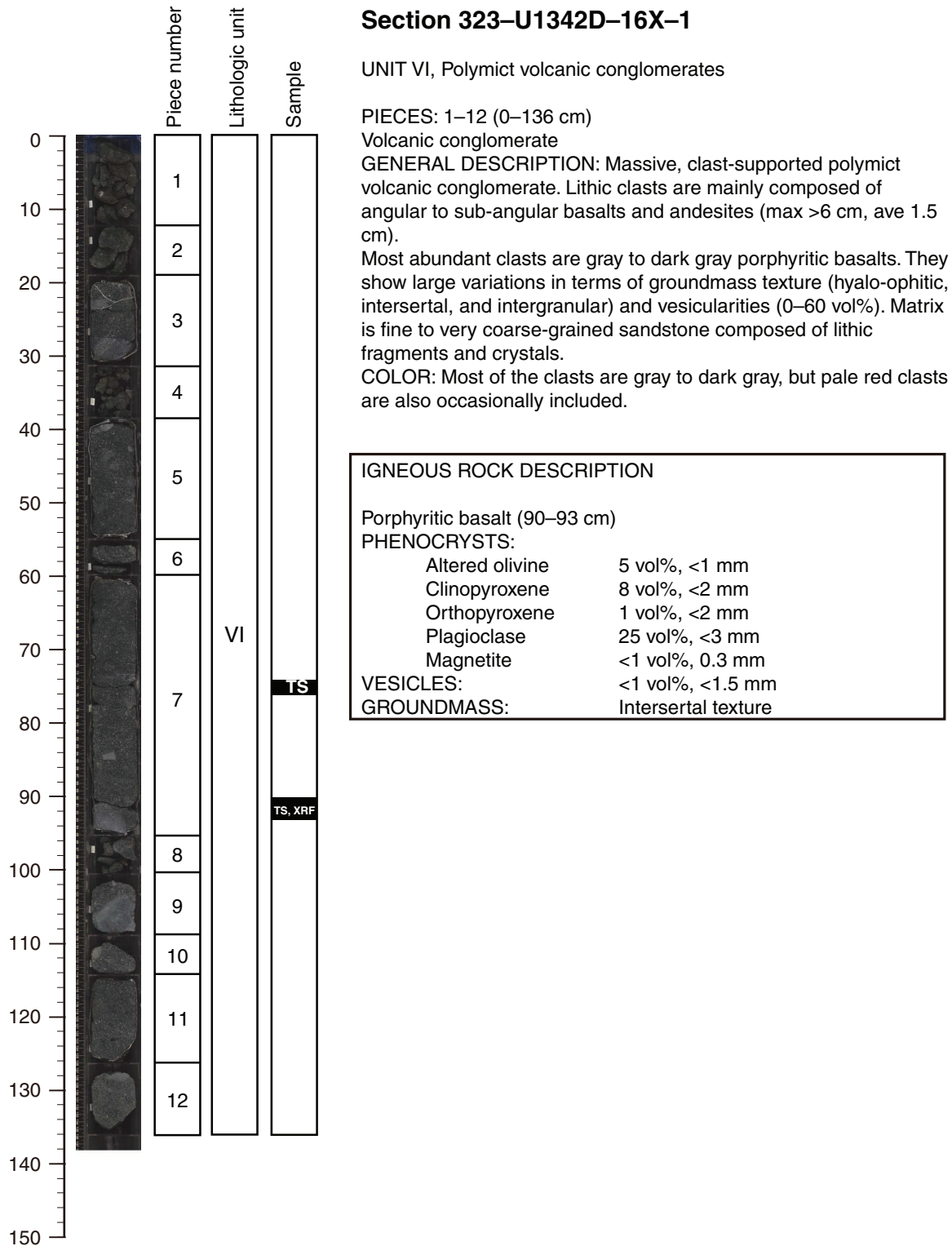


Figure F12 (continued).

