GRAVITY TECTONICS IN EASTERN CADORE AND WESTERN CARNIA, (RESPECTIVELY PROVINCES OF BELLUNO AND UDINE), NE ITALY,

(WITH ADDITIONAL NOTES ON THE GEOCHEMISTRY OF LEAD)

B. W. VINK

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PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE
WISKUNDE EN NATUURWETENSCHAPPEN AAN DE RIJKSUNIVERSITEIT
TE UTRECHT, OP GEZAG VAN DE RECTOR MAGNIFICUS,
PROF.DR. J. LANJOUW,
VOLGENS BESLUIT VAN DE SENAAT IN HET
OPENBAAR TE VERDEDIGEN OP MAANDAG 18 NOVEMBER 1968
DES NAMIDDAGS TE 2.30 UUR

DOOR

BERNHARD WILLEM VINK

GEBOREN OP 14 DECEMBER 1941 TE BILTHOVEN

1968
BRONDER-OFFSET ROTTERDAM

PROMOTOR: PROF.DR.IR. R.W. VAN BEMMELEN

Aan mijn moeder

WOORD VOORAF

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L'ospitalitá che essi mi hanno offerto ha reso il mio soggiorno in Carnia e Cadore sempre piú piacevole.

CONTENTS

LIST OF ENCLOSURES

STELLINGEN

1. Een der belangrijkste factoren voor de tectonische interpretatie van het structuurbeeld van Carnia en Cadore (resp. provincies Udine en Belluno, Noordoost Italië) moet worden gezocht in de aard van het metamorfe basement complex.
   Dit proefschrift.

2. Het is waarschijnlijker dat de oorsprong van Pb-anomalieën in de permische Gardena Zandsteen in Noordoost Italië verband houdt met het metamorfe basement complex dan met de permische kwartsporfier van Bolzano, waarmee Pb-voorkomens in de Dolomieten zijn geliëerd.
   Dit proefschrift.

3. Bij epi- of mesozonale metamorfose loopt de partiële CO_2-druk tijdens de metamorfose zelfs in calcium-rijke gesteenten niet hoger op dan 200-300 bars/cm^2, en blijft daarom slechts een kleine fractie van de totale druk tijdens de metamorfose.
   R.D. Schuiling, B.W. Vink — Geochim.Cosmochim.Acta,1967,vol.31.

4. Granieten van het eiland Paros (Cycladen, Griekenland) zijn van prae- of synmetamorfe ouderdom.

5. De methode die Eugster en Prostka geven voor de synthese van meioniet en marialiet, eindleden der skapoliet reeks, is van twijfelachtige waarde en is in geen geval reproduceerbaar.
   H.P. Eugster, H.J. Prostka — Bull.Geol.Soc.Am.,1960,vol.52.

6. De mening van Marinos, dat ogengneisen die de kern vormen van een dôme-vormig lichaam op het eiland Ios (Cycladen, Griekenland) kataklastisch gedeformeerde granieten zouden zijn, wordt door diverse veldwaarnemingen tegengesproken. Een betere verklaring wordt gegeven o.a. door Agterberg, die voor de Riesenferner Augengneiss in Noord Italië aannemelijk maakte dat een actieve kaliummetasomatose in samenhang met een nabije tonaliet intrusie de beste verklaring is voor het ontstaan van deze ogengneis.
   G. Marinos — Ann.Géol.Pays Hell.,1947, 1e ser.
   F.P. Agterberg — Geol.Ultraiect.,1961, no 8.

7. De methode die Muan geeft voor de berekening van thermodynamische gegevens uit experimentele ternaire fasediagrammen heeft zoveel practische bezwaren, dat de methode nauwelijks toepasbaar is.
   A. Muan — Am.Min.,1967,vol.52.

8. Uit recente vondsten in de Quercy (Zuid Frankrijk) blijkt dat de kenmerken, waarop Hürzeler het genus *Paroxacron* baseert, aanvechtbaar zijn.
   J. Hürzeler — Mém.Soc.Paléont.Suisse,1937,vol.59.

9. De verklaring van de Exodus van het volk Israël uit Egypte, zoals die wordt gegeven door Velikovsky heeft geen enkele wetenschappelijke basis.
   Eleganter is de theorie van Ninkovich en Heezen, die de Exodus in verband brengen met een vulkanische eruptie van het Cycladen eiland Santorini, waarbij de huidige caldeira ontstond, welke eruptie volgens dateringen met de C^{14}-methode heeft plaats gevonden in omstreeks 1470 v.Chr.
   I. Velikovsky — Worlds in collision,1950,[2] 1967
   D. Ninkovich, B.C. Heezen — Colston Papers,vol.XVII,1965.

10. De houding van de Italiaanse regering in de afgelopen jaren ten opzichte van de ontwikkeling van de economie in de berglandstreek Carnia, Noordoost Italië, is laakbaar.

11. Het is raadzaam dat agenten van politie bij de handhaving van de orde tijdens belangrijke voetbalwedstrijden geschoeid gaan op voetbalschoenen.

B.W. Vink
18 november, 1968.

SAMENVATTING

In dit proefschrift worden de resultaten besproken van een vijftal zomers veldwerk, door de schrijver verricht (1963-1967) in de gebieden van oostelijk Cadore (Provincie Belluno) en westelijk Carnia (Provincie Udine), Noord-Oost Italie. Gedurende de eerste twee zomers werd dit onderzoek uitgevoerd met hulp van enkele candidaatsstudenten.
De studie was geheel gericht op het geven van een tektonische interpretatie van dit gebied in de Zuidoost Alpen. Aan gedetailleerde stratigrafische problemen is dientengevolge weinig aandacht besteed. De stratigrafische gegevens, opgesomd in hoofdstuk II, pretenderen slechts een sleutel voor de tektonische interpretatie te zijn.

In het bestudeerde gebied ligt op een metamorf grondgebergte een successie van sedimenten, in ouderdom reikend van Perm tot Onder-Jura. De totale dikte van deze kolom varieert van 4 tot 5 km.
In Cadore bestaat het grondgebergte uit een epimetamorfe kwartsfylliet; in Carnia is het ontsloten in de Centrale Carnische Alpen, waar het zich manifesteert als een heterogene serie paleozoische gesteenten, die tijdens de Hercynische orogenese zijn gemetamorfoseerd.
Wat betreft de permo-triadische sedimenten is veel aandacht geschonken aan dikte variaties der verschillende formaties, vooral van Onder- en Midden-Trias (resp. Scythien/Anisien en Ladinien/Carnien). In alle formaties van deze ouderdom komen opvallende dikte variaties voor.
Het zeer lokale voorkomen van breccies uit het Anisien (Ugovizza breccie), waarvan wordt aangenomen dat ze zijn gevormd aan de voet van steilwanden, en tevens het voorkomen van vulkanisch beinvloede formaties uit het Ladinien, doet, - mede in verband met bovengenoemde dikte variaties - vermoeden dat gedurende de Onder- en Midden-Trias horst- en slenkstructuren aanwezig waren, of althans dat de geosynclinale zeebodem gedifferentieerd was in gebieden, die door breuken en/of flexuren gescheiden waren (bekkens en platvormen), en waar langs die breuken plaatselijk een (submariene) vulkanische activiteit optrad.

Hoofdstuk III belicht in het kort regionale bekken- en platvorm-gebieden in Noord Italie gedurende Onder- en Midden-Trias. In het groot worden drie platvormen onderscheiden, (van west naar oost het Lugano-platvorm, het Atesinische platvorm in het gebied van de Dolomieten en het Julische platvorm in de Julische Alpen), waartussen twee gebieden lagen, waar de alpiene geosynclinale sneller daalde: het Lombardische bekken (Bergamasker Alpen) en het Carnisch-Bellunese bekken. Het in dit proefschrift behandelde gebied vormt de oostelijke zijde van het Carnisch-Bellunese bekken. Het blijkt dat de sedimenthuid van de platvormen en bekkens, - de epiderma -, mechanisch op verschillende manieren heeft gereageerd gedurende de latere alpiene orogenese.
In de Boven-Trias was de bovengenoemde periode van instabiele sedimentatie afgelopen: de boven-triadische en juradische formaties zijn over de gehele Zuidalpen tamelijk uniform ontwikkeld.

Hoofdstuk IV behandelt, deels beschrijvend, deels interpretatief, de verschillende tektonische eenheden. Achtereenvolgens worden beschreven:
A. de aard van het contact tussen het metamorfe grondgebergte en de oudste permische sedimenten, (de zog.Gardena Zandstenen). Dit contact is meestal een breukcontact, doch op sommige plaatsen worden flexuren waarschijnlijk geacht. (Phase 1 der tectogenese).
B. Een aantal grote zuidwaartse overschuivingen langs de zuidelijke randen van het bestudeerde gebied. (Phase 2 der tectogenese).
C. Een tweetal slenk systemen in het centrale en noordwestelijke deel van het gebied, resp. de Bordaglia-Sappada-Tudaio-slenk en de Val Visdende slenk. (Phase 3 der tectogenese). De eerste heeft een richting, variërend van zuidwest-noordoost voor het Bordaglia-gedeelte en westzuidwest-oostnoordoost voor het Tudaio-gedeelte. De tweede heeft in het westelijk deel een richting noordwest-zuidoost, die ombuigt tot vrijwel west-oost in het oostelijk deel. Tektonische eenheden van plaatselijke betekenis worden eveneens behandeld in hoofdstuk IV, resp. diapiere verschijnselen in het Val Pesarina (IVG), en klippe structuren en lokale verglijdingen (IV H en I).

Hoofdstuk V geeft de geodynamische interpretatie van de Gardena contactbreuken (phase 1), de overschuivingen (phase 2) en de beide slenk systemen (phase 3). De sleutel hiervoor wordt voor een groot deel gezocht in differentiële verticale bewegingen van het grondgebergte (zie de contourkaart van dit grondgebergte van fig.36).
Het ontstaan van de beschreven structuren wordt mechanisch het best verklaard met de theorie dat onderscheid gemaakt moet worden tussen primaire tecto-

genese, d.i. de oprijzing, in de vroegste stadia der orogenese, van de Centrale Carnische Alpen (de Carnische geanticlinale), en gravitatieve reacties hierop, (de secundaire tectogenese).
De tectonische gebeurtenissen in de sedimentepiderm zijn secundaire reacties op de primaire differentiële opheffingen, waardoor een spanningsveld van arbeidsvermogen van plaats ontstond.
Reeds in het vroegste stadium der geanticlinale rijzing begon de sedimenthuid zuidwaarts af te glijden (décollement), met de plastischer formaties als glijbasis voor de meer competente eenheden. Van deze oudste gebeurtenissen zijn echter in het onderzochte gebied geen of vrijwel geen overblijfselen terug te vinden.
Een verdere geanticlinale oprijzing had breuken in het grondgebergte tot gevolg, zoals de Gardena contactbreuken. Ook in het grondgebergte onder de grote overschuivingen zijn zulke normale breuken aangenomen, die het grondgebergte verdelen in trapvormige, naar het zuiden afzakkende, longitudinale schollen. Als oudste in het hier besproken gebied voorkomende phase, zijn deze breuken met het cijfer 1 aangegeven. De hiermede gepaard gaande meer lokale spanningsvelden van potentiële energie gaven een nieuwe impuls aan de décollement der sedimenthuid: deze meer lokale décollement, aangegeven met het cijfer 2, trad in het onderzochte gebied op grote schaal op, en veroorzaakte de overschuivingen aan de zuidzijde van het gebied.
Een nog verdere oprijzing der geanticlinale tenslotte veroorzaakte phase 3: rekslenken in de kruin der Carnische geanticlinale, vergelijkbaar met de west-oost Tarvis-slenk in de oostelijke Carnische Alpen, beschreven door Guicherit (1964).
Het feit dat deze slenken niet west-oost, maar (west)zuidwest-(oost)noordoost en (west)noordwest-(oost)zuidoost lopen, wordt in verband gebracht met de overgang van het Dolomietenblok in de Carnische Alpen, welke overgang gelegen is in het gebied van Vigo en San Stefano di Cadore.
De Bordaglia-Sappada-Tudaio slenk is de vervolging en noordoostelijke uitloper van de bekende Sugana lijn aan de zuidzijde van de Dolomieten; de Val Visdende slenk sluit aan op de Padola-Candide lijn, die de noord-oostelijke begrenzing van het Dolomietenblok vormt.
Tussen de phases 1 en 2 bestaat een direct causaal verband: phase 1 gaf, tegelijk met verdere oprijzing der geanticlinale, een nieuwe impetus aan de décollement van phase 2.
Tussen de phases 2 en 3 is echter geen direct verband aan te tonen; alleen de verdere geanticlinale rijzing is verantwoordelijk voor de rek in het kruingebied (phase 3).
Uit het voorgaande blijkt dat de primaire oprijzing en de secundaire reacties daarop elkaar in tijd voor een groot deel overlappen: de verschillende phases verliepen min of meer gelijktijdig.

