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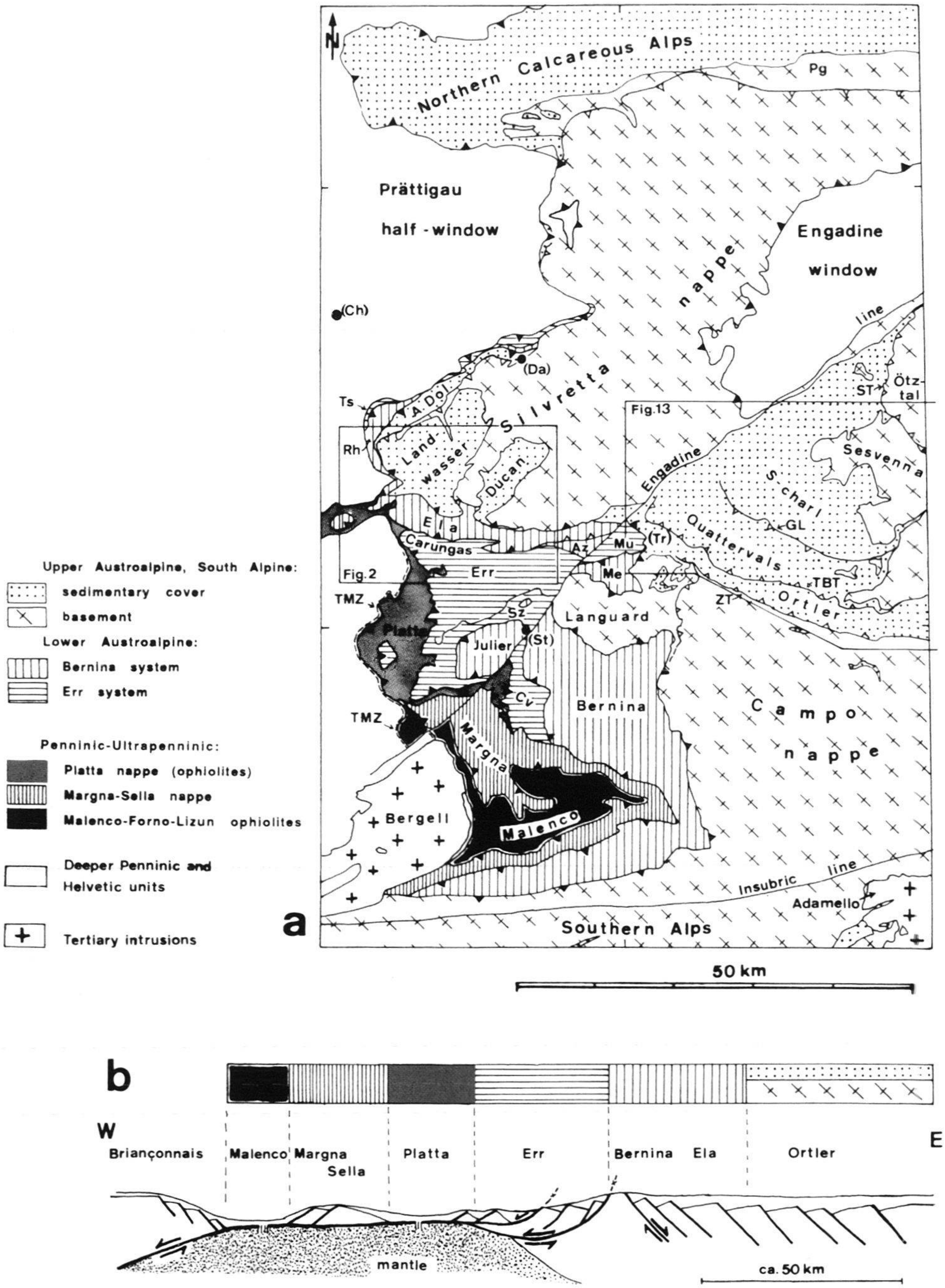
R. Trümpy (Furrer 1993, Eichenberger 1986, Naef 1987, Eberli 1985, 1988, and numerous diploma theses). All these studies provide a very detailed data set concerning the general geology of the area. Within this framework, we studied and mapped outcrop-scale deformation structures with an emphasis on structural overprinting. Direction and sense of displacement of major fault structures were determined by microstructural examination of mylonites and cataclasites.