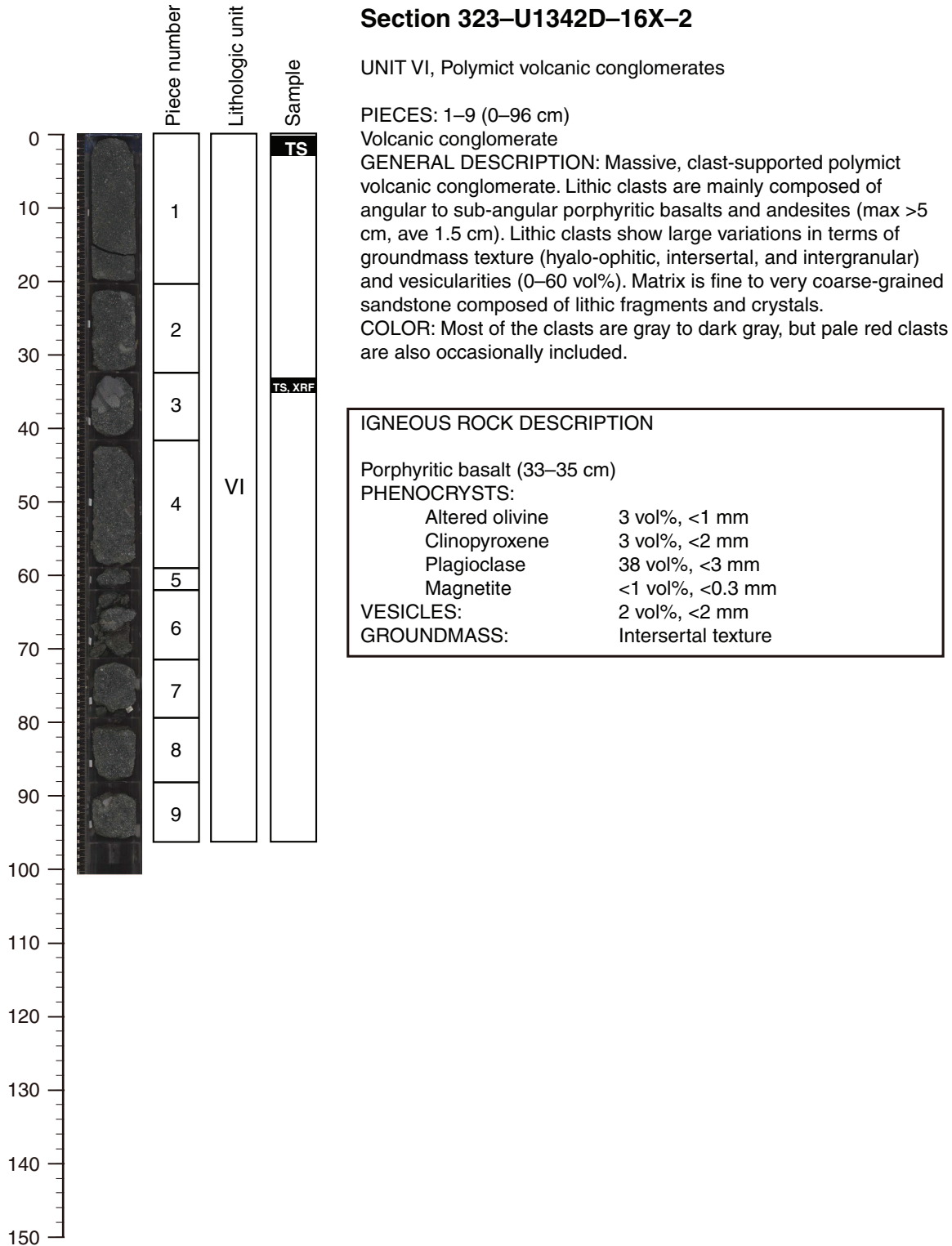


Figure F13. Description of Core 323-U1342D-17X. (Continued on next four pages.)

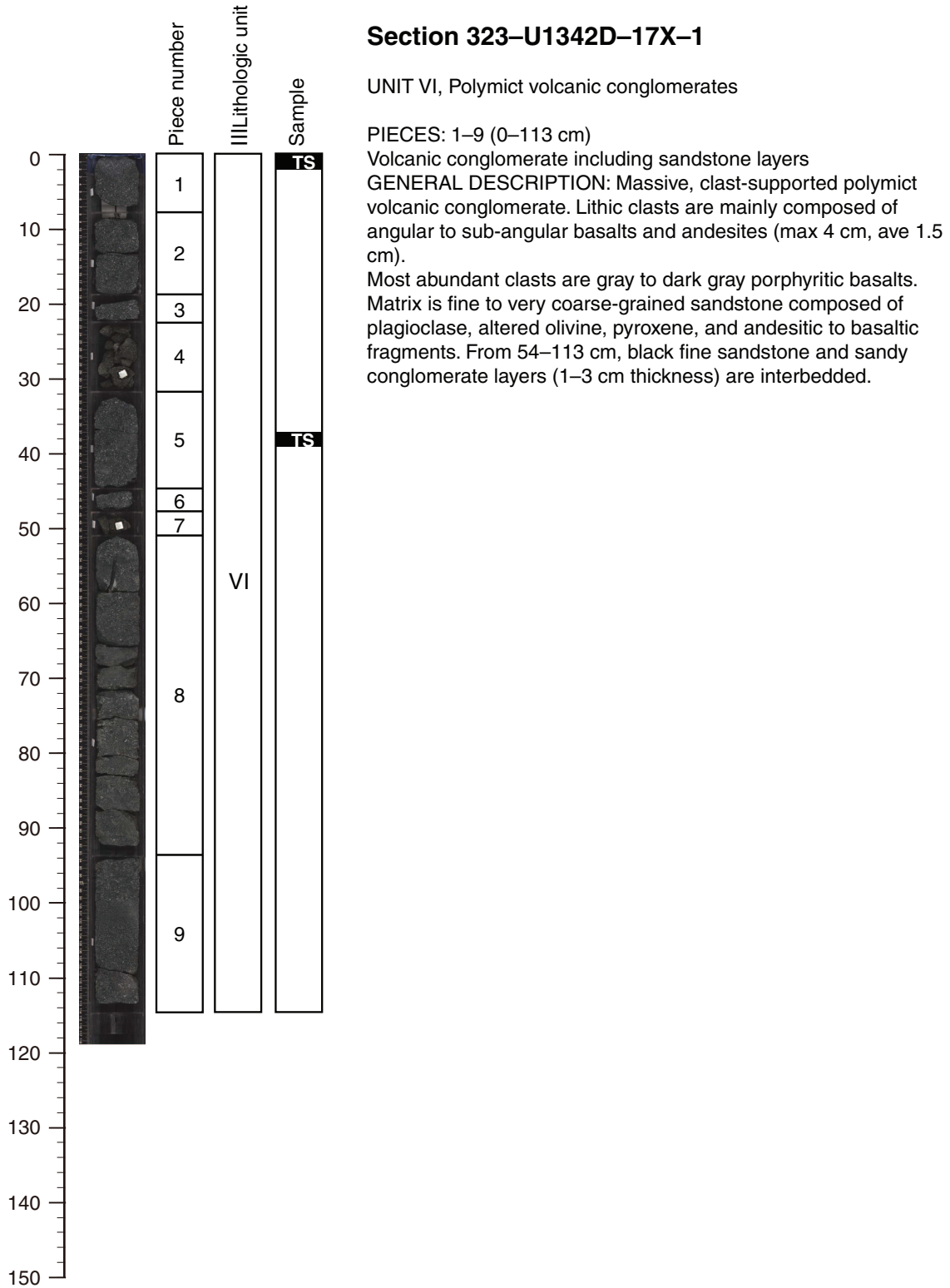
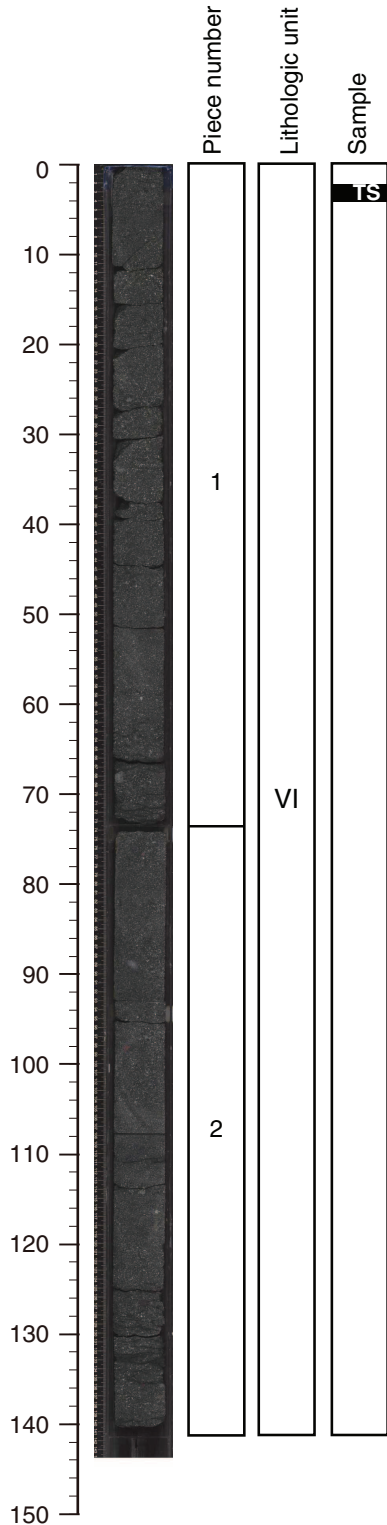


