



THE THICK CEMENTED PLEISTOCENE SUCCESSIONS SURROUNDING MOUNT CANIN (JULIAN ALPS, NE ITALY) AND THEIR TECTONO-SEDIMENTARY IMPLICATIONS

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ABSTRACT: This study describes the thick cemented terrestrial successions surrounding Mount Canin in the Julian Alps, discussing the tectono-sedimentary evolution of this portion of the Alpine Chain. Two main phases of sedimentary aggradation were recognized. The first one was ascribed to an early Middle Pleistocene phase, when this part of the Alpine Chain was lower in elevation and was occupied by the Fella glacier, which flowed from the more elevated Austrian Alps. A second phase occurred later in the Middle Pleistocene and marks the development of glaciers in the northern side of Mount Canin. The angular unconformity between glacial deposits and the underlying deformed breccia unit points to an uplift phase occurred in the time interval. The ongoing uplift of Mount Canin led to the development of large Last Glacial Maximum glaciers, also due to the low environmental Equilibrium Line Altitude, which deeply carved the Raccolana Valley, exposing the older successions.

Keywords: Pleistocene conglomerate, Julian Alps, Pleistocene glaciations, active tectonics, Equilibrium Line Altitude.

1. INTRODUCTION

The European Alps have experienced several glacier expansions during cold Pleistocene phases; these are recorded as glacial sediments in the end-moraine systems at the outlet of major valleys (Ivy-Ochs et al., 2022), in overdeepened troughs (e.g., Gegg et al., 2021; Buechi et al., 2024) or as fluvio-glacial deposits in the foreland basins (e.g., Fontana et al., 2010; Garzanti et al., 2011; Marcolla et al., 2021; Preusser et al., 2021). Normally, the remnants of old glaciations are preserved in end-moraine systems but are lacking or very scarce in the upper catchments; this scarcity is due to continuous reshaping produced by slope and glacial processes (Bini, 1997). For this reason, palaeo-landscape reconstructions are difficult within a mountain range and most of the information on drainage evolution comes from provenance studies of sediments stored in the foreland basins (e.g., Garzanti et al., 2011; Marcolla et al., 2021). In a mountain range made of carbonate rocks, early cementation may enhance the preservation of old deposits (Janssen et al., 2023 and references therein). It has to be considered that, in active mountain ranges such as the Alps, uplift increases erosional processes and may also contribute to changes in the drainage pattern by isolating wind gaps; in glaciated mountains, the uplift can extend the surface above the equilibrium line altitude (ELA).

The Julian Alps (south-eastern European Alps)

represent an example of an uplifting carbonate range in which old terrestrial deposits are scattered over a large area and at various elevations (Gortani & Desio, 1925; Assereto et al., 1968). Their occurrence helps to infer the tectono-sedimentary evolution of the area in the framework of Alpine glaciations.

2. SETTING

The Julian Alps are the highest range of the south-eastern European Alps, close to the plain, with the top-most elevation at 2864 m a.s.l. of Mount Triglav. The most important peaks in the study area are the Mount Canin (Kanin in Slovenian, 2582 m a.s.l.) and Montasio (2754 m a.s.l.). On the Italian side these mountains are cut by the Rio del Lago to the north-east, and by the Raccolana and Resia valleys that host the major tributaries of the Fella River (Fig. 1b), in the Tagliamento catchment (Fig. 1c). The Rio del Lago Valley starts from Sella Nevea and extends towards the north-east. The valley stream is part of the Danube catchment with Sella Nevea saddle acting as the Mediterranean/Black Sea watershed. The Raccolana Valley develops on the western side of Sella Nevea and is characterized by an E-W trend with steep slopes and cliffs, and elevation differences of up to 1500 meters. The Raccolana Stream is a tributary of the Fella River. Wide karst plateaux are located on the northern and southern sides of the Mount Canin (Cucchi et al., 2009; Telbisz et al., 2011), while a

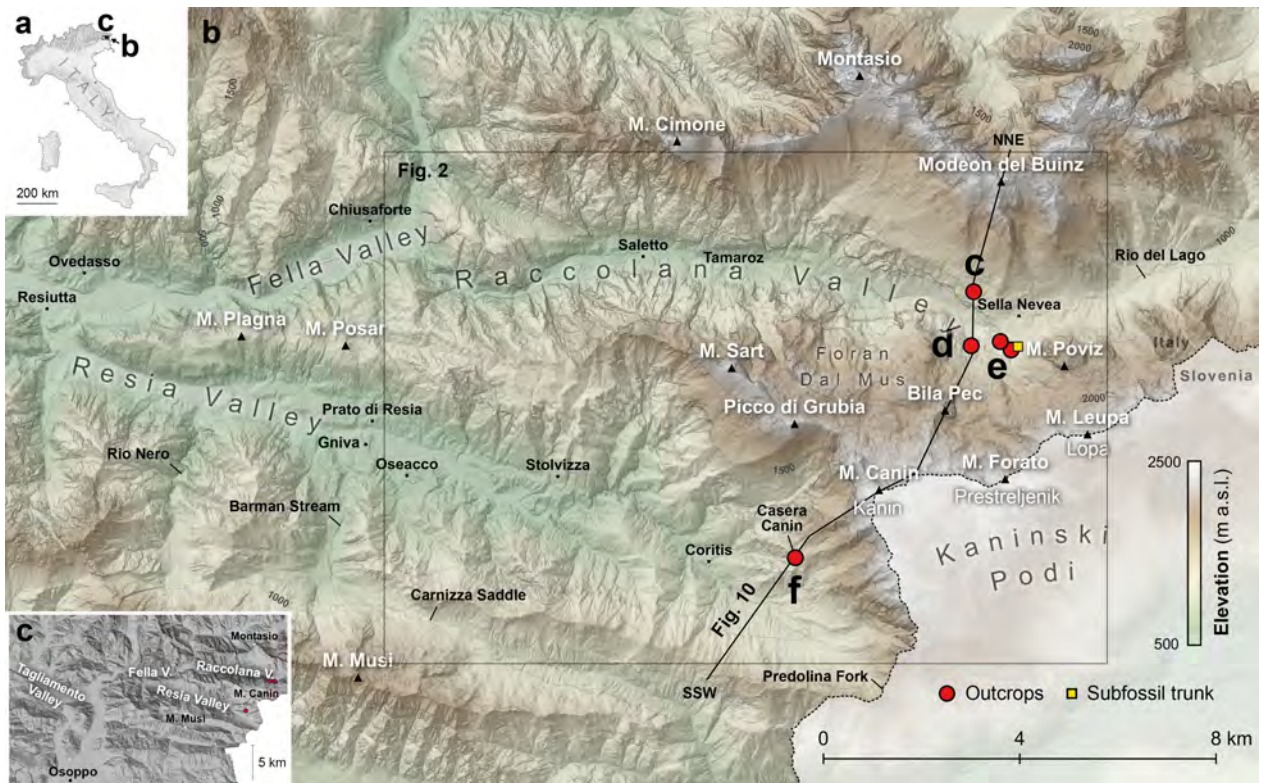


Fig. 1 - a) Position of the study area in NE Italy. b) Study area with main outcrops north (Raccolana Valley) and south (Resia Valley) of the Canin massif. c) Larger scale topography of the study area, including the Tagliamento Valley.

lower plateau characterizes the southern side of the Montasio including the Sella Nevea saddle. The narrow plateaux of Mount Posar (948 m a.s.l.) and Mount Plagna (853 m a.s.l.) separate the Resia Valley from the lower Raccolana and Fella valleys. The Resia Valley has its headwall on the western flank of Mount Canin and to the south has lower elevations ending at ~1640 m a.s.l. at Predolina Fork. The latter also marks the drainage divide with the Soča/Isonzo catchment, reaching even lower altitudes at Carnizza saddle (1086 m a.s.l.).