Based on the structural analysis of the southwestern Silvretta, Ela and Err-Carungas nappes, a sequence of deformational phases will be developed and regional names will be introduced for these phases (chapter 4). In a next step the results from the Silvretta-Ela-Err region will be compared to and complemented with structural observations in the Engadine Dolomites (chapter 5). Finally, we will attempt a synthesis of the tectonic evolution of the Austroalpine units in Graubünden (chapter 6).

2 Austroalpine tectonic units in Graubünden and their position in the Jurassic passive continental margin

In this paragraph we give an overview of the Austroalpine nappe pile. Because the quantity of nappes and minor tectonic units must be confusing to readers not familiar with the area, a block diagram (P1.1) is attached, showing all the mentioned units and their mutual relations in a simplified way. The term "nappe", as used in this paper, simply means a tectonic unit that is internally (more or less) coherent but completely separated from overlying, underlying and adjacent units by major Alpine (Cretaceous or Tertiary) faults.

The Austroalpine nappes resulted from tectonic imbrication of a passive margin of Jurassic to Early Cretaceous age, and the major tectonic units roughly correspond to paleogeographic domains of this margin (Fig. 1b; Froitzheim & Eberli 1990). The following major units or "nappe systems" can be distinguished in this way (Fig. 1, Pl. 1): (1) The Upper Austroalpine nappe system, also called Central Austroalpine (Trümpy 1980), represented by the Ötztal, Silvretta, Campo and Languard basement nappes, the Sesvenna – S-charl nappe (Sesvenna basement and its partly detached sedimentary cover in the S-charl unit of the northern Engadine dolomites), and completely detached sedimentary cover units like the Quattervals nappe, Ortler nappe and the Arosa Dolomites. These nappes were derived from the proximal, continentward part of the passive margin, characterized by east-dipping normal faults active in the Liassic (Furrer 1993, Eberli 1988, Froitzheim 1988, Conti et al. 1994). (2) The Bernina system, comprising the Bernina nappe s.l. with the exception of the Corvatsch and Sella units, further comprising the Mezzaun unit and the Corn slice, the Julier nappe and klippen of the Samedan zone (e. g. Piz Padella), most of the Albula zone, the Ela nappe and the Rothorn nappe (Rothorn basement and sedimentary cover). These units were derived from the "outer basement high" of the passive margin and from a number of basins east of this high which were bounded by east-dipping normal faults, active in the Liassic and a second time in the Middle Jurassic (Furrer 1993, Eberli 1988). (3) The Err system, comprising the Err-Carungas nappe, the Samedan zone with the exception of the klippen of Bernina nappe, the Corvatsch nappe, most of the Murtiröl unit and the Tschirpen nappe. This paleogeographic domain is characterized by one or more top-west directed extensional detachment faults (Froitzheim & Eberli 1990), overlain by tilt blocks, active in the Middle


a
Northern Calcareous Alps
Pg
Prättigau
half - window
Engadine
window
(Ch)
(Da)
Silvretta nappe
line
Ötz-
tal
ST
Ts
A. Dol
Fig.13
Rh
Land-
wasser
Ducan
Engadine
Sesvenna
S-charl
GL
Ela
Carungas
Az
Mu
(Tr)
Quattervals
Fig.2
Err
Me
TBT
Ortler
ZT
TMZ
Platta
Sz
Languard
Julier
(St)
Cv
Bernina
TMZ
Campo
nappe
Margna
Malenco
Bergell
Insubric
line
Adamello
Southern Alps
50 km
Upper Austroalpine, South Alpine:
sedimentary cover
basement
Lower Austroalpine:
Bernina system
Err system
Penninic-Ultrapenninic:
Platta nappe (ophiolites)
Margna-Sella nappe
Malenco-Forno-Lizun ophiolites
Deeper Penninic and
Helvetic units
Tertiary intrusions
b
W
E
Briançonnais
Malenco
Margna
Sella
Platta
Err
Bernina
Ela
Ortler
mantle
ca. 50 km