Figure F13 (continued). (Continued on next page.)



**Section 323-U1342D-17X-2**

Unit VI, Polymict volcanic conglomerates

PIECES: 1-2 (0-140 cm)

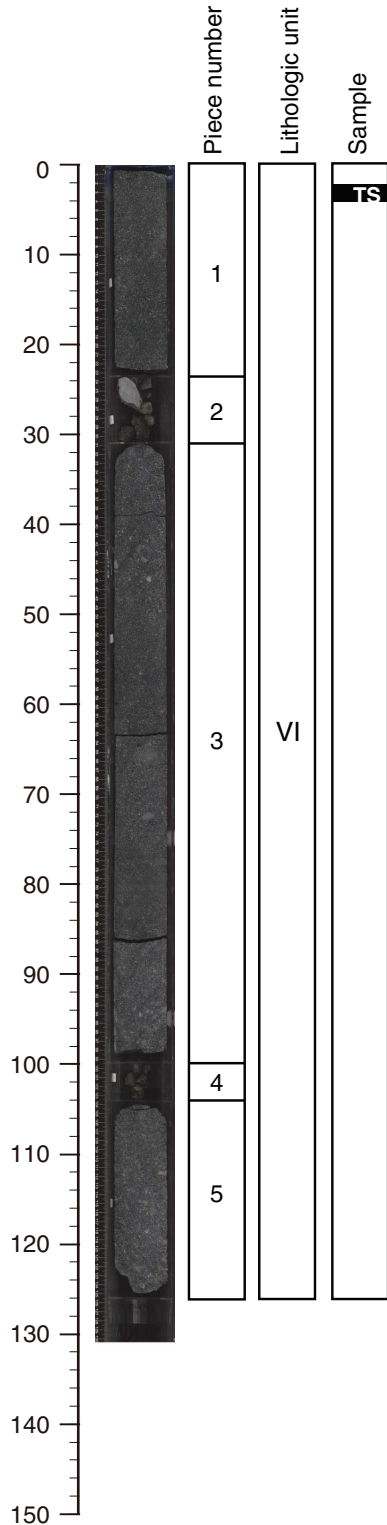
Volcanic sandy conglomerate

GENERAL DESCRIPTION: Massive to weakly stratified sandy conglomerate. Lithic clasts are mainly composed of angular to sub-angular basalts and andesites (max 1.5 cm, ave 0.3 cm). Most abundant clasts are gray to dark gray porphyritic basalt. Matrix is fine to very coarse-grained sandstone composed of crystals (plagioclase, altered olivine, pyroxene, magnetite) and andesitic to basaltic fragments. From 105-108 cm and 113-116 cm, medium dark gray sandstone layers are interbedded.

COLOR: Most of the clasts are dark gray to gray, but pale red clasts are also present.



Figure F13 (continued). (Continued on next page.)



**Section 323-U1342D-17X-3**

UNIT VI, Polymict volcanic conglomerates

PIECES: 1-5 (0-125 cm)

Volcanic conglomerate

GENERAL DESCRIPTION: Massive polymict conglomerate. Lithic clasts are mainly composed of angular to sub-angular basalts and andesites (max 2 cm, ave 0.3 cm). Most abundant clasts are gray to dark gray porphyritic basalt. Matrix is medium to very coarse-grained sandstone composed of crystals (plagioclase, altered olivine, pyroxene, magnetite) and andesitic to basaltic fragments. Thin medium to very coarse-grained sandstone layers are interbedded between 75 and 85 cm.

COLOR: Most of the clasts are gray to dark gray, but pale red clasts are also occasionally included.

Figure F13 (continued). (Continued on next page.)

