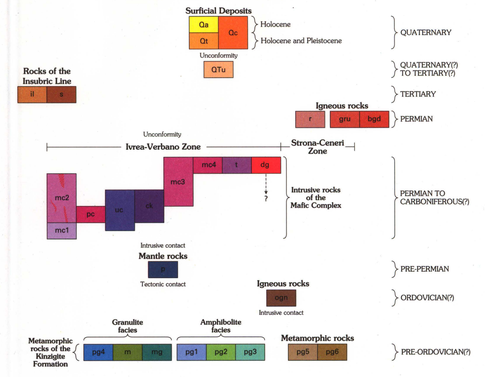
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC INVESTIGATIONS SERIES
MAP I–2776
*Explanatory pamphlet accompanies map*

## CORRELATION OF MAP UNITS




## DESCRIPTION OF MAP UNITS

### SURFICIAL DEPOSITS

**Qa** **Alluvium (Holocene)**—Unconsolidated boulders, cobbles, gravel, sand, and silt underlying flood plains of the Fiume Sesia and its tributaries. Thickness ranges from a thin veneer overlying bedrock and older deposits to several meters

**Qc** **Colluvium (Holocene and Pleistocene?)**—Unconsolidated deposits of locally derived boulders, cobbles, and finer detritus that have been transported downslope by undifferentiated debris flows, avalanches, small or intermittent streams, and frost action. Thickness ranges from a thin veneer overlying bedrock to several meters

**Qt** **Terrace deposits (Holocene? and Pleistocene)**—Poorly consolidated to unconsolidated deposits of boulders, cobbles, gravel, sand, silt, and clay underlying gently inclined surfaces that stand up to 40 meters (m) above the flood plains of the Fiume Sesia and its tributaries. Thickness ranges from a thin veneer overlying bedrock to an estimated 10 m

**QTu** **Sedimentary deposits, undivided (Quaternary? to Tertiary?)**—Conglomerate, poorly sorted sandstone, shale, and minor carbonate. Distinguished from Quaternary deposits by greater consolidation and moderate dips (10°–20°) of bedding. Beds range from 0.5 centimeter (cm) thick (interbedded sandstone and shale) to massive (sandstone and conglomerate)

### ROCKS OF THE INSUBRIC LINE

**il** **Mylonitic rocks of the Insubric Line (Tertiary)**—Synkinematically recrystallized rocks imbricated within the west-dipping, up to 1 kilometer (km) thick, north-northeast-striking, greenschist-facies mylonite belt that constitutes the Insubric Line (Zingg and Hunziker, 1990). Includes mylonite, phyllonite, and schist derived from the Mafic Complex of the Ivrea-Verbano Zone and terranes west of the Insubric Line

**s** **Serpentinite (Tertiary? or older)**—Dark, fine-grained, schistose to massive serpentinite containing quartz and carbonate lenses cropping out within the mylonitic rocks of the Insubric Line

### IGNEOUS ROCKS OF PERMIAN AGE

**r** **Rhyolitic rocks (Permian)**—Orange- to red-weathering volcanic and hypabyssal(?) rhyolite porphyry that contains small (0.5–3 millimeter (mm)) crystals of quartz and feldspar dispersed in a pink aphanitic matrix. Includes ignimbrite with abundant flamme, volcanic breccia, and massive porphyry

**gru** **Granitic rocks, undivided (Permian)**—Light-gray to white granitic rocks, ranging in grain size from medium grained (1–3 mm) to pegmatitic, and consisting chiefly of quartz and feldspar, with variable amounts of biotite, muscovite, and garnet. Characterized by a low color index (<5), these rocks are predominantly leucotonalite, although minor amounts of leucogranodiorite and leucogranite are included. Locally contain inclusions of biotite schist and orthogneiss, and form dikes that cut the foliation in these rocks. The unit is poorly exposed in most places as a result of deep weathering but can be recognized by a grus of quartz and white feldspar