Na of tijdens een periode van erosie en denudatie gedurende het jongere Plio-Pleistoceen werden op het toen bestaande patroon zeer lokale tektonische bewegingen gesuperponeerd. Als phase 4 is aangegeven het diapirisme, als phase 5 de lokale verglijdingen en klippe structuren. Met een aantal postglaciale verglijdingen rond de ingang van het Val Visdende van een aantal rifblokken uit het Anisien en Ladinien, worden een drietal niveaus van meerterrassen stroomopwaarts bij Sappada in verband gebracht.

GEOCHEMIE VAN LOOD

Aangetoond werd de aanwezigheid van positieve lood-anomalieën in de Gardena Zandsteen op alle plaatsen in het onderzochte gebied. De herkomst hiervan wordt gediscussiëerd. Een syngenetisch ontstaan van deze anomalieën is het meest waarschijnlijk; als herkomst gebied lijkt de Bozener kwartsporfier minder waarschijnlijk dan het metamorfe kwartsfyllietische en/of Carnische grondgebergte.

In verband met de lood-zink mijn van Salafossa, 2 km oost van San Pietro di Cadore, in het Ladinien (Schlern Dolomiet), volgt een discussie over de genese van deze ertsen. Een syngenetisch ontstaan is ook hier duidelijk; de herkomst van het erts wordt in verband gebracht met de breuktectoniek uit het Anisien en het vulkanisme uit het Ladinien: endogene ascendente oplossingen hebben het erst waarschijnlijk syngenetisch en synsedimentair aangevoerd en door plaatselijke precipitatie geconcentreerd.
Een alpien-tertiaire herverdeling van het erts, door oplossing, transport en herprecipitatie, zoals dat proces heeft plaatsgevonden bij de lood-zink ertsen van de Cave del Predil in de oostelijke Carnische Alpen, is hier niet opgetreden.

SUMMARY

In this thesis the results are discussed of five summers of fieldwork, (1963-1967), carried out by the author in the areas of Eastern Cadore, (Prov. of Belluno) and Western Carnia (Prov. of Udine), NE Italy.
During the first and the second summer the research was made with the aid of some B.Sc.'s in geology of the University of Utrecht.
The purpose of this study was to give a tectonic interpretation of this area in the Southeastern Alps. Therefore, less attention was paid to detailed stratigraphic problems. The stratigraphic data given in Chapter II pretend only to be the key to the tectonic interpretation.

In the area of study a succession of sediments, ranging from Permian up to Lower-Jurassic, is found upon a metamorphic basement complex. The total thickness of the sedimentary column ranges from 4 to 5 km.
In Cadore the basement complex consists of epimetamorphic monotonous quartzphyllites, whereas in the Central Carnian Alps a heterogenic series of paleozoic rocks occurs.
Much attention has been given to variations in thickness of the various formations, especially of the Lower- and Middle-Triassic, (respectively Scythian/ Anisian and Ladinian/Carnian). All formations of these ages show striking changes in thickness indicating differential vertical movements along faults during their deposition. Breccias of anisian age (the Ugovizza breccia) occur only in some places, and their restricted distribution indicates that they have been deposited at the feet of a local fault scarp. The occurrence of volcanic components in formations of ladinian age, in combination with these changes in thickness, lead to the assumption that during the Lower- and Middle-Triassic horst- and graben-structures were present. The floor of the geosynclinal sea was differentiated into regions which were separated by faults and/or flexures (basin- and platform-areas), and locally along these faults submarine volcanic activity occurred.

Chapter III gives a short description of the basin- and platform-areas in Northern Italy, which occupied the floor of the Thetys geosyncline, during the Lower- and Middle-Triassic. Bosellini (1965) distinguishes three platform areas (from west to east the Luganese Platform, the Atesin Platform in the area of the Italian Dolomites, and the Julian Platform in the Julian Alps), between which two areas were situated, where the floor of the alpine geosyncline subsided more rapidly: the Lombardic Basin (Bergamasc Alps) and the Carnian-Bellunese Basin. The area discussed in this thesis belongs to the eastern part of the Carnian-Bellunese Basin. It appears that the sedimentary epiderm deposited on the platforms reacted during the alpine orogenesis in a way that differed from the structural deformations of the thicker sedimentary sequences in the basin areas. In the Upper-Triassic the period of unstable sedimentation had terminated: the upper-triassic and jurassic formations have a rather uniform development in the entire Southern Alps.

Chapter IV treats, partly descriptively, partly interpretatively the various tectonic units. Successively are described:
A. The nature of the contact between the metamorphic basement complex and the oldest permian sediments, the so-called Gardena Sandstones. In most places a fault contact is present, but at some places flexures are thought to be more probable, (phase 1 of the tectogenesis).
B. An array of overthrusts along the southern margins of the area of study (phase 2 of the tectogenesis).
C. Two graben systems in the central and the northwestern parts of the area of study, respectively the Bordaglia-Sappada-Tudaio graben and the Val Visdende graben (phase 3 of the tectogenesis). The direction of the first series of graben changes from southwest-northeast in the eastern end (the Bordaglia section) to westsouthwest-eastnortheast for the Tudaio section. The Val Visdende graben is directed northwest-southeast in the western part of the graben, turning into an almost west-east direction in the eastern part of the graben.
Tectonic units of a restricted, more local extent are also treated in Chapter IV; successively diapiric phenomena in the Val Pesarina (IVG) and various klippe structures and local slides (IVH and I).

The geodynamic interpretation of the Gardena contact faults (phase 1), the overthrust structures (phase 2) and both graben systems (phase 3) is given in Chapter V. The key to this interpretation has largely been sought in differential vertical movements of the basement complex (see the contour map of the top of the basement complex of fig.36).
The origin of the structures described can best mechanically be explained with the theory that primary tec-

togenesis - the uplift of the Central Carnian Alps in the earliest stages of the orogenesis (the Carnian geanticline) - caused gravitational reactions in the sedimentary epiderm as well as in the basement complex or mesoderm (secondary tectogenesis). The primary differential uplift of the Carnian geanticline created a field of potential energy, leading to the gravitational spreading in epi- and mesoderm.

In the earliest stages of the geanticlinal uplift the sedimentary epiderm began to slide downwards (décollement), over the more plastic formations (for instance, the gypsiferous Bellerophon Strata and the Raibl Strata), which acted as a lubricating base for the more competent formations. In our area of study none or hardly any traces of this oldest phase of decollement could be found (with the exception of the basal breccia in the northeastern end of the Bordaglia Graben, see pag. 28).

Thereafter, the proceeding geanticlinal uplift caused faults in the basement complex such as the Gardena contact faults. Also in the basement complex beneath the great southward overthrust structures such normal faults were assumed, dividing the basement complex into steplike longitudinal blocks.This is the oldest, clearly observable, tectonic phase in the area under discussion, and we therefore indicated it as phase 1 in the tectonic map of fig.34, (pag. 48).

The more local stress fields of potential energy, due to these normal faults, gave new impulses to the decollement of the sedimentary epiderm: this renewed phase of decollement - occurring on a more local scale - is called phase 2.

It is the main phase of folding and thrusting in the area of study, causing the great overthrust structures along the southern margins of the area. Still further uplift of the geanticlinal Carnian Belt was responsible for phase 3: tension phenomena (graben structures) in its crest, comparable to the west-east directed Tarvisio-graben in the eastern part of the Carnian Alps, described by Guicherit (1964).

The graben structures in the area are not directed west-east, but (west)southwest - (east)northeast and (west)northwest - (east)southeast. This feature is related to the transition of the Dolomite Block into the Carnian Alps, which linkage is situated in the region of Vigo and San Stefano di Cadore.

The Bordaglia-Sappada-Tudaio graben is the northeastern extension of the well-known Sugano lineament at the southern margin of the Dolomite Block. The Val Visdende graben forms the southeastern extension of the Padola-Candide line, which forms the northeastern boundary of the Dolomite Block.

Between the phases 1 and 2 a direct causal relation occurred, the proceeding uplift of the Carnian geanticline and the forming of step faulted basement blocks (phase 1) giving impetus to renewed decollement of the sedimentary epiderm (phase 2).

Between the phases 2 and 3, however, no direct causal relation can be demonstrated: only the further uplift of the Central Carnian Alps can be hold responsible for the tension phenomena in the crest of the geanticline (phase 3).

The primary uplift of the Carnian Alps and the gravitational reactions, which reduced the resulting stress fields, occurred more or less contemporaneously: the phases 1, 2 and 3 occurred during the emersion of the Alps. This emersion in Oligo-Miocene time started a period of erosion and denudation.

During the Plio-Pleistocene local tectonic movements were superimposed upon the structures coming into existence during the phases 1 2 and 3. Diapiric phenomena are indicated as phase 4, klippe structures and local slides as phase 5 (see tectonic map of fig.34).

Three levels of lake terraces in the "Conca di Sappada" were associated with a number of postglacial local slides of reef blocks around the entrance of the Val Visdende; anisian and/or ladinian reef blocks slid downwards into the Piave valley, forcing up the water in the Sappada region upstreams.

NOTES ON THE GEOCHEMISTRY OF LEAD

The presence of positive lead anomalies in the Gardena Sandstones at all places in the area of study is demonstrated. The origin of these anomalies is discussed; a syngenetic origin is the most probable. The quartzporphyries of Bolzano seem less likely as area of origin than the metamorphic quartzphyllitic. and/ or Carnian basement complex.

A discussion follows on the genesis of the lead-zinc-copper mine of Salafossa, 2 km east of San Pietro di Cadore. The ore occurs in the ladinian Schlern Dolomite. Here too, a syngenetic origin is rather clear; the origin of the ore has been associated with faulting in anisian time and the volcanism in ladinian time: endogenic ascendent solutions were probably responsible for the syngenetic and synsedimentary transport and for concentration by local precipitation. During the alpine tertiary orogenesis the ore was not redistributed by solution, transport and reprecipitation, such as the lead-zinc ores of the Cave del Predil in the Eastern Carnian Alps.

RIASSUNTO

In questa tési sono discussi i resultati di cinque stagioni estive di lavoro nella campagna, eseguito dall'autore (1963-1967) nelle zone del Cadore Orientale (Prov.di Belluno) e della Carnia Occidentale (Prov.di Udine). Durante la prima e la seconda estate queste ricerche sono state effettuate con l'aiuto di alcuni studenti in geologia.

Questi studi avevano l'intenzione di dare una interpretazione tettonica di questa zona nelle Alpi Sudorientali. In conseguenza, non è stata dedicata molta attenzione ai problemi stratigrafici dettagliati. I dati stratigrafici, enumerati nel Capitolo II, hanno solamente la pretensione di essere la chiave per l'interpretazione tettonica.