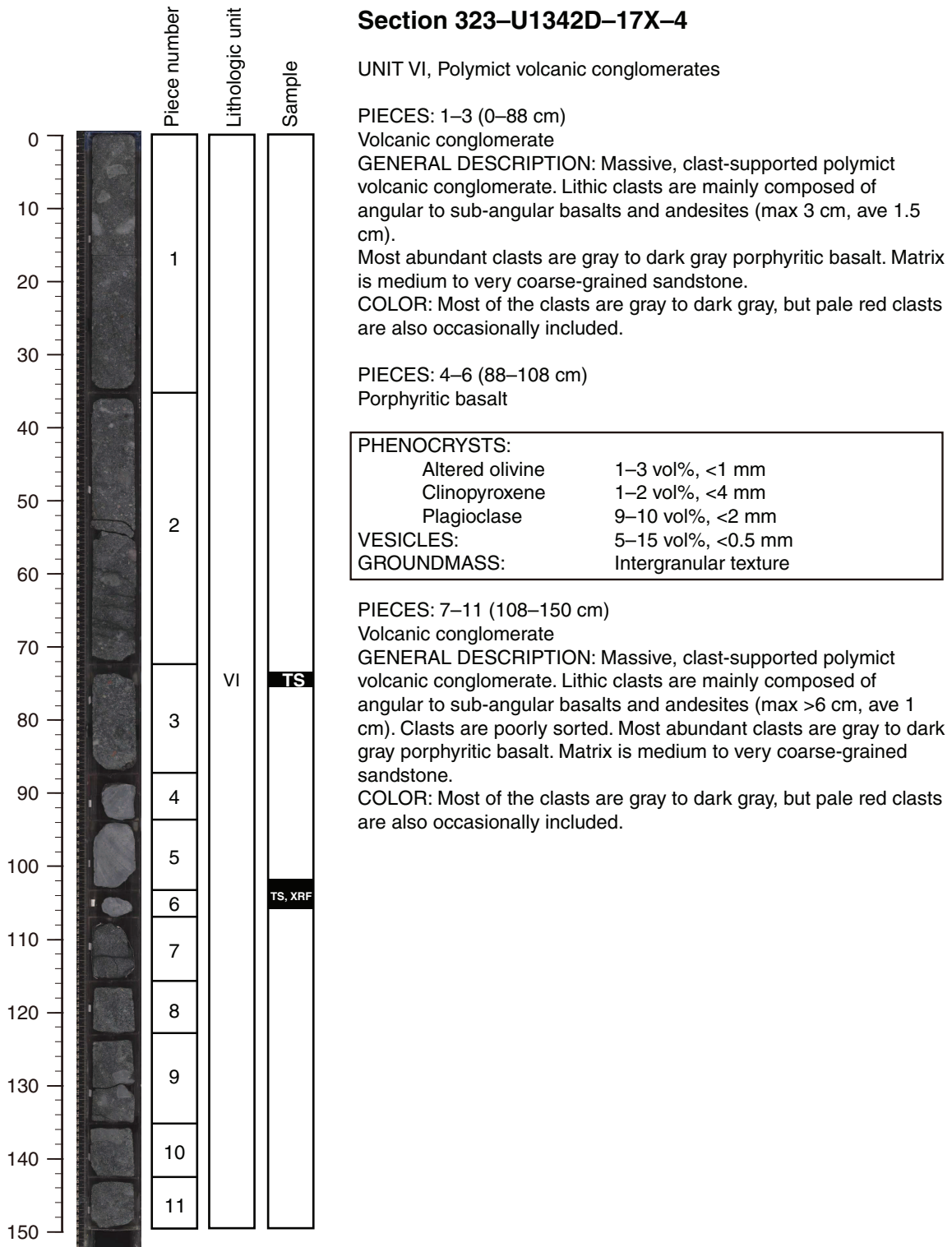


Figure F13 (continued).

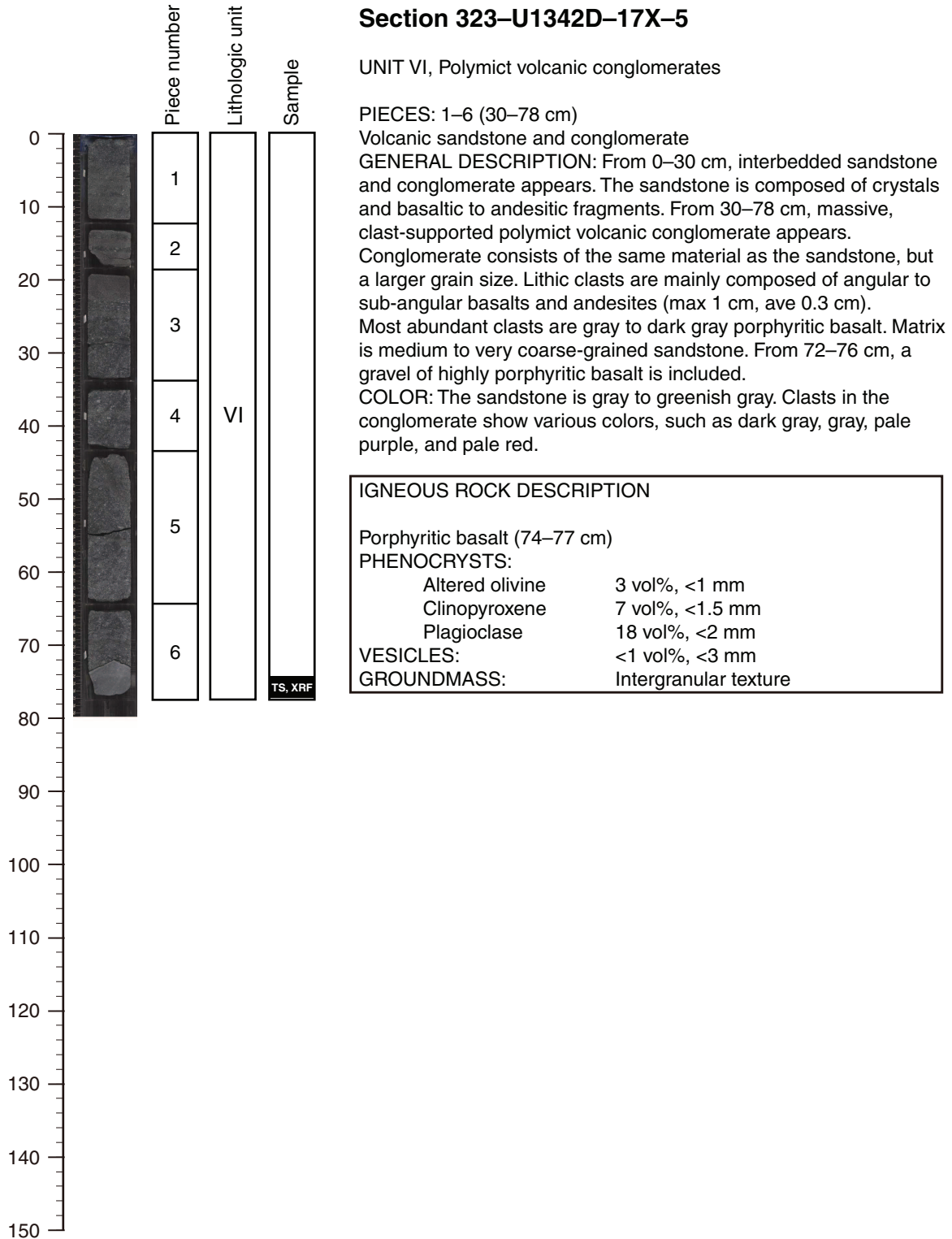


Figure F14. Description of Core 323-U1342D-18X. (Continued on next two pages.)