**bgd** **Biotite granodiorite (Permian)**—Fine- to medium-grained (<1–3 mm), medium-gray biotite granodiorite that contains biotite, quartz, feldspar, and minor muscovite. Color index ranges from 10 to 20. Inclusions of fine-grained, subangular, mafic rock (up to 1 m in size) are locally abundant. Biotite schist and quartzofeldspathic paragneiss inclusions are less abundant. In places, rocks display a strong magmatic flow foliation defined by orientation of biotite grains and by biotite-rich schlieren that drape inclusions. Development of foliation is nonuniform with rocks showing strong flow foliation grading into nonfoliated rocks

### INTRUSIVE ROCKS OF THE MAFIC COMPLEX, IVREA-VERBANO ZONE

**dg** **Dioritic and gabbroic dikes (Permian to Carboniferous?)**—Medium- to dark-gray, fine-grained dioritic to gabbroic dikes and minor coarse-grained pyroxenitic dikes. These rocks are mutually intrusive with white to light-gray tonalitic leucosomes from the Kinzigite Formation

**t** **Leucotonalite of Val Strona di Postua (Permian to Carboniferous?)**—Medium- to coarse-grained (1–5 mm), white to light-gray leucotonalite exposed in Val Strona di Postua that forms a laterally extensive, thin sheet between the eastern contact of the Mafic Complex and the paragneiss (pg1) of the Kinzigite Formation. Extremely low color index (<3) and heterogeneous mineralogy consisting mainly of plagioclase, quartz, and minor biotite, with variable amounts of potassium feldspar, muscovite, garnet, and orthopyroxene. Biotite locally defines a weak foliation. Contains abundant inclusions of paragneiss. Leucotonalite grades into agmatitic paragneiss in the wall rocks as the ratio of paragneiss inclusions to leucotonalite increases

**mc4** **Biotite granodiorite of Val Strona di Postua (Permian to Carboniferous?)**—Light-gray, medium-grained (1–3 mm) biotite granodiorite that crops out near the eastern edge of the Mafic Complex and contains abundant subangular to subrounded, very fine grained (0.1–0.3 mm) mafic inclusions up to 2 m long and less abundant subrounded inclusions of quartzofeldspathic paragneiss. Rock consists of feldspar, quartz, biotite ± garnet and is locally porphyritic with blocky plagioclase phenocrysts up to 2 cm across. Color index ranges from about 10 to 20. Biotite-rich schlieren up to 2 m long and 10 cm wide define a magmatic flow foliation

**mc3** **Diorite of Val Sesia (Permian to Carboniferous?)**—Medium-gray, medium-grained (1–4 mm) biotite-rich rocks composed mainly of plagioclase and biotite. Lithologies include diorite, quartz diorite, and monzogabbro. Amphibole, orthopyroxene, and clinopyroxene locally present but subordinate to biotite in abundance. Quartz and potassium feldspar locally present. Garnet is abundant near the contact with the Kinzigite Formation. Color index ranges from 30 to 40. Nonfoliated to weakly foliated with foliation best developed near the contact with paragneiss of the Kinzigite Formation (pg1). Fine-grained (≤0.2 mm), porphyritic mafic enclaves with plagioclase phenocrysts (≤1 cm) are common

**ck** **Charnockitic rocks (Permian to Carboniferous?)**—White to light-gray, medium- to coarse-grained (1 to >5 mm) granitic rocks that crop out within the Mafic Complex and consist of quartz and plagioclase, variable amounts of alkali feldspar, and minor red-brown-weathering, iron-rich orthopyroxene. Garnet is locally abundant, and biotite is present in rocks that crop out in the eastern 2 km of the Mafic Complex. Color index is typically ≤3. Igneous foliation is common, especially deep in the complex. Outcrops weather white to orange and have a rubby surface due to resistant weathering of quartz