Nella zona di studi si trova sul basamento metamorfico una successione di sedimenti, i quali per quanto riguarda l'età vanno dal Permiano fino al Jurassico Inferiore. Lo spessore totale di questa successione varia dai 4 ai 5 km.

Nel Cadore il basamento è composto di filladi quarzose epi-metamorfiche, nella Carnia il basamento affiora nelle Alpi Carniche Centrali, dove si trova una serie eterogenica di rocce paleozoiche, che si sono metamorfosate durante l'orogenesi Ercinica.

Molta attenzione è stata dedicata alle variazioni nello spessore delle varie formazioni di sedimenti permotriassici, sopratutto a quelle del Triassico Inferiore e Medio (resp. Werfeniano/Anisico e Ladinico/Carnico). Presso tutte le formazioni appartenenti a quest'età si incontrano delle variazioni notevoli di spessore.

La presenza molto locale di breccie dell'Anisico (breccia di Ugovizza) delle quali si suppone che siano state formate al piede di pareti ripide, e anche la presenza di formazioni ladiniche, influenzate volcanicamente, danno motivi per la supposizione, che - in relazione alle variazioni in spessore, menzionate qui sopra - durante il Triassico Inferiore e Medio vi erano strutture di horst e graben, o almeno che il fondo del mare geosinclinale era differenziato in regioni, separate da faglie e/o flessure, lungo le quali localmente si verificava un'attività sottomarina.

Il Capitolo III contiene un prospetto breve delle zone regionali di "bacino" e di "piattaforma" nell' Italia del Nord durante il Triassico Inferiore e Medio. Grosso modo si distinguono tre piattaforme (da Ovest all'Est la Piattaforma Luganese, le Piattaforma Atesina nella zona delle Dolomiti, e la Piattaforma Giulia nelle Alpi Giulie), in mezzo alle quali erano situate due zone dove la geosinclinale alpina à scesa con una velocità più grande: il Bacino Lombardo (Alpi Bergamasche) ed il Bacino Carnico Bellunese. La zona trattata in questa tesi, è la parte orientale del Bacino Carnico Bellunese.

Risulta che la pelle sedimentaria - l'epidermide - delle piattaforme e dei bacini ha reagito meccanicamente in differenti modi durante l'orogenesi alpina avvenuta più tardi.

Il periodo di sedimentazione instabile era finito nel Triassico Superiore: le formazioni del Triassico Superiore e del Jurassico si sono sviluppate abbastanza uniformamente nelle intere Alpi Meridionali.

Il Capitolo IV tratta, in parte descrivendo, in parte spiegando, le differenti unità tettoniche. Successivamente sono discussi:

A. La natura del contatto tra il basamento metamorfico ed i sedimenti più anziani di età permiano, (le cosidette Arenarie della Val Gardena). Questo contatto il più delle volte è un contatto di faglia, invece a certi posti sono più probalili strutture di flessura, (fase 1 della tettogenesi).

B. Alcuni grandi sovrascorrimenti con una vergenza a Sud, lungo i margini meridionali della zona di studi, (fase 2 della tettogenesi).

C. Due sistemi di graben nella parte centrale e nordoccidentale della zona, resp. il Bordaglia-Sappada-Tudaio-Graben ed il Val Visdende Graben, (fase 3 della tettogenesi). Il primo mostra una direzione che varia da Sudovest-Nordest per la parte della Bordaglia e da Ovestsudovest - Estnordest per la parte del Tudaio. La direzione del secondo è Nordovest-Sudest nella parte occidentale, mentre gira quasi verso Ovest-Est nella parte orientale.

Unità tettoniche di importanza locale sono ugualmente state discusse nel Capitolo IV, resp. fenomeni diapirici nella Val Pesarina (IVG), e strutture di klippe e scivolamento locale (IVH e I).

Il Capitolo V tratta l'interpretazione geodinamica delle faglie di contatto tra basamento metamorfico ed Arenarie della Val Gardena (fase 1), dei sovrascorrimenti (fase 2) e di ambedue i sistemi di graben (fase 3). La chiave per questa interpretazione si deve cercare per gran parte in movimenti differentiali e verticali nel basamento metamorfico.

Meccanicamente si spiega meglio la genesi delle strutture descritte partendo dalla teoria che occorre distinguere tra tettogenesi primaria, cioè il levamento nei periodi più anziani dell'orogenesi, delle Alpi Carniche Centrali (la cosidetta geanticlinale Carnica), e le

reazioni gravitative, cioè tettogenesi secondaria, che ne provengono.

Gli avvenimenti tettonici nell'epidermide sedimentaria sono reazioni secondarie al levamento primario differenziale, per cui nacque un campo di energia potenziale.

Già nel periodo più anziano del levamento geanticlinale l'epidermide sedimentaria cominciava a scivolare verso il Sud (décollement, scollamento). Le formazioni relativamente plastiche hanno servito da base lubrificante per le formazioni più competenti. Però, non si trova nella zona di studi nessuno o quasi nessun rimasuglio di questi avvenimenti più anziani.

Un ulteriore levamento della geanticlinale causava faglie nel basamento metamorfico, come le faglie di contatto di fase 1. Ugualmente nel basamento metamorfico si suppongono tali faglie sotto i grandi sovrascorrimenti, le quali scompartiscono il basamento metamorfico in blocchi longitudinali, a forma di scala, che scendono verso Sud. Queste faglie normali costituiscono i fenomeni più anziani nella zona di studi; per quello esse sono state indicate con la cifra 1.

I campi più locali di energia potenziale, causate da queste faglie normali, hanno dato un nuovo impulso allo scollamento dell'epidermide sedimentaria: l'importanza di questo scollamento più locale nella zona di studi è grande; questa fase è indicata con la cifra 2 e causava i grandi sovrascorrimenti lungo i margini meridionali nella zona.

Un progressivo levamento della geanticlinale alla fine causava la fase 3: fenomeni di tensione, (strutture di graben), nella cresta alta della geanticlinale Carnica; questi graben possono assomigliare al Tarvis-graben di direzione Ovest-Est, nelle Alpi Carniche Orientali, descritto da Guicherit (1964).

Il fenomeno secondo il quale questi graben non sono stati formati nella direzione Ovest-Est, invece in quella (Ovest)sudovest - (Est)nordest e (Ovest)-nordovest - (Est)sudest, è spiegato in relazione alla transizione delle Dolomiti nelle Alpi Carniche, la quale transizione è situata nella regione di Vigo e San Stefano di Cadore, (la Giunzione Cadorina). Il Bordaglia-Sappada-Tudaio-Graben è la continuazione e la propaggine nordorientale della conosciuta linea di Val Sugana lungo il margine meridionale delle Dolomiti.

Il Val Visdende Graben è la continuazione della linea di Padola-Candide, che forma il limite nordorientale del blocco delle Dolomiti. Tra le fasi 1 e 2 esiste una relazione causale diretta: la fase 1 dava, insieme col levamento della geanticlinale, un nuovo impulso allo scollamento di fase 2.

Tra le fasi 2 e 3 invece, non si trova una relazione causale e diretta: il solo levamento geanticlinale è responsabile dei fenomeni di tensione nella cresta alta della geanticlinale.(fase 3).

Appare dal precedente che il levamento primario e le reazioni secondarie, per quanto riguarda il tempo, si sovrapongono per gran parte: le differenti fasi avvenivano più o meno simultaneamente.

Sul modello, esistente dopo la fase 3, movimenti tettonici molto locali sono stati sopraposti, dopo o durante un periodo di erosione e denudazione (Plio-Plistoceno). Le fasi di diapirismo sono state indicate con la cifra 4, gli scivolamenti locali e le strutture di klippe con la cifra 5.

Vi esiste una relazione tra un numero di scivolamenti posglaciali di blocchi recifali, dell'Anisico e Ladinico, intorno all'entrata della Val Visdende, (Monte Tezza Piccola, Monte Curie e Monte Carro), e tre livelli di terrazzo di lago contro corrente nella Conca di Sappada.

GEOCHIMICA DEL PIOMBO

E' stata dimostrata la presenza di anomalie positive di piombo nelle Arenarie della Val Gardena, in tutti i posti nella zona di studi. Viene discussa l'origine di queste anomalie. Un'origine singenetica è la più probabile; il basamento metamorfico (filladi quarzose e/o il basamento delle Alpi Carniche), quindi non i porfidi permiani di Bolzano, è probabilmente la zona di provenienza.

In merito alla miniera di Salafossa, a 2 km ad Est di San Pietro di Cadore, nel Ladinico (Dolomia di Sciliar), segue una contemplazione intorno alle genesi di questi minerali (piombo, zinco, rame).

L'origine singenetica anche qui è evidente; la provenienza dei minerali è relata alla tettonica di faglie anisica ed al volcanismo ladinico: soluzioni endogene ascendenti probabilmente hanno apportato singeneticamente e sinsedimentariamente i minerali, concentrandoli per precipitazione locale.

Una ridistribuzione alpidica-terziaria dei minerali, attraverso soluzione, transportazione e reprecipitazione, come è avvenuto presso i minerali piombo-zinciferi di Cave del Predil nelle Alpi Carniche Orientali, non è accaduta qui.

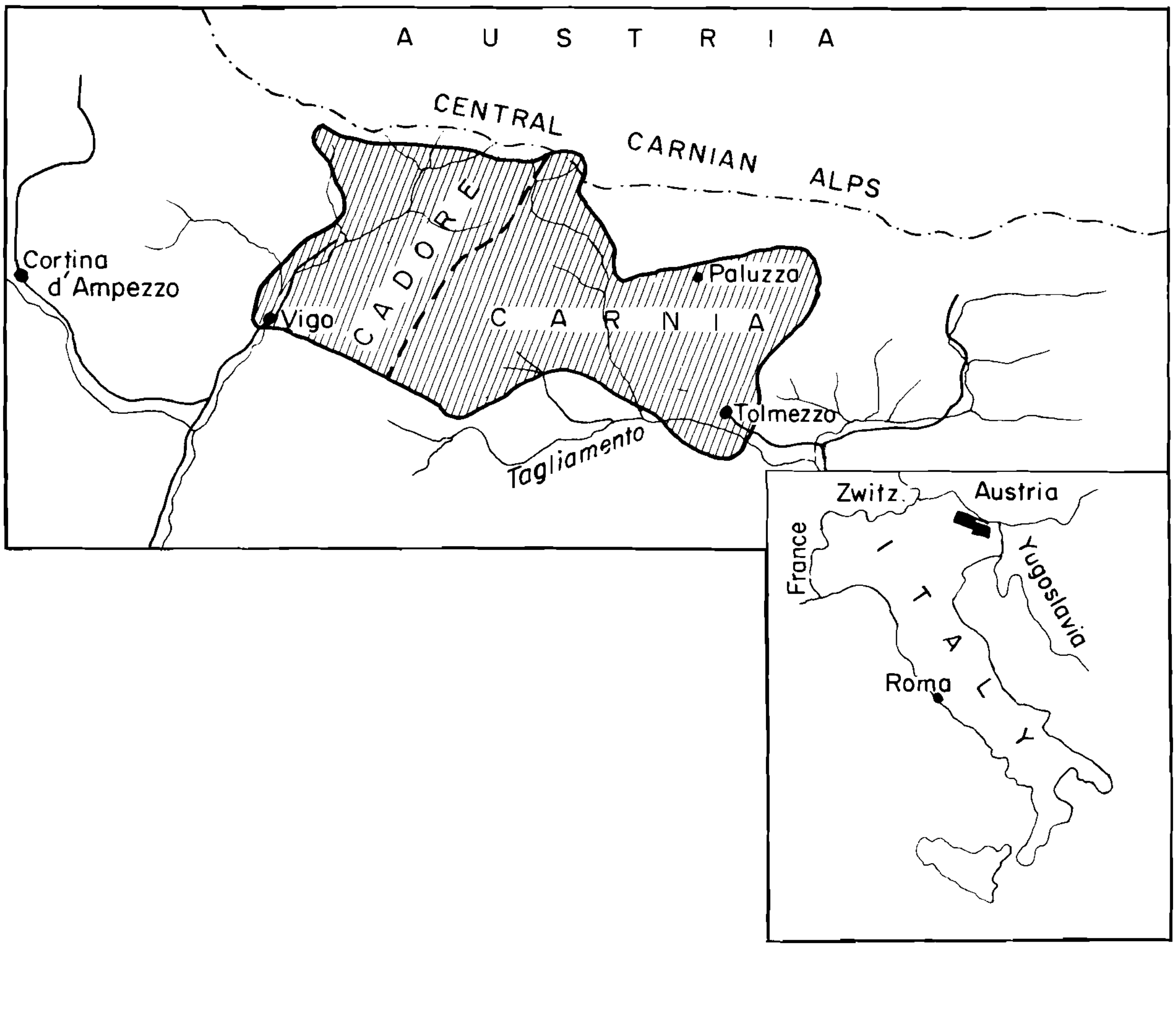

Fig. 1. Situation of the area of study.