The bedrock characterizing the Mount Canin area (Fig. 2) mainly consists of Upper Triassic-Lower Jurassic dolostones and limestones, with minor occurrence of Cretaceous Scaglia Rossa and flysch (Assereto et al., 1968; Ponton, 2008; Zanferrari et al., 2013). In the Resia Valley, the main tributary is the Barman Stream, whose catchment is mostly characterized by Jurassic limestones, while the upper part of the valley is dominated by Triassic dolostone and limestone.

The cemented Quaternary deposits of the area were interpreted as pre-würmian in the official geological maps (Gortani & Desio, 1925; Assereto et al., 1968). Desio (1926), who described most of these deposits, reported them in detail and his interpretation was influenced by the models of the time, including the attribution of plateaux to ancient landscapes molded by glacial and fluvial erosion. He attributed the cemented deposits of the area to a pre-würmian age (sensu Penck & Brückner, 1909). Their distribution in the Sella Nevea area was interpreted as the evidence of an ancient watershed that migrated eastward because of the progressive headwall erosion of the Raccolana Stream. This hypothesis was later adopted by Venturini (2003) and Venturini & Discenza (2009; 2020), who described the flat area between the Montasio and Canin massifs as a former

cirque of glaciers flowing eastward; the same direction was inferred by the authors for the groundwater karst system. In these works, the deposits were described as glacial or related to slope deposits in a glaciated area. Recent investigations on the hydrogeology of the Canin (Turk et al., 2014) show that the flow direction of most of the karst water is towards the Soča/Isonzo Basin.

In the Resia Valley, the cemented deposits at the junction of the Resia and Barman streams were referred to a pre-würmian depositional event (Feruglio, 1925; Desio, 1926, Cucchi & Finocchiaro, 2009), while in the new geological map (Zanferrari et al., 2013) they are ascribed to a pre-LGM (pre-Last Glacial Maximum) depositional event, but it cannot be excluded that the younger deposits can be related to the late Pleistocene (early and middle würmian sensu Chaline & Jerz, 1984). In the Resia Valley other fluvial deposits related to pre-LGM deposition are found at the junction with the Rio Nero. In the Fella Valley, fluvial conglomerates are located near Ovedasso and are attributed to an interglacial period by Desio (1926).

The Mount Canin is cut by the Ravne Fault (Kastelic et al., 2008; Marchesini et al., 2023) and is bordered to the south by the parallel Idrija fault-system, which includes Idrija-Ampezzo, Idrija-Resia and Idrija-Moggio faults (Fig. 2), which cross the Resia/Soča watershed at Predolina Fork and Carnizza Saddle (Fig. 1 for location). The Idrija fault is the major active fault in the area, responsible for the most severe historical earthquakes (e.g., Zupančič et al., 2001; Poli & Zanferrari, 2018). The tectonic structure, with a N100 strike, cuts the Resia Valley and continues into the Tagliamento Valley, where it is named as Idrija-Ampezzo fault (Zanferrari et al., 2013).

In the present day, the Julian Prealps represent the

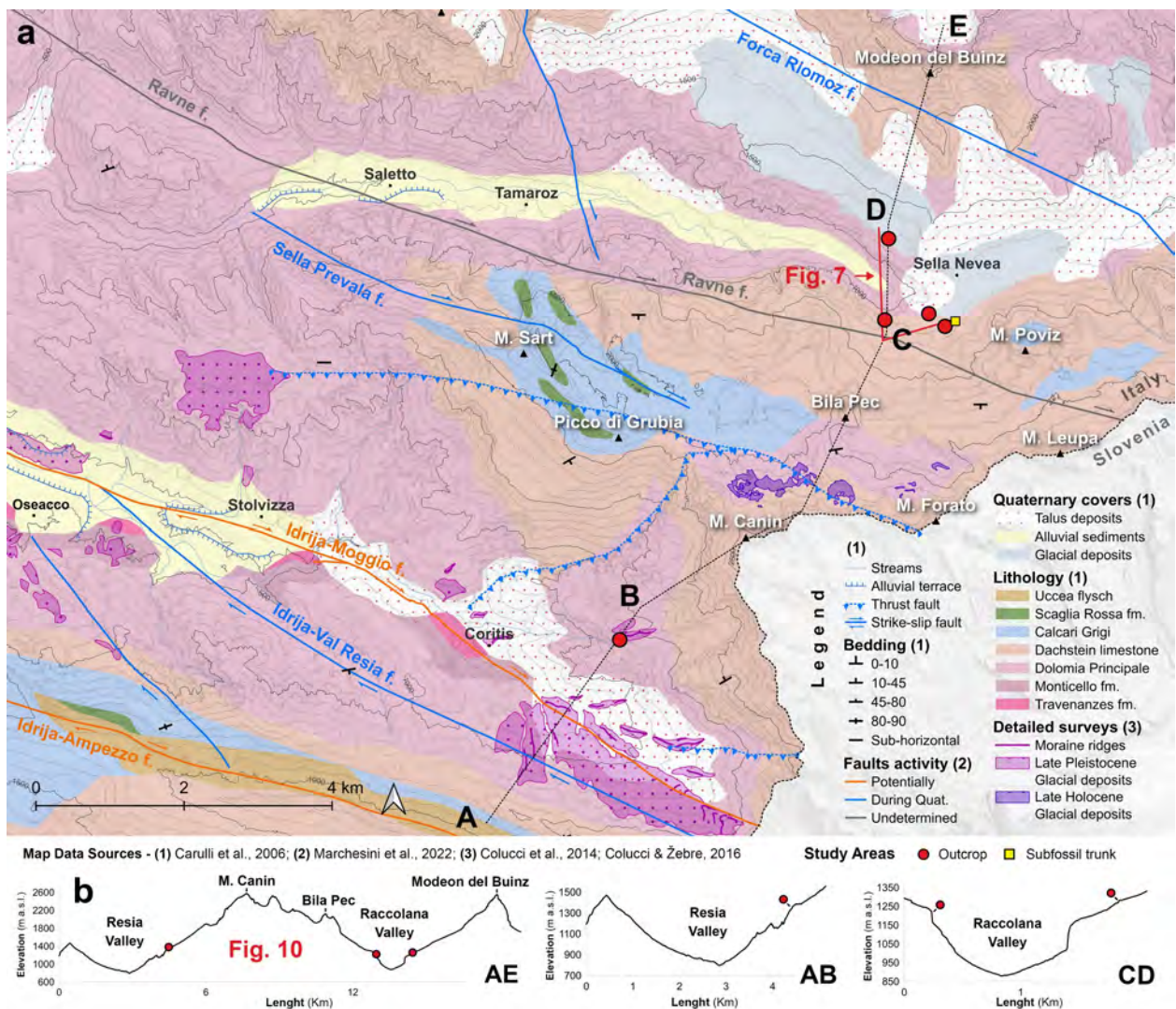


Fig. 2 - a) Geological map of the study area with lithology retrieved from Carulli et al. (2006), faults from Marchesini et al. (2023) and Resia Valley-Canin glacial deposits from Colucci et al. (2014) and Colucci & Žebre (2016), respectively. b) Profiles from the study area (AE), Resia Valley (AB) and Raccolana Valley (CD).

sector of the Alps with the highest Mean Annual Precipitation (MAP) (Isotta et al., 2014; Crespi et al., 2018). Data from the Canin-2200 Automatic Weather Station (AWS), located at 2203 m a.s.l., indicate that the 1981-2010 MAP is 3335 mm water equivalent (w.e.; Colucci & Guglielmin, 2015), with a maximum in November (460 mm w.e.) and a minimum in February (180 mm w.e.). Orographic forcing by the outer Alpine ranges, which block moist southerly air masses originating over the Adriatic and the Mediterranean Sea, is the main driver of this peculiar precipitation distribution (Colucci et al., 2021).