**uc / pc** **Cumulus ultramafic rocks (Permian to Carboniferous?)**—Dark-gray ultramafic rocks including dunite, harzburgite, and websterite. Dunite and harzburgite weather orange to red, and websterite weathers dark gray to black. Resistant-weathering, poikilitic orthopyroxene in harzburgite results in distinctive hobnail surface. Bodies near and within the Kinzigite Formation are locally rich in amphibole and phlogopite, and contain accessory apatite, iron-titanium oxides, and carbonate. Form sheet-like bodies and isolated pods in the gabbroic and noritic rocks (mc2). Form discordant intrusions and dikes (dashed where approximately located) that cut the amphibole gabbro (mc1) and paragneiss of the Kinzigite Formation (pg1). Locally contain copper- and nickel-rich sulfides

**pc** **Pegmatitic clinopyroxenite (Permian to Carboniferous?)**—Pegmatitic, locally feldspathic clinopyroxenite with green clinopyroxene crystals up to 20 cm long. Located at the contact between peridotite (p) and gabbroic and noritic rocks (mc2). Grades into gabbro with increasing feldspar

**mc2** **Gabbro and norite (Permian to Carboniferous?)**—Light- to dark-gray, medium-grained (1–3 mm) gabbroic and noritic rocks composed primarily of plagioclase, pyroxene, and amphibole and distinguished from amphibole gabbro (mc1) by the presence of abundant pyroxene and from diorite (mc3) and biotite granodiorite (mc4) by minor or absence of biotite. Garnet crystals up to 10 mm across are present in proximity to or along strike with septa of paragneiss (pg4); these rocks are shown by pattern south of the Fiume Sesia and are present, although not depicted, north of the Fiume Sesia. In the central to eastern exposures of the Mafic Complex, minor biotite (<5 percent) is present near charnockitic rocks (ck), septa of paragneiss (pg4), diorite (mc3), and biotite granodiorite (mc4). Foliation is defined by the preferred orientation of mafic mineral grains. Lineation is defined by the elongation of mafic mineral grains within the plane of foliation. Locally, centimeter-thick to meter-thick banding is defined by variation in color index. In general, foliation, lineation, and banding are weak in the valley of the Fiume Sesia and near the eastern contact of the Mafic Complex but are increasingly more clearly defined westward. Synmagmatic boudinage and small stretching faults deform banding. In the valleys of the Fiume Sesia and the Torrente Mastallone, the dominant lithology is gabbro with a color index between 40 and 50 and composed primarily of plagioclase, brown-weathering orthopyroxene, green clinopyroxene, and black amphibole. South of Monte Luvot and Castello di Gavala, norite and leuconorite are abundant, consisting of plagioclase, brown orthopyroxene, black amphibole ± quartz. The color index is typically lower than 40. Black amphibole oikocrysts locally form distinctive large (~3 cm) grains that grow across the foliation in the easternmost outcrops but are flattened in the plane of foliation elsewhere. Less abundant rock types are anorthosite, which forms layers up to 3 m thick, amphibole gabbro, and scarce olivine-bearing gabbro, which crops out in the Val Sesia, Val Mastallone, and Val Strona di Postua

**mc1** **Amphibole gabbro (Permian to Carboniferous?)**—Medium- to dark-gray, medium-grained (2–4 mm) gabbro with distinctive granoblastic texture composed mainly of white plagioclase and black amphibole, minor pyroxene ± spinel. The color index is close to 50. Locally, noritic rocks are interfingered. Garnet is present locally in Valmala. A weak foliation is defined by the trails of amphibole grains. Centimeter-thick to meter-thick banding defined by variation in color index and deformed by synmagmatic boudinage and small stretching faults