CHAPTER I

INTRODUCTION

The area investigated is situated partly in the region of Cadore, province of Belluno, and partly in the region of Carnia, province of Udine, as shown in fig.1. It occupies the northwestern part of Carnia and the eastern part of Cadore.
The boundaries of this area are formed by the following topographical lines: San Stefano di Cadore - Lorenzago di Cadore in the west; Lorenzago di Cadore - Sauris - Villa Santina - Tolmezzo in the south; Tolmezzo - Paularo in the east and Paularo - Comeglians - Forni Avoltri - Bordaglia - Val Visdende - San Stefano di Cadore in the north. The diameter of this region is in E-W direction about 45 km, and in N-S direction about 25 km.

Geological researches have been carried out since 1868, when von Hauer mapped this region, making his geological map of the entire Austro-Hungarian Monarchy.
The next geological work was done by Frech, whose important monograph on the Carnian Alps appeared in 1894.
In 1900 Geyer published some data about the development of the Trias near Sappada and San Stefano di Cadore.
The greater part of the literature from the end of the last century and the beginning of the present one is dealing with the geology of the Central Carnian Alps, consisting of paleozoic rocks. The first who studied seriously also the permo-triassic sediments discussed in this thesis, was Gortani, who published between 1902 and 1959 a great number of papers, containing data about stratigraphy, paleontology, morphology, hydrology, botany, speleology, petrography, tectonics, agriculture, and ethnology. His encyclopedic knowledge in all these fields made him one of the most famous specialists Carnia ever had.
It is not necessary to give here a complete list of all the publications on the geology of the area investigated. Most of them are dealing with stratigraphical descriptions and studies. R. Selli, Professor at the University of Bologna, has been doing stratigraphical, paleontological, and tectonic work in Carnia since 1960, with the aid of assistants and students. Apart from a compilation by Selli (1963) we may mention here papers by Carloni and Ghiretti (1966), Pisa (1966), Elmi and Monesi (1967) and Carloni (1967). Also papers by Semenza (1965), Larghaiolli and Semenza (1966) and P.G. Leonardi (1964) are cited for the part of the area studied in this thesis and situated in Cadore.

The geological theories discussed in this thesis are based upon data, collected during five summers, from 1963 to 1967.
Mapping was carried out on the topographic maps of the: "Tavolette della Carta Italiana", scale 1 : 25.000, edited by the "Instituto Geographico Militare" at Firenze. Use was made of the sheets Lorenzago di Cadore, San Stefano di Cadore, Comelico, Val Visdende, Sappada, Monte Bivera, Sauris, Prato Carnico, Forni Avoltri, Comeglians, Ovaro, Villa Santina, Tolmezzo, Arta, Paluzza, Monte Sernio and Paularo.
For the completion of the geological map (Enclosures sheet I and II in this paper), use was made of the geological map "Carta Geologica delle Tre Venezie", foglio 13, by Gortani, de Toni and Zenari (1934), at a scale of 1 : 100.000, and of the geological map by Selli (1963): "Schema Geologico delle Alpi Carniche e Occidentali", at a scale of 1 : 100.000.

The object of this study was to obtain an insight into the structural evolution of this region, to explain the complicated structures of the Southern Carnian Alps and part of Cadore. The work was carried out under the supervision of Prof.Dr. R.W. van Bemmelen of the State University of Utrecht, the Netherlands.

CHAPTER II

STRATIGRAPHY

GENERAL

The area investigated has an almost continuous succession of rocks, according to previous investigators extending from the Ordovician up to the Lower- and Middle-Jurassic.
A major unconformity occurs between the non-metamorphic sedimentary rocks, reputed to be Permian in age, and folded metamorphics of older paleozoic age.
In all sedimentary rocks fossils are scarce. No detailed description will be given because excellent treatment can be found of the stratigraphy of this region in ancient and recent Italian, French and Austrian literature, such as papers by Geyer (1900), Gortani (1924), Vetters (1947), Selli (1963), P.G. Leonardi (1964), Pisa (1966), Elmi and Monesi (1967), Carloni (1967).
Only a brief summary of the different stratigraphic units will follow. Three stratigraphic columns of different parts of the investigated area, are given in fig.2.

PALEOZOIC BASEMENT

The metamorphic paleozoic rocks were not studied in detail here. However, a brief description is thought to be necessary, on account of the great differences between the Cadorian and the Carnian paleozoic formations.
1. In Cadore the metamorphic basement is formed by quartz phyllites, such as have been found also in the entire area of the Italian Dolomites. The structures of the phyllites of the San Stefano di Cadore region, situated in the NW part of our area, have been described by Agterberg (1961, p.61-66).
These phyllites are epi- to meso-metamorphic rocks, representing possibly detrital sediments of silurian age: a *Rastrites* has been described from a graphitic variety in the vicinity of Bressanone, proving this part of the series to be Silurian in age (Dal Piaz, 1942).
The phyllites were metamorphosed during the Hercynian orogenesis.
Thin-sections of samples taken near Lorenzago di Cadore show a fine-grained schistose rock with many quartz grains and mica flakes, (sericite-muscovite) and fewer components of feldspar (mainly albite). Accessory minerals and secondary quartz veins are of common occurrence.
2. In Carnia the stratigraphic column of the older paleozoic rocks is more complex and heterogeneous. Many units have been distinguished in the literature, and local names have been given to occurrences with a local facies. Selli has given a summary of published and unpublished data in 1963.In this paper mention is made only of the calcareous reef formations of devonian age, forming the longest and highest chain of the Carnian Alps (Monte Peralba, 2693 m, Monte Avanza, 2489 m, Monte Coglians, 2780 m). This reef formation has a maximum thickness of 1100 m (Selli, 1963, p.27). The differences of facies between the paleozoic formations of Carnia and those of Cadore had consequences during the Alpine orogenesis, as will be shown in Chapter V.
The Cadorian basement of quartz phyllites behaved more plastically during theAlpine orogenesis than the Carnian basement, the greater rigidity of the latter resulting partly from the presence of the great units of monolithic devonian reefs.

THE AUERNIG-RATTENDORF-TROGKOFEL FORMATION (Upper-Carboniferous and Permian).

The oldest non-metamorphic sediments in the area of study can be found only in one locality, namely about 2 km SE of Forni Avoltri, (enclosure I), along the river Degano (Locality 200 m SW of "Temerat"). These sediments can be correlated with the Auernig-, Rattendorf- and Trogkofel-Formations described by Kahler and Prey (1963) for the Naszfeld-Gartnerkofel region farther to the east in the Carnian Alps.
The oldest non-metamorphic formation is the Auernig Formation. It consists of dark grey shales with intercalations of quartz conglomerates.
The formation, deposited upon the Auernig Formation, - the Rattendorf Strata - consists of dark grey fine-grained sandstones with many secondary mica flakes, whereupon a number of conglomeratic layers has been deposited. Almost all components of this conglomerate are quartz pebbles and smaller lydite fragments. The Trogkofel Formation is deposited upon the Rattendorf Strata, and it consists of badly stratified grey limestones with a reddish colour in some places. Many calcite veins intersect the limes

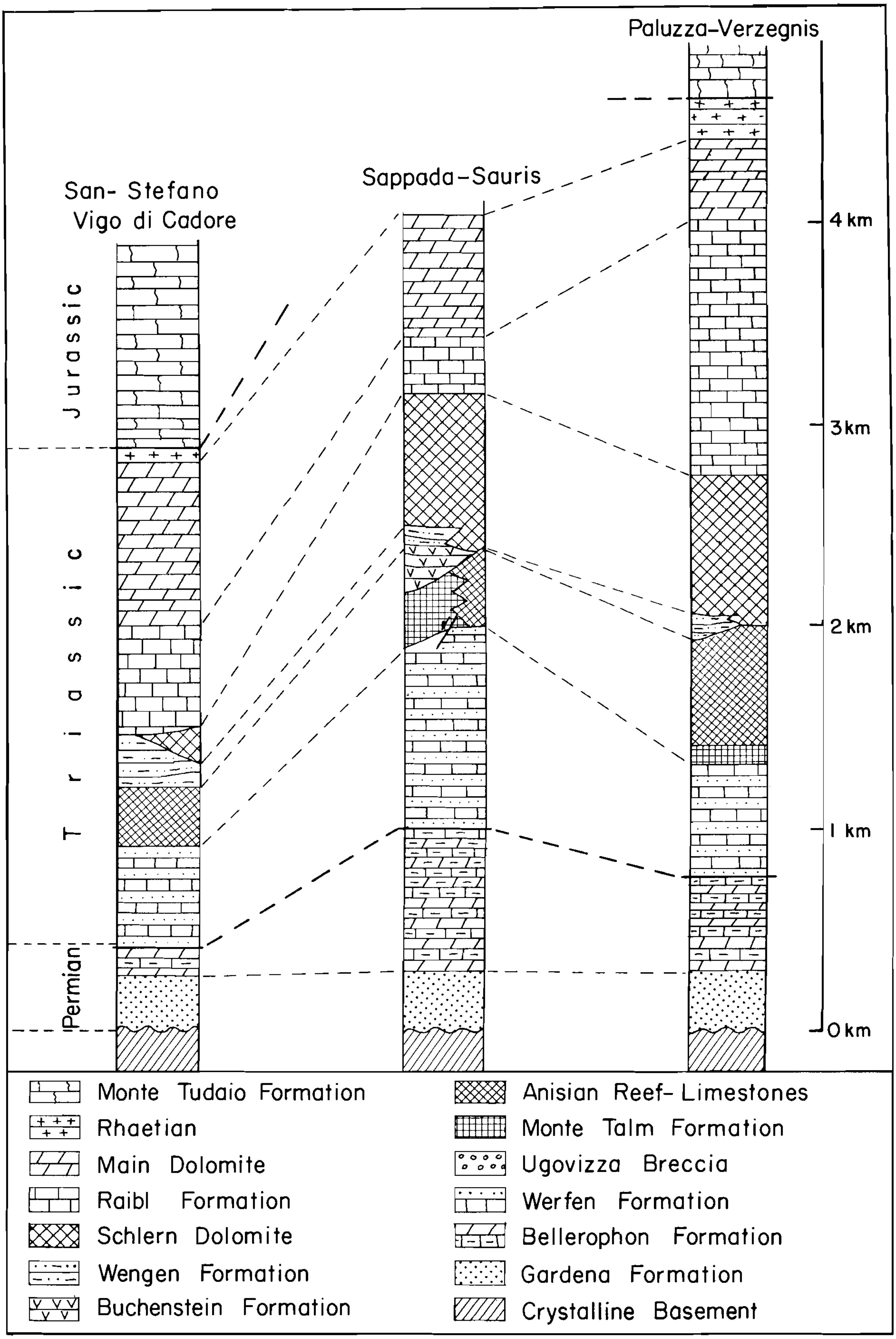

Fig. 2. Stratigraphic columns.

tone strata, and some layers with Foraminifera are found.
A green and red-coloured breccia is deposited upon these limestones. The components are for the greater part also limestones. It is not clear whether this breccia must be correlated with the Trogkofel breccia from the Naszfeld-Gartnerkofel region, where quartz components dominate in the dolomitic matrix of the breccia, or with the Tarvis breccia, well known from the region of Tarvisio, where dolomite components dominate in the likewise dolomitic matrix of the breccia. This Tarvis-breccia has also been classified as belonging to the Trogkofel Formation by Kahler and Prey (1963).
Upon the Trogkofel Formation the Gardena Sandstone Formation is conformably deposited. It is discussed in the next paragraph. In the entire area of study an unconformity exists between these sandstones and the metamorphic basement. The locality, 200 m SW from "Temerat", near Forni Avoltri, is the only place where between the metamorphic basement and the Gardena Sandstones other formations were deposited.