From the same site the 1981-2010 Mean Annual Air Temperature (MAAT) is $1.1 \pm 0.6^\circ\text{C}$, with monthly extremes ranging from $-6 \pm 2.9^\circ\text{C}$ in February to $9.2 \pm 1.3^\circ\text{C}$ in July.

Despite the present-day environmental Equilibrium Line Altitude (envELA) located above the highest peaks of the Julian Alps (Colucci, 2016; Žebre et al., 2021) and summer temperature constantly increasing since the mid-1980s (Securo et al., 2022), the peculiar climatological setting of the area and local topography support the persistence of ice patches on the north-facing slopes of

Mount Canin at relatively low elevations (between 1830 and 2340 m a.s.l.; Colucci, 2016) compared to the rest of the Alps. Moreover, high-elevation snow patches on the southern side of the Resia Valley can also persist until late summer (Colucci et al., 2014). Snow preservation is further enhanced by avalanche activity, which delivers significant snow accumulations to the base of the rock cliffs and mitigates summer melting. According to Del Gobbo et al. (2023), during the last phase of the LGM, mean air temperatures in the area were about $9\text{--}10^\circ\text{C}$ lower than at present in winter (i.e. $7\text{--}8^\circ\text{C}$ lower than preindustrial levels), and $6\text{--}7^\circ\text{C}$ lower in summer. The precipitation pattern was similar, driven by the same mechanisms as today, but summer convection provided an important source of snowfall on the glaciers, thereby limiting melting. Overall, total precipitation was about 25-30% greater in summer, and 0-10% in winter.

For this reason, the reconstructed LGM envELA was drastically lower in the study area, at about 950-1000 m a.s.l., compared to a mean Alpine envELA of 1444 m a.s.l. (Del Gobbo et al., 2023).



Fig. 3 - a) Fluvial conglomerates outcrop at the bend at 1250 m a.s.l. along the road to the Piani di Montasio. b) Detail of the trough cross-bedded clast supported conglomerate. c) 3D view of the outcrops obtained from LiDAR data. d) Detail of the bedding of the gravel bars gently dipping to WNW. e) Panorama of the fluvial conglomerates at the bottom of the main cliff.

3. METHODS

Sub-metric topographic surveys available from airborne light detection and ranging (LiDAR) data of the Friuli Venezia Giulia Region (RAFG, 2020) were used prior to field surveys of the outcrops to frame the area of interest and understand its general morphology. Orthometric heights were used to characterize maximum deposit thicknesses, produce topographic profiles and, during interpretation, were useful for visualizing macroscopic structures and stratifications helpful in the recog-

nition of quaternary deposits. However, airborne LiDAR was not suitable for characterizing sub-vertical outcrops due to the expected reduction in points density for near-vertical features when no specific oblique-acquisition is performed (Buckley et al., 2008).

We therefore carried out additional surveys using an unmanned aerial vehicle (UAV) to obtain more topographic data of the main outcrops (Fig. 1). The surveys, consisting of a series of overlapping photographs, were shot with a DJI Mavic Air 2 without using ground control points and processed following the traditional structure

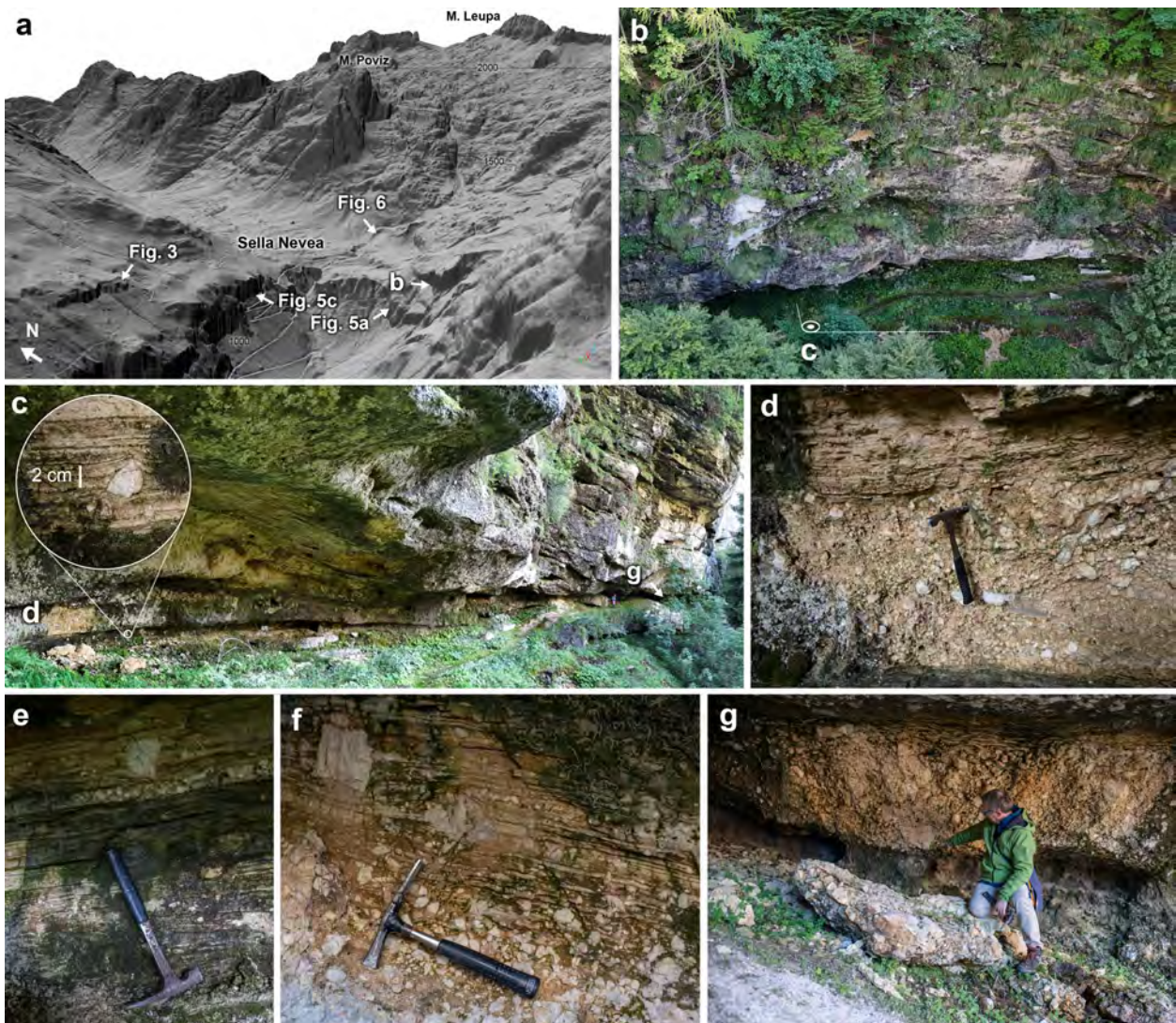


Fig. 4 - a) 3D view of the outcrops obtained from LiDAR data. b) Drone view of the fluvial conglomerate of the climbing crag cliff. c) Shelter of the climbing crag cliff with the outcrops of laminated sandstones with angular clasts (d-e-f). g) Toe of the landslide breccia interfingering with the fine grained fluvial deposits.

from motion (SfM) pipeline (Carrivick et al., 2016). The resulting point clouds and orthophotos of the outcrops were used in the interpretation of the results and figures.