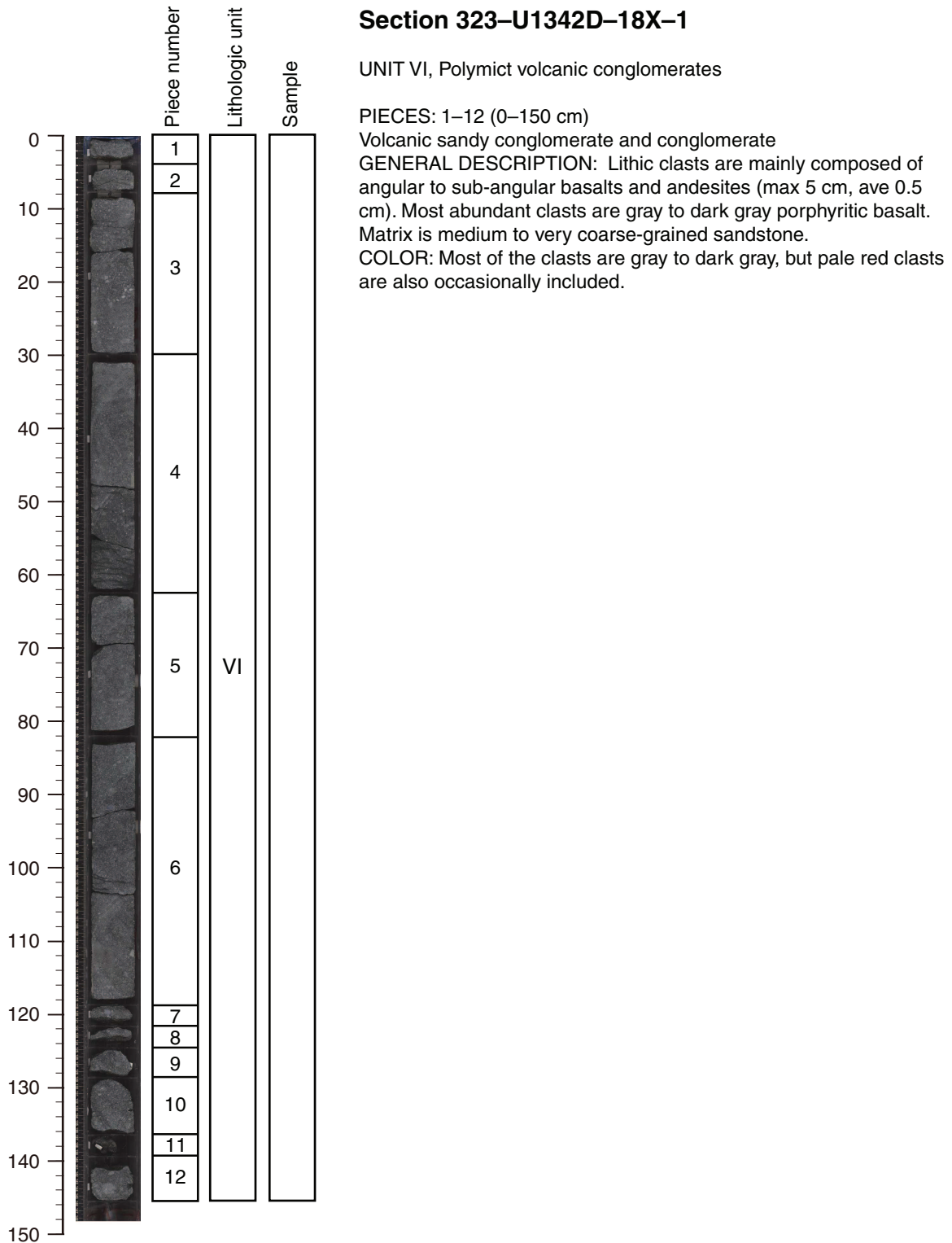


Figure F14 (continued). (Continued on next page.)