PERMIAN

The Gardena Sandstone Formation

(Italian: Arenarie della Val Gardena; German: Grödener Sandstein).

The Gardena Formation lies unconformably upon the metamorphic basement. The sandstones have originally been described from the Val Gardena in the Central Dolomite region. There is no doubt that in this area we have the same formation.
A transgressive conglomerate is often found at the base, consisting mainly of small quartz pebbles, 2-5 mm in diameter. The overlying strata consist of fine to medium finegrained wine red sandstones, cemented by a ferruginous quartz matrix. Their maximum thickness is about one meter. They are alternating with micaceous shales with thicknesses of the individual beds ranging from 5-25 cm. Fossils are not found. There are no differences in lithologic aspects between the Gardena Formation in Cadore and in Carnia, but there is a great variation in thickness of the entire formations in Cadore. Agterberg (1961) observed changes in thickness from 100 m up to 2 km within the vicinity of San Stefano di Cadore. At Lorenzago di Cadore the thickness is about 250 m. In some places these differences cannot be explained tectonically. They must therefore have resulted from a local relief during the Lower- and Upper-Permian, owing to contemporaneous different velocities of subsidence (block faulting, formation of troughs, see Chapter III).
On the other hand, in Carnia the thickness of the Gardena Formation is rather uniform, being some hundreds of meters in almost all places.

The Bellerophon Formation (Upper Permian)
(Italian: Formazione à Bellerophon)

This formation has traditionally been called "Bellerophon Formation" or "Bellerophon Strata" in all literature since 1876 (Hoernes, 1876a), although it is, according to the rules of stratigraphic nomenclature, not correct to give the name of a fossil genus to a formation of occasionally 500 m thickness. However, erroneously, the name Bellerophon Formation is maintained in order to save a confusion of names.
Three different members can be distinguished:
a. The basal member consists of gypsum and gypsiferous shales. It is difficult to estimate the thickness of this member because of its being intensely folded. Between Sostasio and Comeglians in the Val Pesarina it must be 100 m at least. The gypsum is multicoloured.
At Prato Carnico in the Val Pesarina the gypsum occurs also in the higher levels of the Gardena Formation, forming lense-like intercalations in the sandstones. The gypsous evaporites of the basal member of the Bellerophon Formation are part of the change in the terrestric environment to the marine conditions of the Triassic, thus initiating the sequence of marine alpine geosynclinal sediments.
b. The middle member of the Bellerophon Formation consists of yellowish grey cellular dolomites (Italian: dolomia cariate). On account of a lack of stratification the thickness is again difficult to determine, but does not exceed 100 m. At some places the occurrences of cellular dolomites are accompanied by sulphur-bearing mineral springs. (Pesariis, Arta).
c. The upper member of the Bellerophon Formation is formed by well-stratified grey and black dolomites, and dolomitic limestones, alternating with marly and occasionally sandy shales. The thickness of the dolomite strata does not exceed one meter, the average being about 20 cm. In this dolomite *Bellerophon*, the fossil genus after which the name of the formation has been given, is found in several localities, but always badly preserved. The rocks are intersected by many calcite veins.
The thickness of the upper member of the Bellerophon Formation ranges from 100 m near Vigo di Cadore up to a maximum from about 500 m near Culzei in the Val Pesarina.
The formation has the same facies in Cadore and in Carnia, showing merely some differences in thickness.

TRIASSIC

The Werfen Formation (Scythian)

The type locality of this formation is the village Werfen, Salzbachtal, Austria, described for the first time by Lill von Lilienbach (1830).
The formation has been found in extensive areas in the Northern and Southern Alps, and belongs to the scythian stage, according to many authors (Stur 1871, v.Pia 1930, Cornelius 1937 and others).
In the area described this formation consists mainly of yellow and red-coloured sandy limestones, lime-bearing sandstones, and also pure sandstones and limestones, the thickness of the single stratum not exceeding 50 cm. The passage from the Bellerophon Formation to the Werfen Formation is gradual: therefore, it is often hard to draw a clear boundary line on the geologic map.
Some horizons of lumachelle and oolitic limestones are typical.
Depositional structures like ripplemarks, cross bedding, and load casts are very common. Detrital mica is a common constituent. Many calcite veins occur.
The general facies is that of sedimentation in shallow water, with a prolific supply of mainly finegrained detritus. The lithology in Cadore is the same as in Carnia. In the field a great variation in the total thickness can be seen, partly caused by later tectonic movements, partly owing to the initial sedimentation. This can be observed in the Val Pesarina, near Pesariis: in the northern slope of the valley the thickness of the Werfen strata ranges from 50-200 m; the southern slope the thickness of the same formation attains about 1000 m, (between Pesariis and Sauris). Although in the northern slope of the valley a part of the Werfen Formation may have been squeezed out by tectonic movements, it is not likely that about 800 m disappeared in this way: the sequence between Pesariis and Sauris may have been deposited in a local basin existing at the time. The cause of the formation of such a local basin is almost always a matter of speculation: many authors (von Mojsisovics 1879, Ogilvie Gordon 1929, Agterberg 1961) suggest the possibility of syngenetic faults in anisian and ladinian time, probably caused by different velocities of subsidence of the alpine geosyncline. The occurrence of a 1000 m thickness of the Werfen Formation in the area mentioned above, suggests that such troughs could have been formed already in scythian time.

Anisian.

a. The Ugowitz Breccia
(Italian: Breccia di Ugovizza).

This breccia originally has been described by Stache (1874). The type locality is the village Ugovizza in the Eastern Carnian Alps (where white, red and yellowish calcareous components are described to occur in a sandy, wine red, matrix). The breccia is found in the entire Carnian and Julian Alps. Though fossils are absent, the formation is traditionally included in the anisian stage.
The components are rounded to a various degree. In some places in the area investigated it is a true breccia, at other places it would be better to describe it as a conglomerate. The dimensions of the components vary from few centimeters to 20-30 cm.
The matrix is calcareous and/or sandy cement, red, grey or yellowish coloured. The components are in general recognizably derived from the Gardena-, Bellerophon- and Werfen-Formations. The thickness of the single strata ranges from 1-10 m. The thickness of the entire formation ranges from some meters in the Val Pesarina to some hundreds of meters near Cima di Sappada (Monte Chiaine).
In the southern slope of the Monte Chiaine near Cima di Sappada a remarkable occurrence has been observed. In the lowest level (1325 m) the components are found of the Gardena-, Bellerophon- and Werfen-Formations and also of anisian reef limestones. However, in a higher level (1400 m) the components of the Gardena Formation do not occur any more, only those of the Bellerophon- and Werfen-Formation and the anisian reef limestones. In a still higher level (1450 m) the Bellerophon components have also disappeared, only the components of the younger formations being found. In the highest level (1550 m) the only components to occur are anisian reef limestones.
These observations can only be logically explained by differential vertical movements along faults, the fault-scarps being subsequently covered by a talus of breccias, the Ugowitz Breccia being not the result of a general strong erosion, but more likely only representing local cones of debris along escarpments, formed by faulting in werfenian and anisian time.

b. Reef limestones

At many places the anisian stage is represented by partly dolomitized reef limestones. These reefs have largely been formed by Algae *(Diplopora)*. Their maximum thickness of about 1000 m is found north of Pesariis in the Val Pesarina (Monte Entrelais and Monte Creta Forata).
Generally the reefs are not stratified. Selli (1963, p.62) gives a list of fossils: Brachiopoda *(Spirigera, Waldheimia, Metzelia, Spiriferina)* and Cephalopoda *(Cuccoceras, Balatonites, Ceratites, Arcestes)*, testifying the anisian age of the reefs.
At some places the growth of the reefs proceeded also in ladinian time: in that case it is hardly possible to draw a boundary between the two stages. This situation occurs at the Monte Tezza Piccola and the Monte Carro, respectively south and northeast of the entrance of the Val Visdende, between San Pietro di Cadore and Sappada.
At other places however, the growth of the reefs discontinued at the end of the Anisian, and strata with ladinian fossils and of a different facies were deposited on top of the reefs. P. Lagny (1967) has demonstrated that in this case the surface of the anisian reefs is characterized by a certain amount of dolomitization and silicification of the outer crust of the reefs, and by cracks filled with detrital material. These phenomena indicate a phase of local emersion between the Anisian and the Ladinian. See fig.3 after Lagny (1967), modified.

c. The Monte Talm Formation

The name of this formation is derived from the occurrence at the Monte Talm, north of the village Sostasio in the Val Pesarina (Enclosure sheet I). Well-stratified dolomitic limestones lie generally upon the Werfen strata. The maximum thickness of the single strata amounts to about 5 m. The entire sequence has a maximum thickness at the Monte Talm of at least 400 m. At some places the Monte Talm Formation changes laterally into the reef limestones mentioned above, from which it may be concluded that the dolomitic limestone strata were deposited between the massive reef bodies, resulting in an interfingering of the two facies (See fig.3).
At other places the reef limestones are underlain by the Monte Talm strata. In the Pesarinian Dolomites the anisian reef bodies have the greatest thickness of the entire area, i.e. 1000 m. It is also in the same area (Monte Talm) that the Monte Talm Formation reaches the maximum thickness of 400 m. At other places the Monte Talm Formation is less competent, and partly consisting of the dolomitic limestone strata mentioned above, partly of grey nodulous limestones. According to Selli (1963, p.61) this formation belongs to the lower and middle parts of the anisian stage.