Fieldworks included outcrop description, lithofacies analysis was performed using fluvial (Miall, 1996) and glacial (Eyles et al., 1983) facies codes. The coordinates and a brief description of how to access the investigated outcrops can be found in the Supplementary Material (Table S1).

Samples of the subfossil wood remnants, found embedded in one of the Sella Nevea deposits, were sampled and sent to the AMS laboratory (ETH Zürich) for ^{14}C analysis, where they were dated (Stuiver & Polach, 1977).

4. RESULTS

4.1. Sella Nevea

On the northern side of the Sella Nevea, along the road to the Montasio plateau, a thick clastic succession crops out between 1200 and 1300 m a.s.l. (Fig. 3). The main outcrop area is characterized by rock shelters due to cementation, which is locally strong but there are also

weakly cemented parts. The succession hangs over the 400 m high cliff of the Raccolana Valley (Fig. 3c), pointing to a deep post-depositional incision.

The succession comprises different facies. At the bottom, in the eastern part, fine-grained laminated silt and sand deposits, weakly cemented, crop out at about 1230 m a.s.l. (Fig. 3b). To the west, the main outcrop is a 300 m-long cliff made of graded, clast-supported to partially open-work conglomerates (Fig. 3d,e), with a well-sorted sandy matrix interbedded in thin sandy layers that are more frequent at the base. Clasts are subangular to subrounded, they are made of carbonate lithotypes (white limestones and dolostones with rare pinkish limestones); clasts are mostly few cm in size, with maximum dimension around 30 cm. Subangular clasts of black cherts are the only non-carbonate lithology; these belong to the Calcarei Grigi Group (Early Jurassic), presently outcropping in the slopes of Mount Povic (Assereto et al., 1968). The deposit shows trough cross-to planar cross-bedding with a gentle inclination of the gravel bars towards the west, and an outcropping thickness of about 50 m. To the east, towards Cregnedul, the slopes are characterized by scattered outcrops of angu-

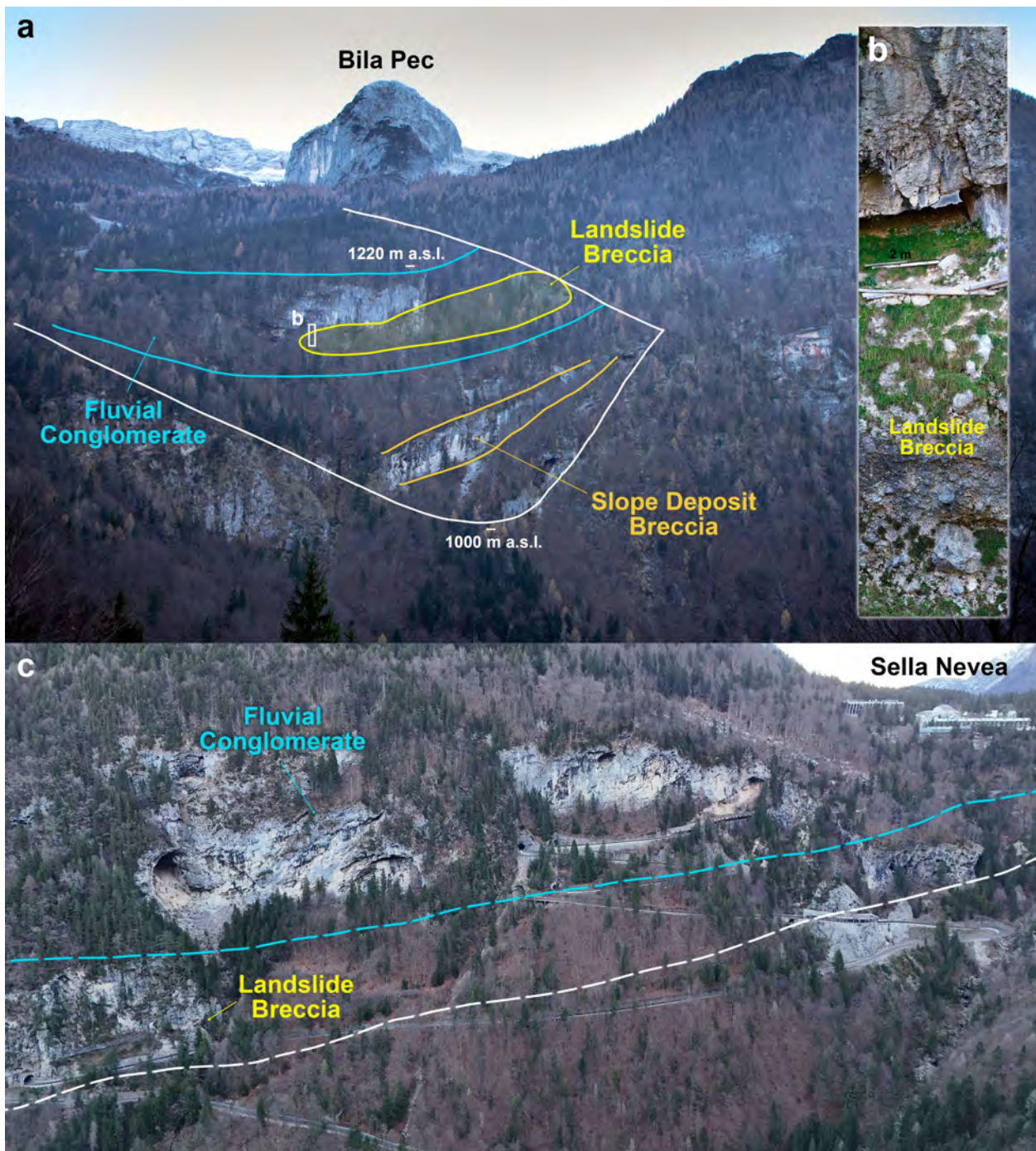


Fig. 5 - a) Panoramic view of the climbing crag cliff (Fig. 4a for location) and stratigraphic interpretation (Fig. 7 for details), basal white line indicates the former valley floor. b) Detail of the landslide breccia. c) Panoramic view of the Sella Nevea road section, where thick fluvial and slope succession is cut by the road.

lar breccias. The overall succession can be interpreted as consisting of fluvial deposits with gravel bars related to a river flowing from the east to the west, with lateral and basal interaction with slope deposition. Fine-grained layers are scarce, while the abundance of subangular clasts suggests an important local contribution and the presence of black cherts may be interpreted as a source from the area of Mount Povic and Mount Leupa.

Moving to the saddle, the cliff crossed by the Sella Nevea road at the headwall of the Raccolana Valley is made of chaotic breccias at the bottom, with a visible

thickness of more than 100 m, from 960 to 1080 m a.s.l. Above, to around 1250 m a.s.l., the succession is made of clast-supported conglomerate, very well cemented, made of sub-rounded pebbles of carbonate lithology. The conglomerate shows a planar to trough cross-bedding with a gentle dip toward the west and forms a deposit more than 200 m thick (Fig. 4a and 5). It is likely that this deposit can be heteropic with slope deposits, but the scarcity of reachable outcrops and the cementation hamper a clear stratigraphic description.

In the western side of Sella Nevea, another thick

Sample-Nr.	Description	C14 age BP	F14C	$\delta^{13}C$ ‰	$\pm 1\sigma$	mg C	C/N
ETH-70936	silt and sand wi	>48400	<0.0024	-25,1	1	0,99	123
ETH-70937	silt and sand wi	>48700	<0.0023	-23,6	1	1	252

Tab. 1 - Results of the dating analysis of the wood remnants (Fig. 6e) from the yellowish-green silty-sandy deposit with wood inclusions (wi) of Sella Nevea.