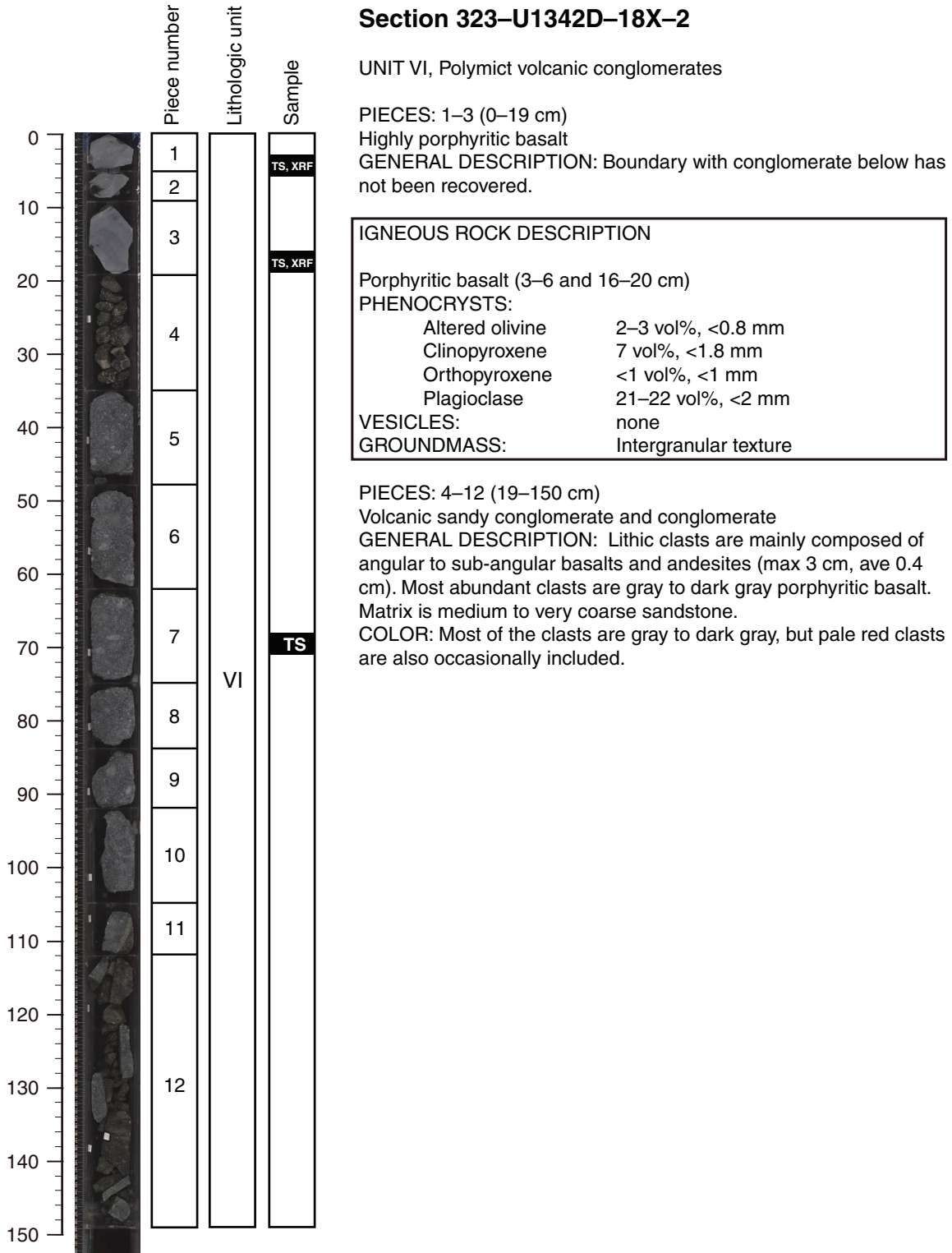


Figure F14 (continued).

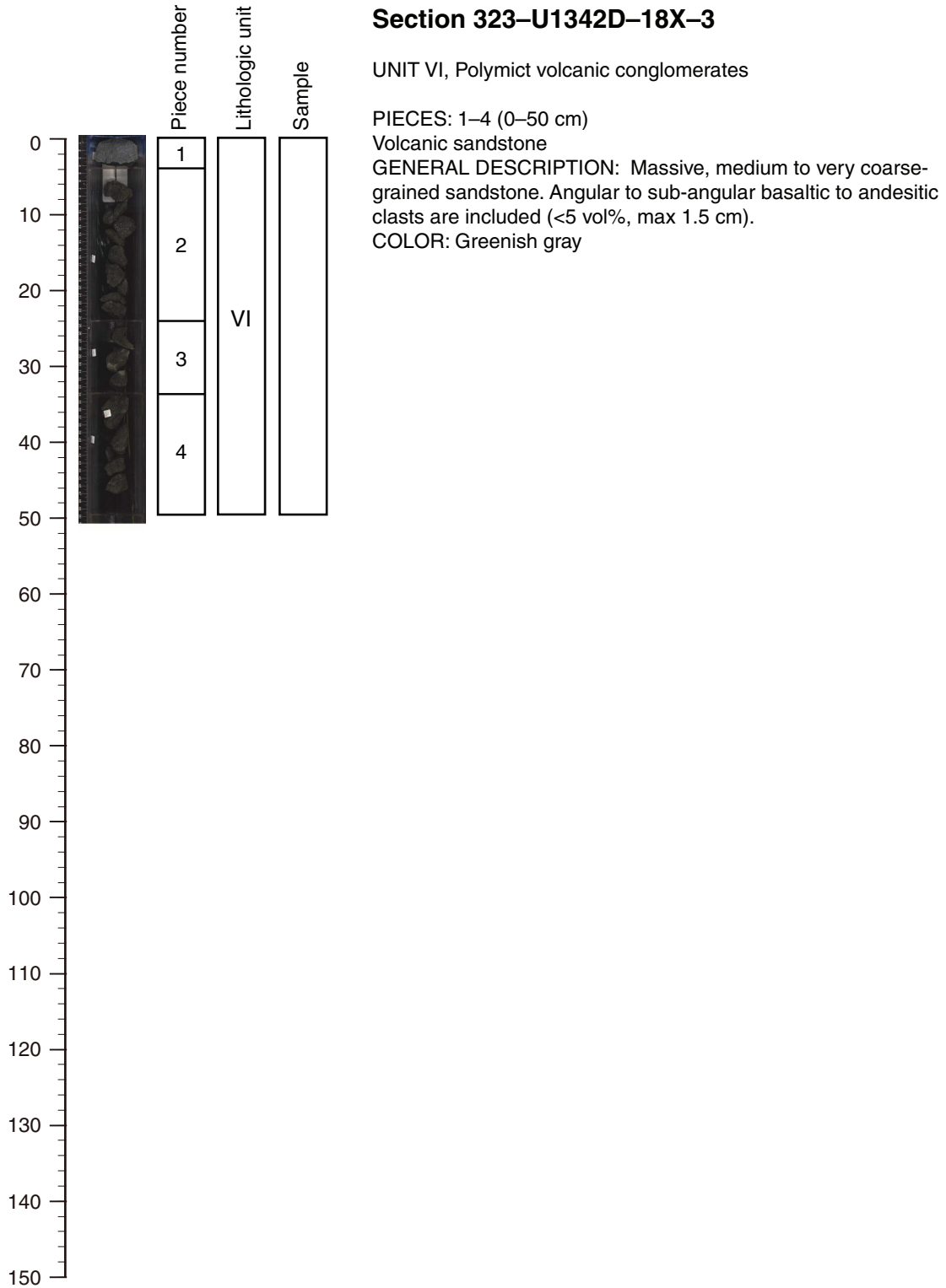


Figure F15. Description of Core 323-U1342D-19X. (Continued on next three pages.)