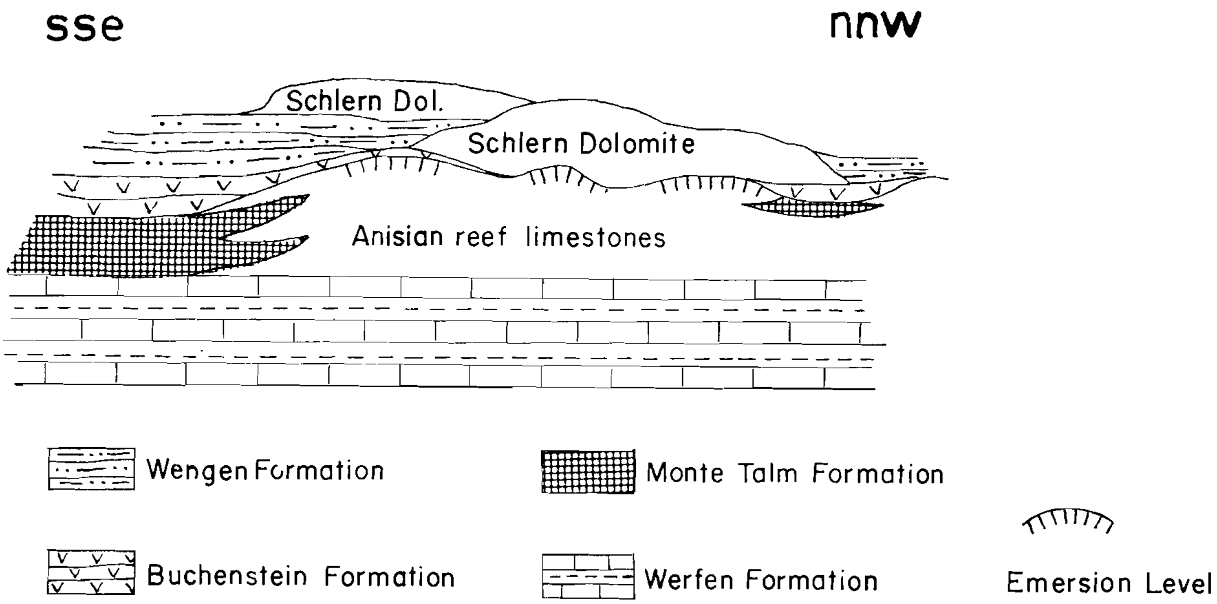

Fig.3. (modified) after Lagny (1967), interpretative position of the Anisian and Ladinian formations in the Sappada area.

Ladinian

a. Buchenstein Formation
(Italian: Formazione di Livinallongo)

This formation has been described for the first time by von Richthofen (1860); the type locality is found in the valley of Cordevole in the Dolomite Region (Livinallongo), where yellowish green nodulous limestones and wellstratified black limestones occur, with intercalations of volcanic tuff ("pietra verde").
In our area the formation consists of wellstratified greencoloured siliceous limestones and pure siliceous rocks. The thickness of the single strata ranges from some centimeters to about 30 cm.
In the Dolomite Region the formation is characterized by volcanic activity during its deposition. In Cadore and Carnia, however, the presence of the silica is the only phenomenon that might be interpreted as an indication for volcanic activity at some distance. (Volcanic dust falls).
Coarser tuff deposits have not been found. Extrusive rocks, while very common in the Dolomite Region and the Julian Alps, are represented here only by a thin intercalation of melaphyr between the sediments, near the village Vinaio, north of Villa Santina (Enclosure sheet II).
Fossils in the Buchenstein Formation of the investigated area are mentioned only by Geyer (1898): near Sappada a species of *Protrachyceras* has been found, fixing a lower ladinian age for the Buchenstein Formation.

b. Wengener Formation
(Italian: Strati di la Valle).

The type locality of this formation is the village la Valle (Wengen in German literature) in the Val Badia, Dolomite Region, where the formation is represented by wellstratified brownish black limestones and sandstones, with intercalations of extrusive rocks and tuffs. Various fossils indicate that the formation is of upper ladinian age.
In the area treated in this work, the Wengener Formation, overlying the Buchenstein Formation, consists of wellstratified limestones and sandstones, but the most common are sandy limestones and calcareous sandstones. The thickness of the single strata ranges from few centimeters up to half a meter. Clays and marls are intercalated between the sandstones, respectively limestones.
The Wengener Formation near Sappada has been described by P.G. Leonardi (1964), who considers the sandstones to be laid down by turbidity currents. This idea is based upon the presence of typical phenomena of deposition, such as graded bedding, load- and flute casts, rill marks, etc. For this reason the Wengener Formation is occasionally called "Pseudo-Flysch", as this triassic formation obviously does not belong to the much younger, synorogenic Flysch of other alpine areas.
During the deposition of the Wengener Formation there was intermittantly a prolific supply of detrital matter owing to the volcanic activity at that time; there is no evidence that, as in the case of the "true" Flysch, the deposition of the Wengener Formation was synorogenic. The thickness of the formation is about 80 m near Sappada. In the region of Vigo di Cadore it amounts to about 250 m, and in the Val Pesarina near Culzei to about 130 m.
Fossils are mentioned by Leonardi (1964): some species of *Daonella* and *Posidonomya* have been found; also a flora is represented by *Cycadaeospermum* and *Cordaicarpus* . The attribution of the Wengener Formation in Cadore and Carnia to the ladinian stage rests on little evidence. The Wengener Formation appears to be very plastic and soft under the influence of tectonic movements, so that locally extremely strong folding occurred. At many places, however, the formation can be found without any intensive folding, probably caused by its position in pressure shadows between the triassic reefs.

c. The Schlern Dolomite Formation
(Italian: Dolomia di Sciliar).

The type locality of this formation is the Monte Sciliar in the Dolomite Region - described for the first time by von Richthofen (1860) - where the formation occurs as limestones and dolomitic limestones in reef facies, build up from corals and alghae.
In the Dolomite Region various reef bodies are extending from the Upper Anisian up to the Lower - and partly Upper Carnian, forming massive monolithic blocks, whereas other reefs are confined in extension to some levels from the ladinian and/or carnian stages. In all occurrences of the Schlern Dolomite fossils are scarce.
In our area a reef facies is present which is considered to be the equivalent of the Schlern Dolomite Formation of the Dolomite Region, with the same problems in regard to its vertical extension.
It is also developed as limestones and dolomitic limestones, not stratified. The total thickness amounts to about 800 m in the Pesarinian Dolomites (Monte Siera) and to 750 m near Fusea, NE of Villa Santina (Enclosure sheet II).
According to Selli (1963) no determinable fossils

have been found in these reefs. It is often difficult to discern differences between the anisian reef limestones and the Schlern Dolomite Formation. Nevertheless, a small difference in colour between both formations can be seen at the Passo della Creta Forata, between the Monte Creta Forata and the Monte Siera, in the Pesarinian Dolomites, where both formations have been brought at the same topographical height by a normal fault. The Schlern Dolomite reefs (Monte Siera) have a reddish accidental colour, whereas the Anisian reefs (Monte Creta Forata) are pure grey.
North of Culzei in the Val Pesarina the Schlern Dolomite is underlain by the Wengener Formation: in this case it is easy to differentiate these reefs from those regarded as belonging to the anisian stage.
At other places, however, the Schlern Dolomite is not underlain by the Wengener Formation; it might be concluded therefore that, assuming that the Wengener Formation indicates a time-stratigraphic level (Ladinian), the growth of the anisian reefs locally proceeded also in ladinian time, so that only massive dolomitic reef block of anisian and ladinian age originated (Monte Tezza Piccola and Monte Carro, respectively south and northeast of the entrance of the Val Visdende, Enclosure sheet I).

The Raibl Strata (Carnian)
(Italian: Raibliano; German: Raibler Schichte).

The type locality of this formation is the village of Raibl in the Eastern Carnian Alps, near the frontier between Italy and Yugoslavia. The formation overlying the Schlern Dolomite, respectively Wengener Formation, is generally assumed to belong to the Carnian stage. However, it is not sure that the limit between the Schlern Dolomite, respectively Wengener Formation, and the Raibl strata represents also the time boundary between the ladinian and carnian stages. It is possible that the upper part of the Schlern Dolomite, respectively Wengener Formation, belongs already to the carnian stage, or, on the other hand, that the lower members of the Raibl strata still belong to the ladinian stage. The same uncertainty between lithology and time scale exists in regard to the boundary between the Carnian and the overlying Norian.
For convenience, the names Schlern Dolomite, Raibl strata, and Main Dolomite will be traditionally assumed to represent respectively the ladinian, carnian and norian stages, and vice versa.
Lithologically the Raibl strata are rather heterogeneous, locally showing important changes of facies. In the centre of the Pesarinian Dolomites, (Creton di Clap Grande) they consist of wellstratified dolomitic strata, so that it is difficult to establish the boundary between the Raibl strata and the overlying Main Dolomite, which is also developed as stratified dolomites. Massive strata of limestones and dolomites are always present, especially in the lower part of the formation. Strata of 10 m thickness are not an exception. The limestones are occasionally silica-bearing.
Between the carbonatic strata, marls and clays are intercalated. They are generally coloured grey and black, in places alternating with thin limestone banks. Pyrite and marcasite are found, partly weathered into limonite, which gives a red colour to the strata.
Sandstones occur, and intercalations of gypsum are very common, especially in the upper members of the formation. Just like the gypsum of the Bellerophon Formation this gypsum is thought to have played an important part in gravitative tectonic movements, acting as a lubricating base for the sliding of the overlying, more competent, formations.
The Raibl strata in the area investigated are characterized by great differences in thickness. In the region of the Monte Tudaio and the Monte Brentoni (Cadore), its thickness ranges from 300 to 500 m. At the Passo Mauria, outside the investigated area (south from the line Lorenzago di Cadore - Sauris), it ranges from 1000 to 2000 m. The sections I and II of sheet II of the geologic map are showing a thickness of the Raibl strata of 1000 to 1250 m, for the area of Villa Santina and Tolmezzo.

The Main Dolomite (Norian)
(Italian: Dolomia Principale; German: Hauptdolomit)

Redcoloured dolomites and partly dolomitic limestones, overlying the previously described formations and traditionally included in the norian stage, are developed uniformly in the area, studied in this thesis.
Their thickness is about 600-700 m at the Monte Tezza Grande (Pesarinian Dolomites) and 800-1000 m at the Monte Popera Valgrande (Cadore).
Fossils are mentioned by many authors. In Selli's compilation (1963) species of *Myophoria, Megalodon* and others are described.
The stratified nature of the Main Dolomite can be explained better by biostromal conditions of formation or by direct chemical precipitation than by their formation as biohermal reefs, as is suggested by Selli (1963, p.73).

Rhaetian

This stage is represented by some isolated occurrences in the area under investigation. Grey lime-

stones, partly silicified, are found on the top of the Monte Col, SE of San Stefano di Cadore (Enclosure sheet I), with Brachiopoda of rhaetian age.
South of Tolmezzo in the Verzegnis Region (Enclosure sheet II) a formation of limestones occurs of which the rhaetian age is based upon the fossil *Dimyodon* sp. (Selli, 1963, p.75).
The uniform development of wellstratified Main Dolomite forms an indication that the unstable conditions of sedimentation during the Lower- and Middle-Triassic were terminated. Not only in the investigated area, but also in much more extensive areas of the Southern Alps is the norian Main Dolomite developed in the same facies, and differences in thickness are generally small.

JURASSIC

The Monte Tudaio Formation.

The local name of this formation is derived from the Monte Tudaio complex in Cadore, between the villages of Vigo di Cadore and San Stefano di Cadore, (Enclosure sheet I).
The formation consists of grey limestones, rarely oolitic, with some conglomeratic lenses and intercalations of massive dolomites, partly wellstratified. The thickness of the Jurassic in the Tudaio Region, where the formation is present in the about 8 km long mountain chain of the Monte Tudaio, Monte Popera Valgrande and Monte Brentoni, amounts to about 1000 m. According to Selli (1963, p.76) a species of *Spiriferina* indicates a lower liassic age. But Semenza and Larghaiolli (1965) found some paleontological indications for a wider range of age, from Rhaetian up to the time boundary of Dogger and Malm.
The Liassic occurs also south of Tolmezzo in the Verzegnis region, (Enclosure sheet II), where it is developed as wellstratified limestones and dolomitic limestones about 250 m in thickness.

CHAPTER III

THE PERMO-TRIASSIC EVOLUTION OF THE SOUTHERN ALPS

In the preceding chapter much attention has been paid to the thicknesses of the various formations, striking differences of thickness between formations in the region Vigo - San Stefano di Cadore and those of the same age in Western Carnia have been mentioned with a special stress.

Fig.2 shows the stratigraphical columns of both regions, the part of Carnia, investigated here, divided into two columns.

In Cadore the average thickness of the permo-triassic sediments amounts to about 2800 m, whereas in Carnia it is about 4000-4400 m. The facies of the various stratigraphical units in Cadore and in Carnia is generally the same, which leads to the conclusion that the subsidence of the geosynclinal basement occurred in Carnia with greater speed than in Cadore.