### PRE-PERMIAN MANTLE ROCKS

**p** **Peridotite (pre-Permian)**—Dark-gray-green, medium-grained (1–3 mm) spinel lherzolite and associated ultramafic rocks that crop out near the Insubric Line. Lherzolite, the dominant lithology, consists of orange-weathering olivine, greenish-brown-weathering orthopyroxene, green-weathering clinopyroxene, and black-weathering spinel. Includes minor amounts of dunite and harzburgite. High-temperature foliation defined in outcrop by trails of flattened spinel grains. Dikes and bands of bright-green-weathering clinopyroxenite are abundant and invariably cut by younger aluminum-augite dikes composed of lavender-weathering augite and black spinel. The peridotite is distinguished from the cumulus ultramafic rocks by lighter orange weathering and the presence of pyroxenite dikes and a spinel foliation

### IGNEOUS ROCKS OF ORDOVICIAN(?) AGE

**ogn** **Orthogneiss (Ordovician?)**—Light-gray, medium- to coarse-grained (1–6 mm) granodioritic orthogneiss composed of quartz, feldspar, biotite, and minor muscovite. The color index is ≤20. Gneissic banding well defined and ranges from 0.1 to 2 cm in thickness. Augen structures locally present. Cut by abundant intrusions of leucogranite and fine-grained mafic dikes

### METAMORPHIC ROCKS OF THE STRONA-CENERI ZONE

**pg6** **Schist and quartzofeldspathic paragneiss (pre-Ordovician?)**—Rusty-brown-weathering, interlayered two-mica schist, chlorite schist, and quartzofeldspathic paragneiss. Distinguished from paragneiss of the Kinzigite Formation (pg1) within the mapped area by the presence of abundant muscovite. Sparse andalusite porphyroblasts are replaced by sillimanite. Foliation is defined by biotite and muscovite

**pg5** **Quartzofeldspathic paragneiss (pre-Ordovician?)**—Rusty-brown-weathering, medium-gray, fine- to coarse-grained (0.1–2 mm), banded quartzofeldspathic paragneiss. The rock is composed of quartz and feldspar with minor biotite and muscovite. Banding, defined by variations in grain size and mineral content, ranges in thickness from 0.5 cm to 1 m. Distinguished from other paragneiss units by high abundance of quartz (>50 percent) and paucity of mica schist and leucosomes

### METAMORPHIC ROCKS OF (OR DERIVED FROM) THE KINZIGITE FORMATION, IVREA-VERBANO ZONE

**mg** **Mafic gneiss (pre-Ordovician?)**—Medium- to dark-gray, medium-grained mafic gneiss composed chiefly of plagioclase, amphibole, clinopyroxene, orthopyroxene, and iron-titanium oxides. Granoblastic-polygonal texture is typical, and the rocks are commonly banded

**m** **Marble (pre-Ordovician?)**—White to light-gray, massive, fine- to medium-grained calcite marble with impurities of graphite and spinel

**pg4** **Banded quartzofeldspathic paragneiss (pre-Ordovician?)**—Granulitic-facies rocks consisting of white to light-gray-green, medium-grained (1–3 mm) paragneiss that has a granular intergrowth of quartz, feldspar, garnet, orthopyroxene, sillimanite ± biotite ± corundum ± graphite. Weathers dark rusty brown. Crops out widely north of the Torrente Mastallone and forms sheet-like inclusions within the Mafic Complex termed septa, which range in thickness from <1 m to 100 m. Readily distinguished from other units of the Kinzigite Formation by the uniformity of centimeter-thick to meter-thick banding, an overall higher abundance of garnet, and a lesser abundance of biotite and absence of schistosity. Unit contains charnockitic leucosomes and boudins of mafic meta-igneous rock

**pg3** **Quartzofeldspathic paragneiss and banded amphibolite (pre-Ordovician?)**—Amphibolite-facies quartzofeldspathic paragneiss interlayered with medium- to dark-gray amphibolite underlying a large area north of the village of Varallo. Quartzofeldspathic paragneiss consists of a granoblastic intergrowth mainly of quartz and feldspar. Amphibolite consists of a fine- to medium-grained (0.5–1 mm) intergrowth of plagioclase and amphibole with a color index of up to 60