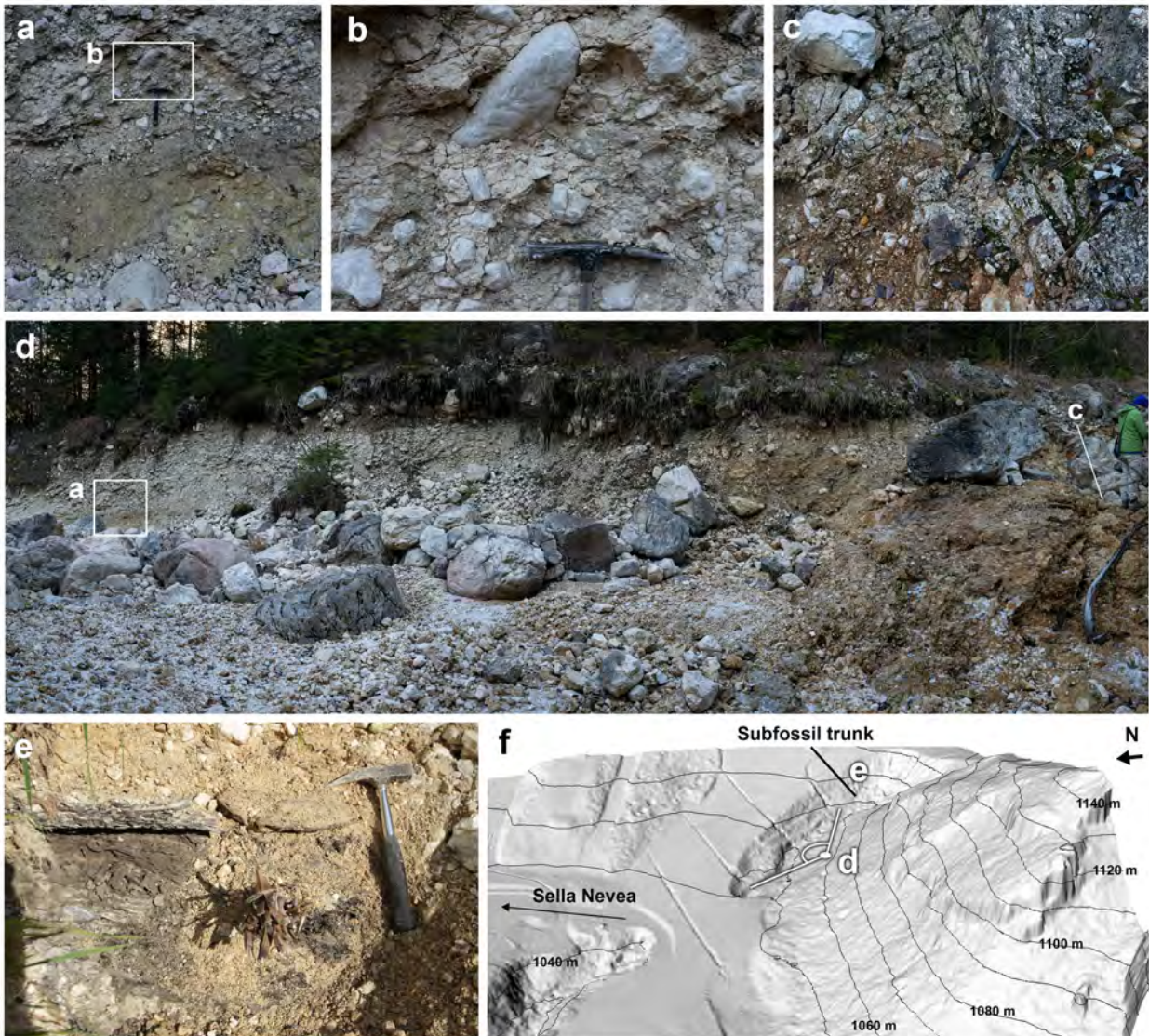


Fig. 6 - Photos of the succession outcropping in the incision south of Sella Nevea (Fig. 4a for location). a) Matrix-supported tillite lying on a yellowish-green alluvial deposit embedding the trunk remnants. b) Detail of the tillite. c) Detail of the basal breccia deposit interested by faulting. d) Panoramic view of the outcrop with location of the details. e) Detail of the trunk remnants embedded in the yellowish-green alluvial deposit. f) 3D view of the outcrops obtained from LIDAR data.

succession is preserved, between 1000 and 1250 m a.s.l., forming a high cliff at the headwall of the Raccolana Valley (Figs. 4 and 5a). The succession consists of three main sedimentary bodies, all well cemented. The basal one is a clinostratified breccia, about 200 m thick and made of angular clasts and boulders; it is interpreted as a slope deposit partially heteropic with fluvial deposits. The upper deposit is a clast-supported conglomerate of fluvial origin, composed of sub-rounded pebbles of carbonate lithology that show a planar to the

conglomerate trough cross-bedding with a gentle dip toward the west. Fine-grained intervals with laminated silt and sands were observed at its basal boundary with some angular dropstones that are interbedded within the laminae. This unit is about 100 m thick and it is interbedded with a coarse limestone breccia containing angular boulders; it represents a third sedimentary body that pinches out towards NE and its toe is visible along the track of the climbing crag. It is remarkable that the fine-grained deposition on top is characterized by lami-

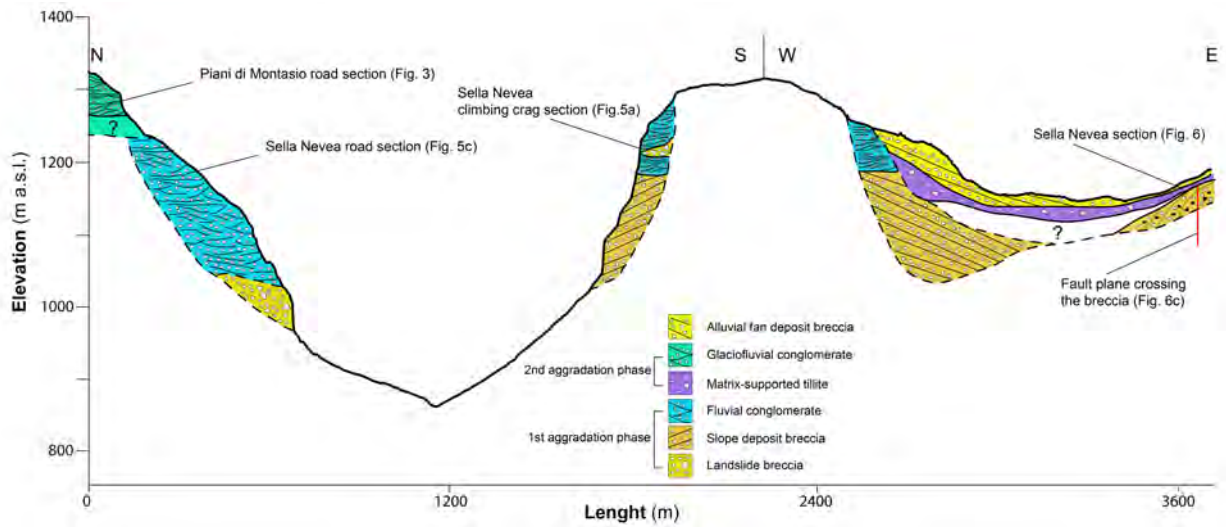


Fig. 7 - Geological cross-section of the Sella Nevea successions (see Fig. 2 for location).