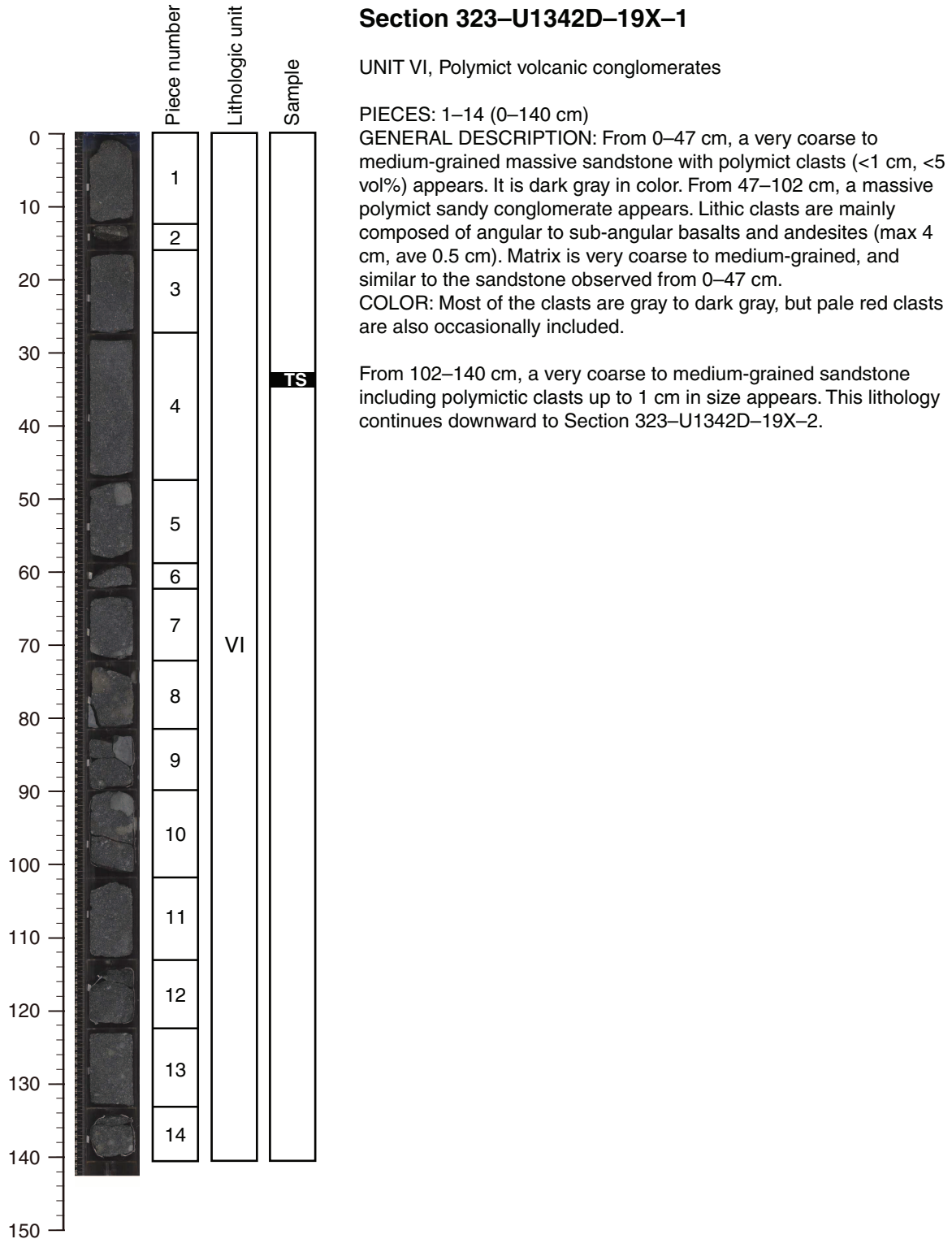




Figure F15 (continued). (Continued on next page.)