**pg2** **Calc-silicate paragneiss and marble (pre-Ordovician?)**—Amphibolite-facies rocks consisting of white- to light-brown-weathering calc-silicate paragneiss and marble. Grain size ranges from 0.1 to 5 mm. Calc-silicate rocks have distinctive rough outcrop surface due to differential weathering of carbonate and silicate grains (especially diopside and amphibole). Locally includes scarce forsterite-bearing metadolomite. Unit also includes very fine grained calc-mylonite. Rocks form karst and dramatic cliffs southeast of the village of Varallo

**pg1** **Paragneiss, undifferentiated (pre-Ordovician?)**—Amphibolite-facies rocks consisting of mainly rusty-weathering, semi-pelitic paragneiss and pelitic, biotite-rich schist with lesser amounts of white-weathering leucosome, white to light-gray calc-silicate paragneiss and impure calcite marble, rusty-brown- to black-weathering, banded quartzofeldspathic paragneiss, and black-weathering amphibolite. The semi-pelitic paragneiss consists of medium- to coarse-grained quartz, biotite, garnet, plagioclase, perthitic alkali feldspar, sillimanite, and cordierite. Sillimanite is generally fibrous and can be difficult to identify in hand sample. Biotite defines a strong planar fabric. Tonalitic to granitic leucosomes ranging in thickness from centimeters to meters are interlayered with the semi-pelitic paragneiss and biotite-rich schist and are particularly abundant within about 2 km of the contact with the Mafic Complex where they form up to 30 percent of the rock. Quartzofeldspathic paragneiss is a banded rock consisting chiefly of fine- to medium-grained (<0.05–5 mm) quartz and feldspar with lesser amounts of biotite ± garnet. Amphibolite consists of fine- to medium-grained black amphibole ± feldspar ± iron-titanium oxides ± titanite and typically forms boudins that range in size from decimeters to meters. Foliation is defined by biotite in the semi-pelitic and pelitic rocks, whereas amphibole defines the foliation in the amphibolites. All rock types have been affected by multiple deformational phases, locally yielding complex fold patterns. Disharmonic folding, widespread boudinage, and agmatite development are common within 100 m of the contact with the Mafic Complex

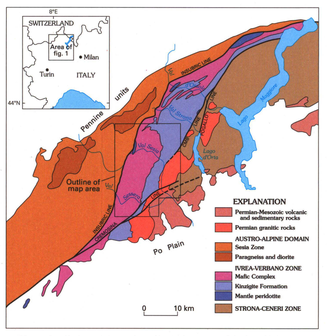
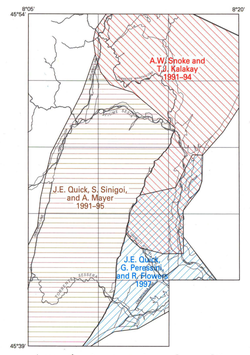



*Figure 1.*—Geology of the southern Alps in the vicinity of the Ivrea-Verbano Zone based on Zingg (1983) and showing tectonic boundaries, terranes, and geographic features referenced in the text. Cossato-Mergozzo-Brissago Line abbreviated as CMB Line. Ivrea-Verbano Zone contains pre-Permian peridotite, pre-Ordovician(?) paragneiss of the Kinzigite Formation, and Carboniferous(?) to Permian intrusive rocks of the Mafic Complex. Strona-Ceneri Zone contains pre-Ordovician gneiss and schist. Austro-Alpine Domain contains high-pressure, low-temperature metamorphic rocks of the Sesia Zone and thrust sheets of diorite and paragneiss. Pennine units include Pennine basement, ophiolites, and schistes lustrés.




Areas of primary mapping and compilation responsibility. Outlines of 3-min by 5-min quadrangles are shown; quadrangle names are listed in the index figure below.