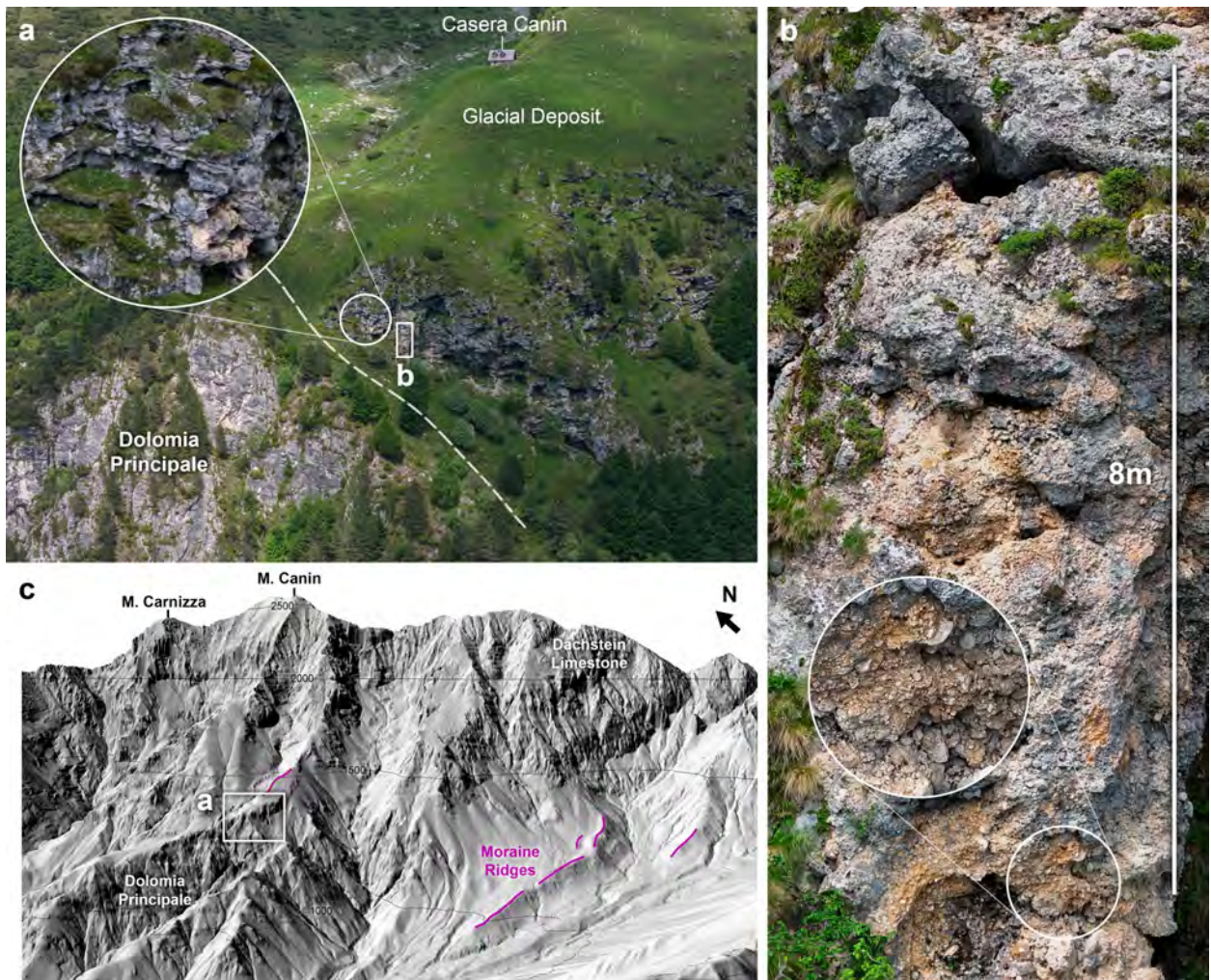


Fig. 8 - a) UAV photo of the outcrop in Resia Valley, close to Casera Canin, dashed white line indicates the basal surface of the Casera Canin Breccia. b) Detail of the outcrop and c) 3D overview obtained from LiDAR data. Moraine ridges retrieved from Colucci et al. (2014).

nated sands with angular clasts (Fig. 4e,f). The whole succession can be interpreted as a slope deposit passing to an alluvial deposition. The dropstones can be

interpreted as having fallen from the surrounding cliffs, as they are close to the breccia body, which can be interpreted as a landslide. The strong cementation sug-



Fig. 9 - Panoramic view of the conglomerate of Gniva (Fig. 1 for position), in the Resia Valley.

gests a long phase of diagenesis due to groundwater flow before the incision of the Raccolana Valley, over which the deposit is presently hanging on a 200 m high cliff.

In the incision south of Sella Nevea (Fig. 6), for about 400 m in length, another sedimentary succession is visible. At the base is a breccia body, made of carbonate clasts in a silty-sandy matrix. The deposit is well cemented, and many clasts show dissolution patterns, especially the dolostone ones. The bedding is rough but appears to be inclined at more than 50° (Fig. 6d). The deposit can be interpreted as a slope deposit and is cut by several joint fractures and by a vertical fault plane with strike N40°. The breccia is unconformably overlain by a yellowish-green silty-sandy deposit with subangular pebbles, about 1 m thick, showing a gentle dip towards NW (Fig. 6a-c). Embedded in the deposits, a large piece of wood and several small wood remnants were found. The radiocarbon analysis yielded infinite ages beyond the method's limit (>46.000 a BP, Tab. 1), pointing to a pre-LGM age. This deposit can be interpreted as a local alluvial deposit. It is covered by a matrix-supported massive diamicton, cemented with subrounded, striated, and faceted pebbles of carbonate rocks indicating a glacial deposition and thus interpreted as tillite (Fig. 6b). It has a preserved thickness of about 3 m and is cut by an erosional surface. Above, another breccia body lies; it is crudely bedded and dips towards N-NNW, and is composed of subangular to subrounded clasts, mainly white limestone and dolostone with some dark-grey limestone pebbles. The breccia body is 4-5 m thick but to the west, it has an overall thickness of some tens of meters and rests beside the fluvial conglomerate of the climbing crag. This latter unit can be interpreted as a proximal alluvial fan, whereas the basal unit should be remarkably

older than the topmost ones, as indicated by its post-lithification weathering and tectonic deformation, which point to the occurrence of a post-depositional uplift phase. The younger slope deposits, containing wood remnants and tillite, lie on an erosional surface. The radiocarbon age beyond the method's limit and the cementation of the till indicated a generic pre-LGM and a likely Middle Pleistocene age. The subsequent alluvial fan deposit suggests an important aggradation phase after a cold period.

4.2. Resia Valley

The Resia Valley hosts thick and diverse sedimentary units related to the LGM (Colucci et al., 2014), which are the result of the development of local glaciers from the western side of the Canin and the northern side of the Julian Prealps. The valley is also characterized by scattered cemented deposits. A breccia body is located at the headwall of the valley, next to Casera Canin (Fig. 8a); it is clast-supported, with scarce sandy matrix, and is composed of monogenic angular clasts with a maximum size of about 40 cm. The deposit is crudely bedded with a gentle dip towards the south. The thickness of the deposit is up to 110 m and it onlaps the bedrock at 1570 m a.s.l. along the crest of the Canin filling a palaeo-incision towards the south with an increase in thickness from 90 to 110 m. It forms a ridge that hangs on a 500 m-high cliff of cataclastic dolostones; the southern cliff of the breccia body is cut along a surface with the same strike as the cleavage in the underlying dolostones. The deposit can be referred to a proximal slope at the outlet of the valley, whereas the lack of evidence for glacial diamicton may suggest deposition during a climatic phase without glaciers. Considering the present-day setting, the deposit should have formed

when the deep incision of the upper Resia was not yet developed.