Jurassic, and by the widespread occurrence of basement clasts in Middle to Upper Jurassic breccias. (4) The Platta nappe, including ophiolites and thin slivers of continental basement, Triassic and Jurassic sedimentary rocks in Austroalpine facies, representing an oceanic domain between the margin s. str. and the Margna-Sella continental fragment. (5) The Margna-Sella system, continental basement with a Mesozoic sedimentary cover in Austroalpine facies, derived from a continental fragment that became separated from the margin by extensional faulting in the Middle Jurassic. This fragment may have been connected to the Austroalpine farther south. (6) The Malenco-Forno-Lizun ophiolites of the South Penninic ocean.

All these units together form the "orogenic lid" (Laubscher 1983), a nappe pile that was assembled in the Cretaceous and that overrode the deeper Penninic units as a coherent thrust mass during the Early Tertiary. The lid includes not only Austroalpine units but also the South Penninic ophiolite units mentioned above (Liniger & Nievergelt 1990).

Bernina and Err systems are traditionally termed Lower Austroalpine. The Margna-Sella system may be referred to as "Ultrapenninic" following a suggestion by Trümpy (1992). Following Liniger (1992), we assume that the present position of the Platta ophiolites between the Lower Austroalpine above and the Margna-Sella system below does not result from Alpine backfolding or backthrusting but reflects the original paleogeographic arrangement of these units. The Ela nappe is Upper Austroalpine according to most authors (e. g. Spicher 1972) but belongs to the Lower Austroalpine Bernina system in our view (Schmid & Froitzheim 1993, see also chapter 5.2).

3 Alpine deformation of the southwestern Silvretta, Ela and Err-Carungas nappes

In the following, an area of the Austroalpine nappe edifice west of the Engadine line is described in detail (Fig. 2). The structural architecture of this area records the sequence of Alpine deformation events in a particularly clear way.

In this area, three major tectonic units of the Austroalpine are exposed (Figs. 1, 2): Silvretta nappe, Ela nappe and Err-Carungas nappe. The Silvretta nappe is a large Upper Austroalpine thrust sheet consisting predominantly of basement rocks, mostly gneiss and amphibolite. Cover rocks of Permian to Late Triassic age are only preserved at its southwestern edge in the Landwasser and Ducan synclinal areas (Fig. 1). Along its southern border, the Silvretta nappe is underlain by the Ela nappe, a detached and folded thrust sheet of Upper Triassic dolomite and Lower Jurassic to Cretaceous shale and limestone, lacking rocks older than Late Triassic. The Ela nappe is underlain by the Err-Carungas

Fig. 1. (a) Tectonic map of the Austroalpine and underlying upper Penninic nappes in Graubünden. Small triangles along tectonic boundaries point in the direction of the structurally higher unit, without indicating the nature of the boundary (some are not thrusts but low-angle normal faults). A Dol, Arosa dolomites; Cv, Corvatsch nappe; Me, Mezzaun unit; Mu, Murtiröl unit; Pg, Phyllitgneiss zone; Rh, Rothorn nappe; Sz, Samedan zone; Ts, Tschirpen nappe; GL, Gallo line; ST, Schlinig thrust; TBT, Trupchun-Braulio thrust; TMZ, Turba mylonite zone; ZT, Zebru thrust; (Ch), Chur; (Da), Davos; (St), St. Moritz; (Tr), Val Trupchun.
(b) Reconstructed east-west cross-section of the southeastern continental margin of the South Penninic ocean in the Late Jurassic and boundaries of the main Alpine tectonic units. Geometry of continent-ocean transition reconstructed assuming tectonic denudation of subcontinental mantle along top-west extensional detachment faults, according to model of Lemoine et al. (1987). For further explanation see text.