The facies heteropies in anisian and ladinian time and the abrupt changes in thickness of the anisian and ladinian formations suggest different velocities of subsidence of the basement. Apparently the underlying crust was broken into blocks, each block subsiding with a different velocity. These synsedimentary basement faults have caused:

a. the Ugowitz Breccia (see pag.13).

b. the variations in thickness of the reef bodies of anisian and ladinian age.

c. the volcanic activity along basement faults, causing the locally volcanic facies of the Buchenstein and Wengener Formations. Volcanic matter could be erupted by way of the faults and fissures between the reef blocks.

Permo-triassic extrusive rocks are scarce in the region of Cadore and Carnia; but in the Central Dolomite Region to the west and the Julian Alps to the east extrusive rocks are very common.

The early geosynclinal blockfaulting was evident in scythian time, when the local basin between Pesariis and Sauris developed, in which the 1000 m thick pile of Werfen strata (Enclosure sheet I) has been deposited, compared with thicknesses of some hundreds of meters of Werfen strata in the surrounding areas.

After the Hercynian mountainbuilding at first a period of degrading occurred, accompanied by a local terrestric deposition of clastic continental sandstones (Gardena Formation).

Differential movements of subsiding and rising blocks started in the Permo-Carboniferous, producing a structural pattern of the geosynclinal floor, which became more clearly developed in the Middle Triassic, (according to Bosellini, 1965, and others).

Five areas, three of which subsided more slowly than the two interjacent ones, can be distinguished in the Southern Alps. The boundaries between these structural units have a N-S direction. The terms "Platforms" and "Basins", as used by Bosellini, do not have a bathymetric significance. His concept of basin- and platform-areas merely indicates a greater and smaller velocity of subsidence of the geosynclinal floor, thus having only a paleostructural and not a paleogeographic sense.

The positions of the basins and the platforms are given in fig.4.

From west to east one can distinguish:

I. Luganese Platform, (Italian: Piattaforma Luganese), with a total thickness of permo-triassic sediments of about 1000 m.

II. Lombardic Basin (Italian: Bacino Lombardo), with a permo-triassic sedimentary column from about 5000 m up to a maximum of about 8000 m.

III. Atesin Platform (Italian: Piattaforma Atesina), the maximum thickness of permo-triassic sediments reaches up to 2000 m.

IV. Carnian-Bellunese Basin (Italian: Bacino Carnico-Bellunese), the thickness of the permo-triassic amounts to about 6000 m.

V. Julian Platform (Italian: Piattaforma Giulia), with an average thickness of permo-triassic strata of about 3500 m.

The geosynclinal subsidence proceeded in the eastern part of the Southern Alps with a somewhat greater velocity than in the western part. This follows from the contrast between the permo-triassic thicknesses of 3500 m on the Julian Platform in the east, and only 1000 m on the Luganese Platform in the west. Another indication for this difference is provided by the fact that the Werfen sediments in the Carnian-Bellunese Basin are developed in a neritic facies, whereas the sediments of the same age on the Atesin Platform have an evaporitic facies.

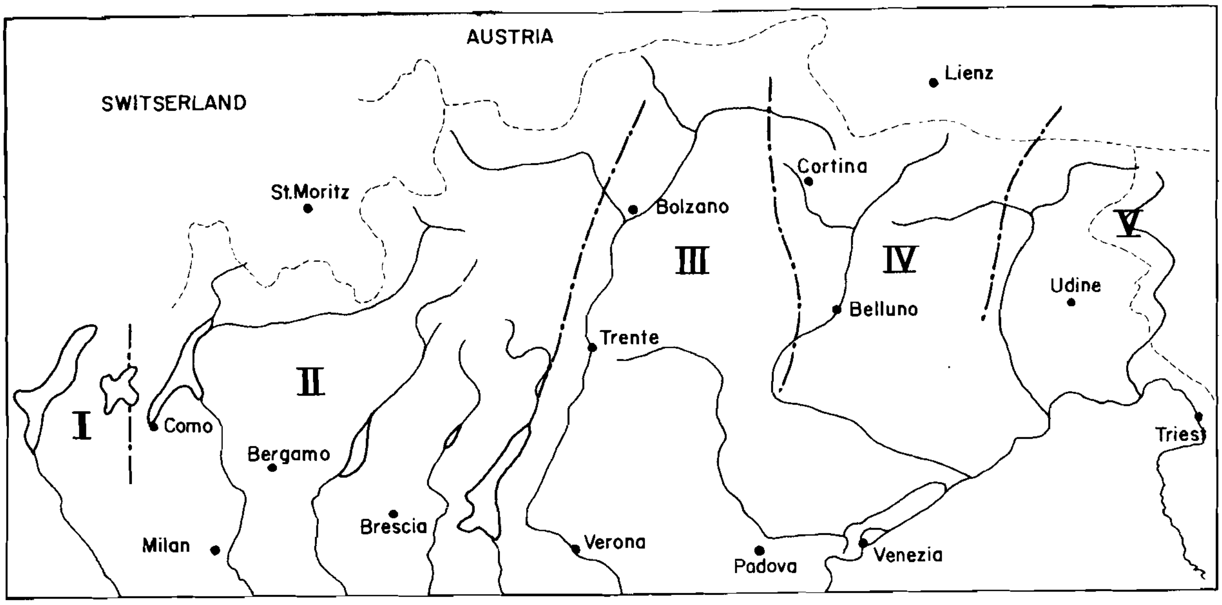

Fig.4. Basin- and Platform-areas in North Italy.
I. Luganese Platform
II. Lombardic Basin
III. Atesin Platform
IV. Carnian Bellunese Basin
V. Julian Platform

The area treated in this thesis is situated in the eastern part of the Carnian-Bellunese Basin. The topographic line Paularo-Tolmezzo, (Torrente Chiarso - Torrente But, Enclosure sheet II), forms the boundary between this basin and the Julian Platform, to the east of it.

Boundaries between platforms and basins are formed by relatively small zones of weakness, the structural phenomena being flexures or normal faults in the underlying basement complex. This can be demonstrated at the N-S line Paularo-Tolmezzo, which represents the boundary between the Julian Platform and the Carnian-Bellunese Basin: E-W sections across this line all show that younger strata to the westside in the basin area are found at the same topographical height as older strata to the eastside in the platform area; the differences in thickness of all permo-triassic formations at both sides, which have nevertheless the same facies, indicate that this line must have been fault or flexure during the deposition of the sediments.

Later on, during the Alpine orogenesis, this triassic fault has acted as a transcurrent fault, as will be shown in Chapter IV.

The first differentiation of the geosynclinal floor into a basin-platform pattern originated in permian time, and it was accompanied by permian volcanism. Permian extrusives are found only on the platforms and not in the basins. The wellknown volcanic province of Bolzano on the Atesin Platform can be mentioned as an example.

The development of the basin-platform contrasts proceeded in lower- and mainly middle-triassic time, and this phase was accompanied by the ladinian volcanism.

The magma could more easily break through the thin sediment epiderm of the platforms than in the basins where a thicker sedimentary epiderm tended to suffocate volcanic activity. However, the lag in subsidence of the platform areas might also result from some buoyance of underlying pockets and/or disks of magma. Nevertheless, also in the basins the conditions of deposition were rather unstable in anisian and ladinian time, causing the lateral changes of facies of the respective formations. Bosellini (1965) suggested that an orogenic phase ("Gardenese Phase") occurred at the boundary between the Scythian and the Anisian. But in our opinion this permo-triassic blockfaulting of the basement complex with the accompanying calc-alkaline volcanism, and the differences in the rate of subsidence of the various blocks, did not have the character of an orogenic phase.

The Carnian-Bellunese Basin subsided almost continuously during the Permo-Triassic. Only some local emersions occurred; one at the boundary between the anisian reefs and the Buchenstein strata (see pag.14), and one in carnian time. In the region between Ampezzo (west from Villa Santina) and Tolmezzo (Enclosure sheet II) carnian emersion and erosion of a nearby area is demonstrated by the presence in the carnian sediments of intercalations which contain terrigenic material. These deposits hampered the growth of the ladinian reefs.

The Upper-Carnian is even characterized by evaporites, which indicate that in the geosynclinal sea some isolated basins came into existence. After the Carnian these rather rapid changes in the conditions of deposition came to an end.

The Norian and the Jurassic are rather uniformly developed, not only in the area investigated in this work, but in the entire Southern Alps. The general facies of the Jurassic indicates that the jurassic sea has been somewhat deeper that the neritic conditions of deposition of the triassic sea. Auboin (1963) says that the individuality of the alpine geosyncline was established since the Lower Jurassic with its extensive and continuous sea, after the pre-geosynclinal cycle of deposition (Pollini, Cassinis, 1963).

CHAPTER IV

TECTONICS

INTRODUCTION

An extensive research programm on the structural evolution of the Southeastern Alps has been carried out since 1955, by students of the Geological Institute of the State University of Utrecht (the Netherlands), under supervision of Prof.Dr. R.W. van Bemmelen (see van Bemmelen, 1960 a and b).

The Alps can be considered as a geanticline or "meso-undation", which has been domed up since the Oligocene. This updoming (primary tectogenesis) created a field of potential gravitational energy, which resulted in secondary tectonic reactions of spreading, called secondary tectogenesis.

The Periadriatic line separates the crest of the Alpine meso-undation from its southern flank, c.q. the Southern Alps. This fault line is composed of a series of sections, namely the Insubric-Iudicaria-Pusteria-Drava- and Gail-sections. Formerly the Periadriatic line was considered to be the root zone of the great nappes in the Central and Northern Alps, but the studies by Van Bemmelen on the Gailtal Alps (1957,1961) and those by Dietzel, Van Hilten and Agterberg on the Iudicaria- and Pusteria sections (respectively 1960,1960 and 1961) have shown that this fault system acted during the Tertiary merely as a system of normal faults, with a great vertical throw (5-9 km), accompanied by minor, partly antithetic, faults.

Our investigations bear upon the tectonics of the sedimentary epiderm of the Carnian Alps, which are situated south of the Gail section of the Periadriatic line. The Central Carnian Alps are situated between this line and the area investigated in this work. In this central part of the Carnian Alps the basement of paleozoic metamorphic rocks is exposed. This basement complex has not been studied, but it is thought to represent the base from which the sedimentary epiderm has been removed by a southward decollement. This general picture is conform to the results of the studies by Engelen on the Central Dolomite Region (1963), de Boer on the Vicentinian Alps (1963) and Guicherit on the Eastern Carnian Alps and Julian Alps (1963). These authors all arrive at the interpretation that the local tectonic structures resulted from gravitational reactions to local accumulations of potential energy. These local stress fields came into being either by differential vertical movements, and/or incision by rejuvenated erosion (relief energy). The reduction of the relief energy can be brought about either by progressing erosion and/or deposition (transport of matter in a dispersed state), or by displacements of larger rock units from places with an excess of relief energy to adjacent places with a relative deficit. Tectonic equilibrium is reached when the stress fields of the relief energy have been reduced to such values that the resistances by inner and outer friction prevent further deformations.

In the investigated area four major types of secondary tectogenesis can be distinguished: a. decollements of the sedimentary strata, causing southward overthrusts and compressive folding downslope, b. a southward toppling over of normal faults and their transformation into apparent upthrusts c. diapiric behaviour of gypsum and gypsum-bearing layers and d. a downslope sliding of minor rock units on a very local scale. Strong internal deformations are apparent in the relatively plastic formations, such as the Bellerophon-, Werfen-, Wengen- and Buchenstein-Formations and partly the Raibl strata, whereas the massive triassic reefs like the norian Main Dolomite and the jurassic Monte Tudaio Formation behaved more as rigid masses, though the uniform lithology may mask the internal deformation. The other formations - the Gardena-, Monte Talm- and partly Raibl-Formations - occupy an intermediate position: internal folds of small wavelengths are rare and generally only large undulations of these strata have been found.