A second thick deposit crops out at the junction between the Resia and the Barman valleys at Gniva (Fig. 9) forming a 50 m-high cliff (Desio, 1926; Cucchi & Finocchiaro, 2009). This deposit is located at the top of cross-bedded gravels with alternating beds richer in sandy matrix, for a thickness of about 6-7 m. Clasts are sub-rounded and of limestone lithotypes, which indicate a provenance from the Rio Barman catchment. Below, the gravels are graded and have a general dip towards NNW. At the bottom a few outcrops expose the basal fine-grained deposits, consisting of silty sand, laminated with the presence of clasts. Another outcrop is located along the Resia River just upstream of the junction with the Barman Stream (Fig. 1). Here, the conglomerate shows a transition to silty laminated deposits, which are consolidated and host dropstones. The deposit shows a strong cementation, but does not show dissolution processes such as karstification. The facies association indicates a Gilbert-type delta deposit related to the Barman stream. The accommodation space that favored the accumulation of this unit is related to the damming of the valley, which can be ascribed to downstream blocking due to a landslide or ice mass. The common presence of dropstones in the bottomset fine-grained deposit indicates a marginoglacial environment existing during a pre-LGM advance. A similar conglomerate crops out at the junction between the Resia and the Rio Nero valleys and has a thickness of about 20 m. Also in this case the deposit is made of carbonate clasts, suggesting provenance from the Rio Nero Valley.

At the outlet of the Resia Valley, a saddle hangs 150 m over the present-day valley floor and this zone is made of carbonate gravels with sandy layers and interbeds (Colucci et al., 2014).

A noteworthy geological issue in the upper Resia Valley is the common occurrence of weathered rounded boulders, up to 1 m in size, of Carboniferous quartz conglomerates, whose outcrop area of origin is in the present-day northern watershed of the Fella River, 25 km to the north. These boulders are embedded in slope deposits or scattered in the lag of the creeks, and it is remarkable that such remnants have not been found in the ridge separating the Resia Valley from the Fella one, at about 800-900 m a.s.l. Some of them are located near Coritis, at the toe of the Mount Canin western slope, 900 m just below the Casera Canin breccia outcrops, while similar boulders are found at high elevation in the Fella Valley. On the eastern ridge of the Amariana Mount, boulders of 3 m in diameter are present at 1100 m a.s.l., about 450 m above the LGM trimline (Zanferrari et al., 2013).

5. DISCUSSION

The Tagliamento catchment is rich in Plio-Pleistocene conglomerate units located from 250 to 1400 m a.s.l. (Astori & Venturini, 2004; Venturini & Disenza, 2009; Monegato & Stefani, 2010, 2011; Zanferrari et al., 2013). These represent the remnants of ancient palaeo-drainages and slope deposition. The presence of thick cemented successions between 1000 and 1400 m a.s.l. in the area surrounding the Canin Mount is peculiar in the framework of the south-eastern Alps. Moreover, the occurrence of erratic boulders of Palaeozoic units at elevations far higher than the trimline of the LGM glacier raises the question of what type of glacial network determined their distribution.

Looking at the present sharp landscape with narrow gorges and up to 2000 m-high mountain slopes in

the Julian Alps, the remnants of thick deposits need preservation mechanisms. The sedimentary successions of the climbing crag at Sella Nevea (Fig. 4), attributed to fluvial and slope deposition and about 300 m thick, and the roughly same succession on the other side of the valley, can be related to a first aggradation phase after an initial base-level below 1000 m (in present elevation a.s.l.). The basal breccia south of Sella Nevea (Figs. 6d,c and 7) can be ascribed to the same sedimentation phase. The thickness of this succession is similar to the conglomerate and breccia successions located in the valley sides of the present Tagliamento Valley at Portis and Braulins (Zanferrari et al., 2013). They were related to the early Middle Pleistocene, when the Fella River merged with the Tagliamento River at Osoppo (Monegato & Stefani, 2010; Zanferrari et al., 2013), 11 km downstream of the present-day junction (Fig. 1c). In this perspective, the successions of Sella Nevea climbing crag and road (Figs. 4 and 5) have similar facies assemblage and preservation feature and may be associated to the same phase of uplift and important slope deposition. The approximately 300 m thick sedimentary stack could have been formed due to downstream damming caused by the Fella glacier or, alternatively, by a landslide. The flow direction of the fluvial deposits towards the west indicates that the Raccolana catchment has been tributary of the Fella Valley since the beginning of its sedimentary infilling, contradicting previous interpretation (Desio, 1926; Venturini & Disenza, 2009) of a watershed demolished by headwall erosion.

The oldest glacial unit in the Tagliamento catchment highlights the contribution of transfluence from the Austrian Alps, located to the north, and the catchment of the Piave River, located to the west. These are marked by the common occurrence of crystalline boulders and Permian conglomerates in the oldest glacial remnants (i.e. Ledrania synthem in Zanferrari et al., 2013). The occurrence of weathered boulders of Permian conglomerates in the high Resia Valley suggests their deposition during an oldest advance of the Fella glacier (Fig. 10a). It is worth noting that, to let this glacier to have entered the Resia Valley, the topography must have been much lower than today. This implies that the present M. Plagna-M. Posar ridge (Fig. 1 for location) should have been much lower, and most of the western slope of Mount Canin would have been below the ELA, likely hosting only cirque glaciers. The 110 m-thick breccia unit at Casera Canin may have been deposited at that time. The northern slope of Mount Canin could have hosted cirque glaciers and the fluvial conglomerates outcropping on both the sides of the high Raccolana Valley (Figs. 7 and 9) could be interpreted as related to distal outwash deposition. The slope and landslide breccias indicate the instability of the steep valley flanks at the beginning and during this phase.

A subsequent tectonic phase due to the Idrija-Ampezzo fault system (Zanferrari et al., 2013) uplifted and deformed the succession, as marked in the basal breccia south of Sella Nevea (Fig. 6c,d). The uplift drove an important incision phase which is recorded at the headwall of the Raccolana Valley, and by the angular unconformity between the breccia body and the alluvial deposits containing wood remnants and the subsequent tillite. In the Resia Valley the Casera Canin breccias were also uplifted, as their southern cliff is located just over a fault. The uplift of M. Plagna-M. Posar ridge, as evidenced by the shift of the Resia Valley outlet (Colucci et al., 2014), likely prevented the transfluence of the Fella glacier into the Resia catchment. All subsequent depositional phases, on both sides of Mount Canin,