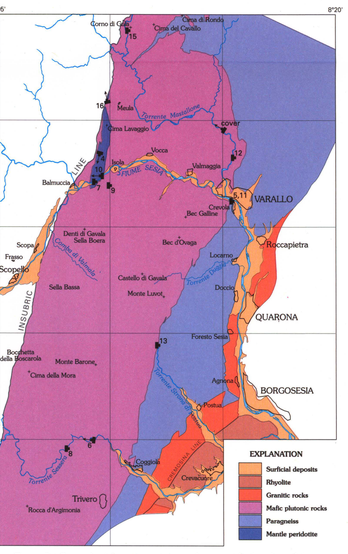
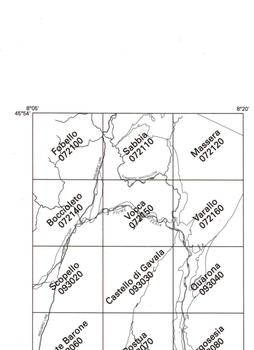



*Figure 3.*—Geographic information superimposed on generalized geology of the map area. Place names are shown for quick reference to localities cited in pamphlet text. Camera icons indicate sites of photographs referred to in pamphlet text; arrows show direction of view; numbers are keyed to figures in text. Outlines of 3-min by 5-min quadrangles are shown; quadrangle names are listed in the index figure at right.




Index of 3-min by 5-min quadrangles contained in the map area and published by the Servizio Cartografico della Regione Piemonte at a scale of 1:10,000. Quadrangles are identified by name and index number.

## EXPLANATION OF MAP SYMBOLS

**Contact**—Dashed where approximately located; dotted where concealed; queried where location and nature are uncertain

**Gradational contact**—Dashed where approximately located; dotted where concealed

**Fault**—Showing dip where measured. Dashed where inferred or approximately located; dotted where concealed; queried where location is uncertain

Brittle (cataclastic) or uncertain style of deformation—Includes faults in which brittle deformation overprints older ductile deformation

Ductile—Characterized by mylonite indicating intracrystalline plastic deformation or inferred on the basis of relative age indicating deep-crustal deformation

**Synform**—Showing trace of axial surface. Arrows show direction of dip

**Isoclinal synform**—Showing trace of axial surface. Arrows show direction of dip

**Antiform**—Showing trace of axial surface. Arrows show direction of dip

### PLANAR FEATURES

**Strike and dip of banding in metamorphic and igneous rocks**

75 Inclined

Vertical

**Strike and dip of bed in sedimentary rocks**

10 Inclined

**Strike and dip of foliation**

67 Inclined

Vertical

**Strike and dip of parallel foliation and banding**

90 Inclined

Vertical

### LINEAR FEATURE

**Bearing and plunge of mineral lineation** 71

### OTHER FEATURES

**Site of photograph**—Number keyed to figure in text; arrow shows direction of view

3649 ● (289±4 Ma) **Geochronology sample site**—Weighted average SHRIMP U/Pb zircon age with 2σ error is shown

Base from Servizio Cartografico della Regione Piemonte, 1991
Universal Transverse Mercator projection, zone 32
1984 World Geodetic System datum
Shaded relief image derived from digital elevation model with 25-meter resolution using contours from the topographic base

SCALE 1:25 000
1 .5 0 1 2 3 KILOMETERS
600 0 600 1200 1800 2400 3000 METERS
CONTOUR INTERVAL 50 METERS
REFERENCED TO AVERAGE SEA LEVEL, MAREOGRAFO DI GENOVA

TRUE NORTH MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2003







INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—2003

# GEOLOGIC MAP OF THE SOUTHERN IVREA-VERBANO ZONE, NORTHWESTERN ITALY

By

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2003

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ISSN 0-607-92120-X

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For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; telephone 1-888-ASK-USGS

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