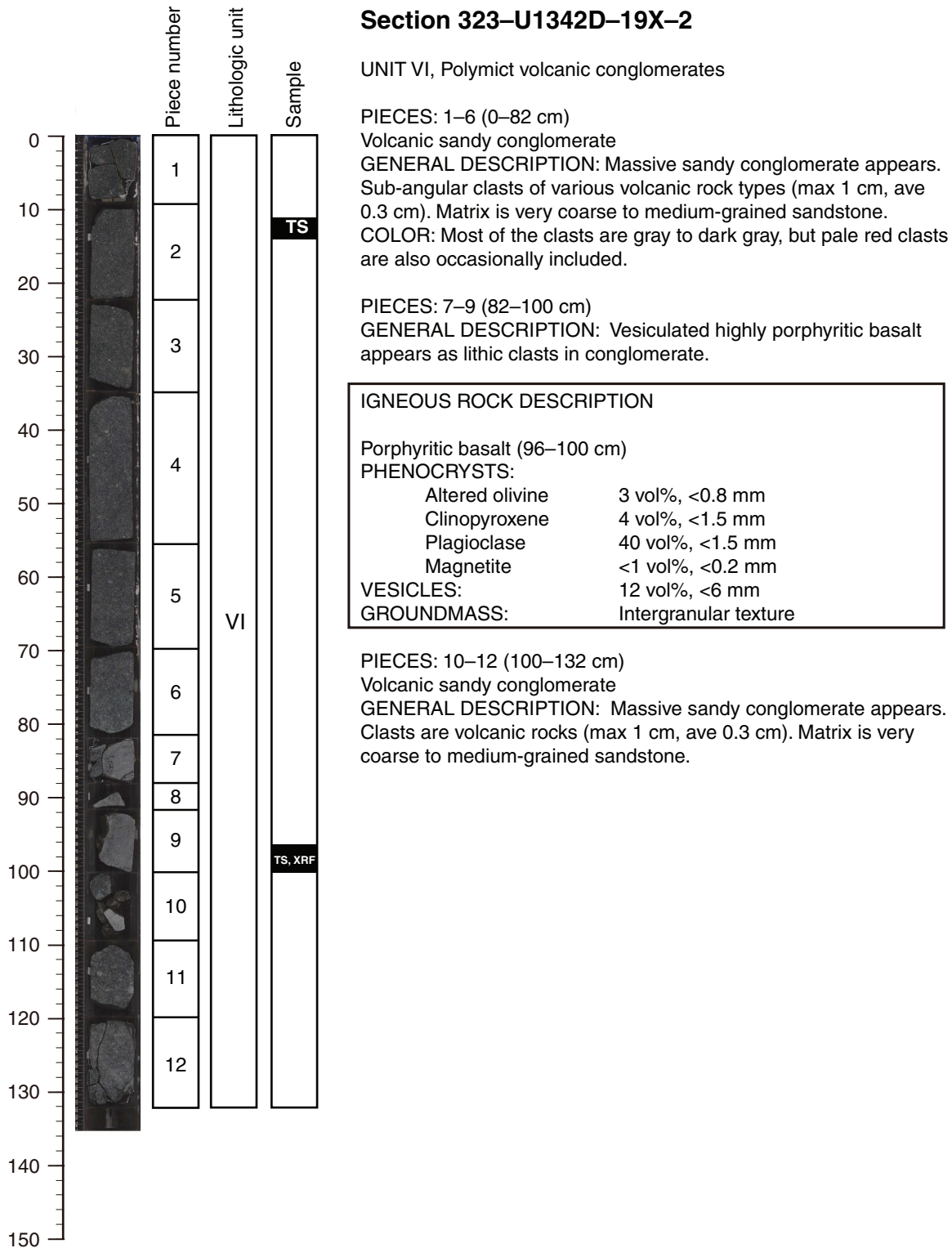


Figure F15 (continued). (Continued on next page.)

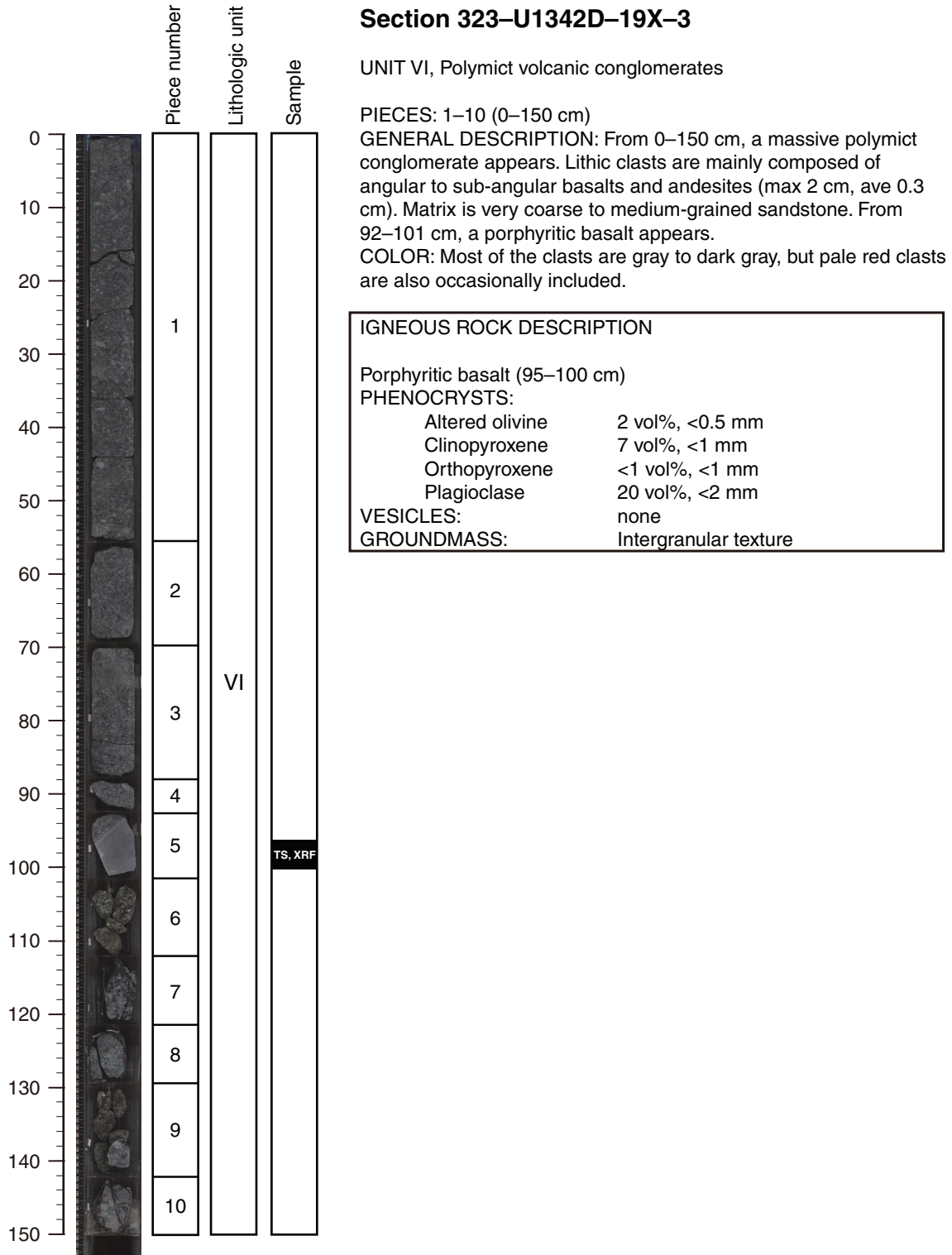


Figure F15 (continued).