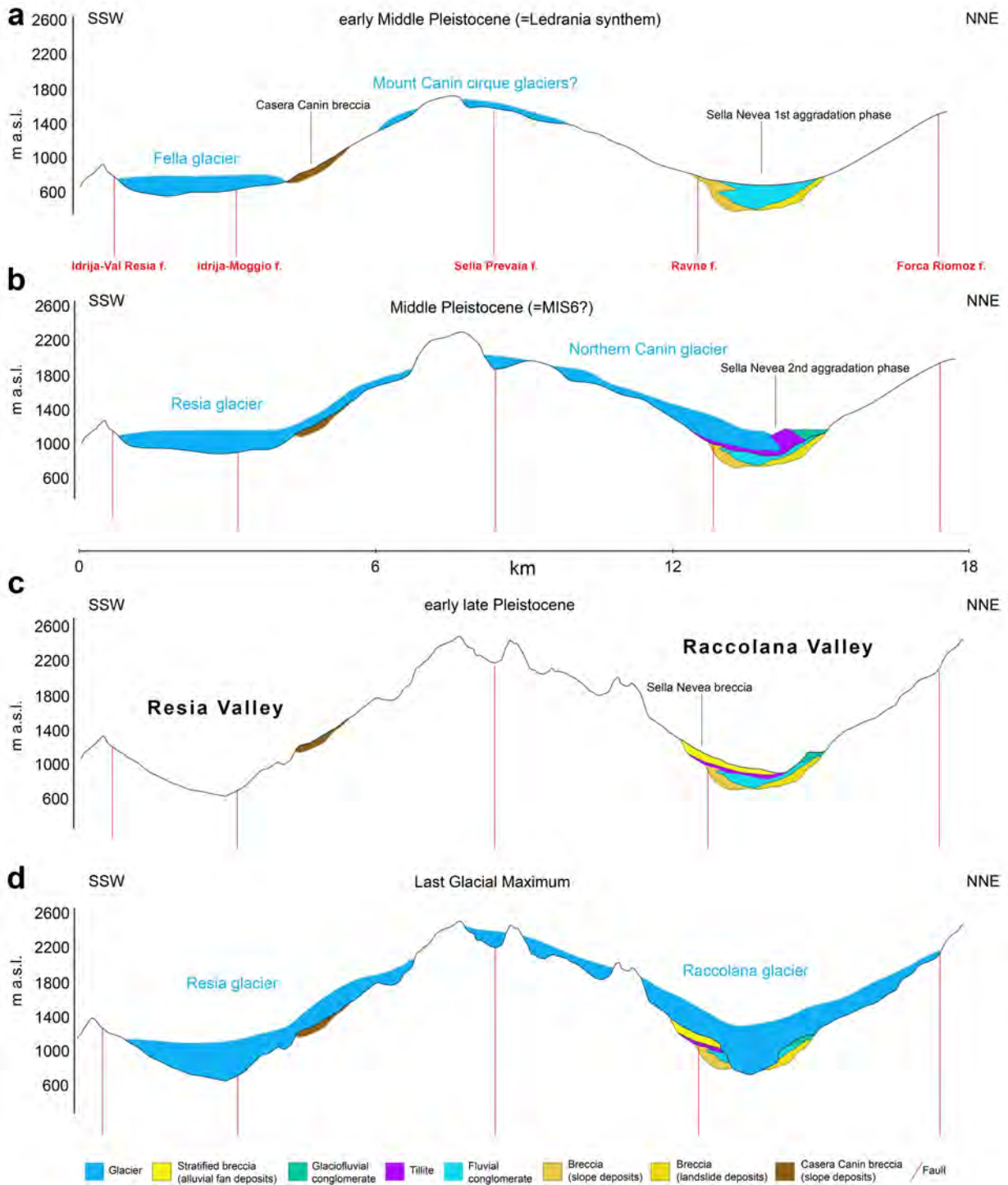


Fig. 10 - Cross-section interpreted scheme of the evolution of Mount Canin and surrounding valleys during the Pleistocene. a) Early Middle Pleistocene cold phase, filling of the Raccolana Valley, transfluence of the Fella glacier into the Resia Valley and deposition of the Casera Canin breccia. b) Middle Pleistocene cold phase (MIS6?), spread of glaciers of Mount Canin, second phase of filling of the Raccolana Valley. c) Early Late Pleistocene (?), erosion of the glacial deposits and development of an alluvial fan on the toe of the northern slope of Mount Canin. d) Last Glacial Maximum, development of large and thick valley glaciers from the Mont Canin area and carving of the Raccolana Valley. Faults are symbolically represented without kinematics and reported according to Figure 2 (Marchesini et al., 2023).

were confined within the older deposits. Also, the northward shift of the Tagliamento/Fella junction may be attributed to this phase (Monegato & Stefani, 2011).

The tillite of Sella Nevea (Fig. 6b) indicates the development of glaciers on the northern side of Mount

Canin during a subsequent cold phase of the Middle Pleistocene (MIS6?), with ice flowing down into the Raccolana Valley and likely into the Rio del Lago Valley (Fig. 10b). The uplift created a larger glacial accumulation area above the ELA, promoting the spread of local

glaciers. If the envELA had been roughly similar to the LGM (around 1000 m a.s.l.) the glaciers would have been of similar extent. In this case, the glacial deposits preserved in the area should be associated to a late-glacial phase. The fluvial succession located on the northern side of Sella Nevea, between 1240 and 1320 m a.s.l., because of its local provenance and the abundance of subangular clasts, may be interpreted as the glaciofluvial deposit related to this phase (Fig. 10b). Similarly, in the Resia Valley, a valley glacier could have developed. The deltaic conglomerate of Gniva (Fig. 9) could represent a withdrawal phase of that event. After this cold phase, the area of Sella Nevea experienced the development of an alluvial fan from the northern slope of Mount Canin and tentatively ascribed to the early late Pleistocene (Fig. 10c). At that time, the headwall of the Raccolana Valley was not as steep as today. Subsequently, the extensive advance of the Tagliamento-Fella glacier network during the LGM, favored by the low ELA, deposited a large amount of glacial deposits within the valleys (Zanferrari et al., 2013; Colucci et al., 2014) and deeply carved the Raccolana Valley (Fig. 10d). The upper Resia Valley has less steep flanks due to the presence of glaciers in the Lateglacial phase (Colucci et al., 2014).

The overall distribution of the sedimentary successions and the phases of incision and valley fill point to the tectonic displacement caused by the activity of the Idrija-Ampezzo fault system (Bavec et al., 2013; Zanferrari et al., 2013; Marchesini et al., 2023) as the major driver of valley evolution surrounding Mount Canin. From this perspective, since the onset of Pleistocene glaciations in the Alps, around 900 ka (Muttoni et al., 2003), important changes in the palaeo-topography of the Julian Alps must have occurred as a consequence of the tectonic activity of this fault system. The development of major valley glaciers originating from Mount Canin since the end of the Middle Pleistocene is well documented on both the Italian (Colucci et al., 2014) and Slovenian sides (Bavec & Verbič, 2011; Jamšek Rupnik et al., 2020; 2022). Old remnants in both the Tagliamento and Soča catchments are very scarce, and those described for the Tagliamento point to an important contribution from outer glaciated catchments (Zanferrari et al., 2013). The contribution of the Julian Alps as an accumulation area became effective only at the end of the Middle Pleistocene, suggesting that their uplift that led to larger accumulation areas above the ELA. In this mean, tectonics acted as the major controlling factor for the geomorphological processes that shaped Mount Canin and the surrounding valleys.

6. CONCLUSIONS

The thick cemented terrestrial successions surrounding the Mount Canin in the Julian Alps represent the steps of the tectono-sedimentary evolution of this portion of the Alpine Chain. Two main phases of sedimentary aggradation occurred. The first, about 300 m thick, could have been driven by the spread of the Fella glacier during an early Middle Pleistocene cold stage. This glacier entered the Resia Valley, lying erratic boulders in the high sector of the valley. The Mount Canin had to be lower at that time, and its glaciers remained confined at high elevation on both sides. On the northern side the outwash streams were funnelled in the Raccolana Valley, whose aggradation could be due to the downstream damming of the Fella glacier. The Mount Canin area experienced an uplift phase in the Middle-Late Pleistocene due to the activity of the Idrija-Ampezzo fault system. The uplift led to larger sectors of

the mountain exceeding the envELA elevation and promoting more extensive glaciers. The tillite of Sella Nevea, laying in angular unconformity on the deformed breccia, indicates that a deformation phase occurred some times during the Middle Pleistocene. The second aggradation phase is ascribed to a later glacial advance. The subsequent incision phase, tentatively attributed to the early late Pleistocene, led to the development of proximal alluvial fans at the toe of the northern side of Mount Canin. The spread of glaciers in the Julian Alps during the LGM led to the carving of the Raccolana Valley, exposing the older successions.

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