The folding of the more plastic formations has often been caused by transport of overlying more competent formations.

Beside folding, internal minor faulting constitutes another common type of deformation. Such faults are apparent in the massive reef bodies, in the strata of the upper-triassic Main Dolomite and in the jurassic Monte Tudaio Formation. Local wrench faults are also of common occurrence.

A. THE CONTACTS BETWEEN THE GARDENA FORMATION AND THE METAMORPHIC BASEMENT

The contact between the permo-triassic sedimentary epiderm and the paleozoic basement complex has been studied in some detail. It shows different

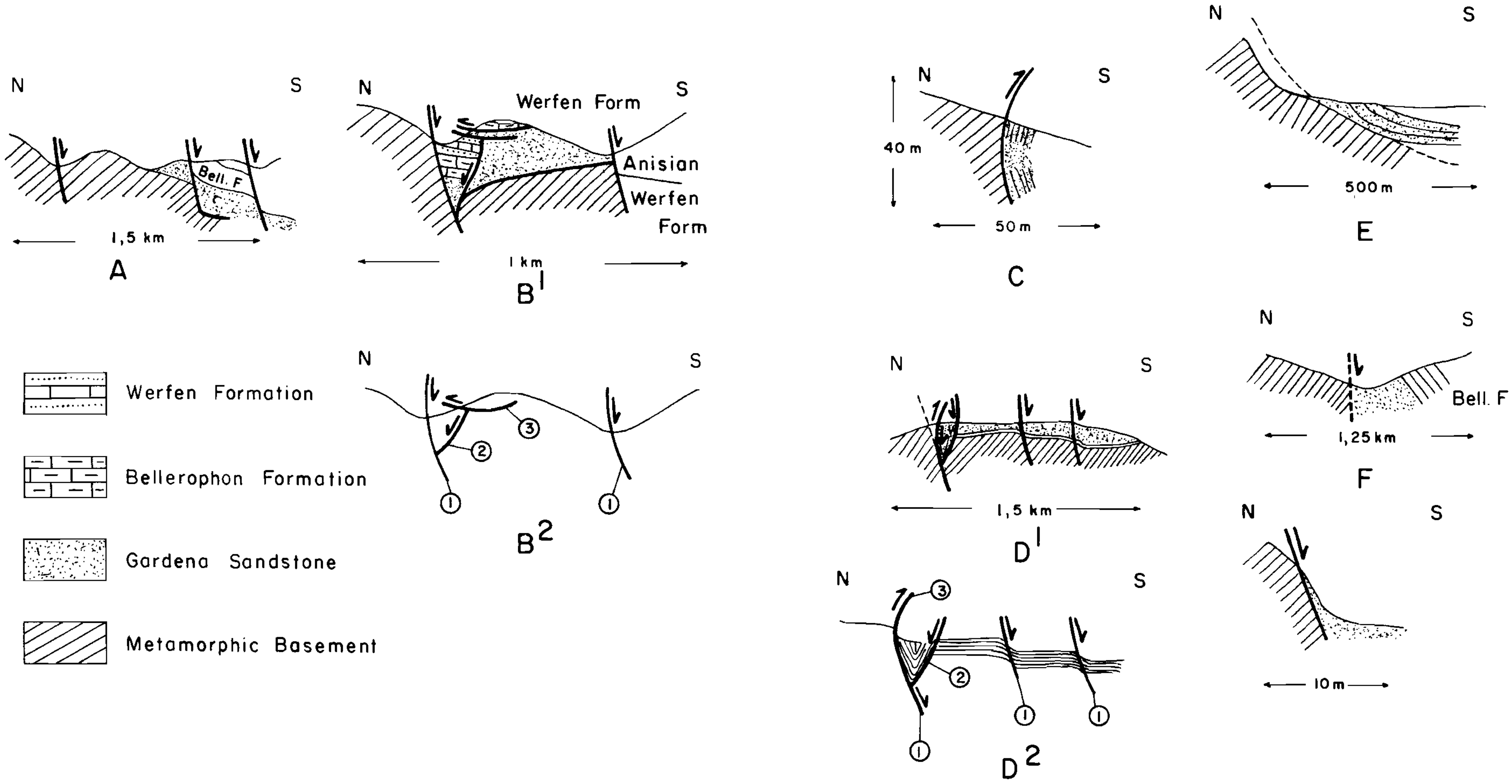

Fig.5. The contacts between the Gardena Formation and the metamorphic basement.

features in the various outcrops (see fig.5).

Fig.5a: the region south of San Stefano di Cadore.

The contact faults can be stated clearly in the field. These faults form also the northern part of the Tudaio Graben Structure (Chapter IV C): over a distance of only 1 1/2 km one traverses all permo-triassic formations, from the basement up to the jurassic Monte Tudaio Formation.

The Gardena Sandstones are mylonitized, so that the original stratification disappeared.

Fig.5b: Passo Palombino, the westernmost part of the Val Visdende.

At this locality there is no direct contact between the Gardena Formation and the basement, but only between the Werfen Formation and the basement. This testifies to the presence of a major fault between these Werfen strata and the basement complex. However, the Gardena Sandstones are found to lie horizontally upon the Werfen strata. This situation resulted from a local northward overthrust over a wedge of subsidence between this major fault and its antithetic northwarddipping counterpart.

Fig.5b1 gives the situation at the moment.

Fig.5b2 shows the succession of deformations: the first phase was the forming of southwarddipping normal step faults in the basement complex, caused by the different lifting up of the basement blocks (Central Carnian Alps). The second phase was the subsidence of a wedge, both forming a so called Y-fault between the major fault 1 and its antithetic counterpart. The third phase was a local gravitational sliding of the northward tilted Gardena Sandstones over the Werfen strata, which became exposed by rejuvenated erosion.

This locality is the only place in the investigated area where another formation than the Gardena sandstones forms the contact between the alpine sediments and the metamorphic basement.

Fig.5c: Near to the Malga di Val Carnia in the central part of the Val Visdende (Enclosure sheet I) a southward dipping normal fault is transformed into an apparent southward upthrust. The upper part of the southward dipping normal fault has been pushed over into an overturned position (see de Jong, 1967, fig.3d).

Fig.5d: Col della Varda in the eastern part of the Val Visdende, also Enclosure sheet I. Here the contact between the paleozoic rocks and the Gardena sandstones is rather complex, though good outcrops occur. The explanation can be given after Sanford (1959): a system of partly overturned faults accompany vertical differential movements of the basement blocks (see also de Jong, 1967, fig.3c).

The situation at the Col della Varda is a little bit more complex than in fig.5c: besides three normal fault an Y-fault can be assumed near the contact between Gardena sandstones and the paleozoic basement.

Fig.5d2 shows schematically the steps in the formation of this pattern: phase 1 represents the forming of step faults, phase 2 the forming of an antithetic fault and phase 3 the toppling over of the major branch of the Y-fault system, causing a compression in the non-metamorphic sedimentary strata of the wedge of subsidence in the graben-like structure, which was formed in phase 2.

Fig.5e: South of the Monte Peralba, sheet I. An apparently normal contact exists between the Gardena sandstones and the basement. However, at least a steep flexure must be assumed in this locality, because of the difference in topographical height of the devonian Monte Peralba (2693 m) and the exposures of permian Gardena Sandstones at its southern side at an altitude of about 1600 m above sealevel.

Fig.5f: Near Ravascletto (Enclosure sheet II) about the same situation is found as in fig.5e. The outcrops do not allow a conclusion about the character of the contact: it might be a normal fault or a flexure.

Fig.5g: Near Ligosullo (Enclosure sheet II) an outcrop of the contact occurs, showing a normal fault, about 70^{o} southward dipping, not transformed into an apparent upthrust. The fault is marked by a mylonitic zone, about 50 cm thick.

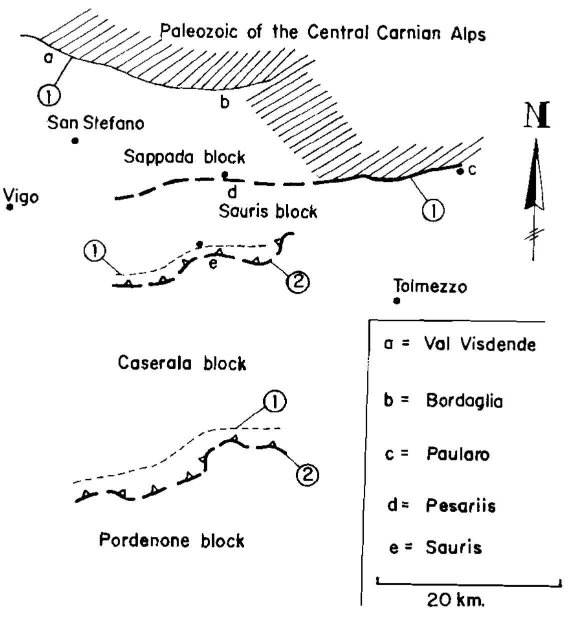

Fig.6. E-W trending blocks in the southern flank of the Carnian Alps, after phase 1.

The faults, respectively flexures which form the contact between the Gardena Formation and the metamorphic basement complex, represent the oldest tectonic phase during the alpine orogenesis in the area under investigation. During this phase the southern flank of the alpine geanticline was tilted southward and in the Carnian Alps it was dissected into some E-W trending blocks, separated by faults and/or flexures (see fig.6).

B. THE ARRAY OF OVERTHRUSTS ALONG THE SOUTHERN BOUNDARY OF THE REGION.

See enclosures of the geologic map, the sections I to VII and the tectonic map of fig.34.

Along the southern boundaries of the area investigated an array of important overthrusts can be demonstrated. Their outcrops stretch over a distance of about 35-40 km in E-W direction, all of them showing displacements to the south.
The Ovaro-unit: this widest and northernmost overlapping slice of alpine sediments begins near the village of Zuglio (enclosure II), extending 12 km westward along Ovaro to the village of Sauris (enclosure I), where the plane of overthrust bifurcates in a major southern branch and a minor northern one. South of Sauris both lines of outcrop curve into a southward trend and they have not been studied in the field by the present author.
ESE of Sauris, near the village of Lateis, the Werfen Formation has been found lying upon the Raibl Formation (section IV). Some hundreds of meters north of this overthrust the outcrop of the minor branch of overthrust shows the Bellerophon strata lying upon the Werfen strata. The planes of overthrust of both branches dip about 20° to the north. The net amount of overlap of the southern branch amounts to about 3 km, and that of the northern one to about 1 km.
According to findings elsewhere in the Southern Alps (see for instance van Bemmelen 1964, fig.12 on p.341 and de Jong 1967, fig.12 on p.766), it is supposed that the stepfaulting in the southern flank of the Alpine geanticline at first caused normal faults in the basement complex, with the same character as the contactfaults between the Gardena Formation and the basement complex (see the preceding chapter A). This primary tectogenesis triggered then the southward decollement of the overlying sedimentary epiderm (gravitational reaction of secondary tectogenesis). The original normal fault or fault-flexure in the basement (phase 1) has thus been transformed into an apparent up- or overthrust by means of the secondary gravitational reactions to the field of relief energy that was created by the primary tectogenesis (see de Jong 1967, fig.12 on p.766).
The outcrops of both branches of the Ovaro-unit curve into a southward direction near Lake Maina, where the small wedge of Werfen strata between them is locally reduced to a thickness of only 50 m.

Southwest of Sauris two other overthrusts have been found, the northern one called Sauris-unit, the southern one Monte Bivera-unit, here again a major southern overthrust and a minor northern one (respectively Bellerophon strata upon anisian reef limestones, and Bellerophon strata upon Werfen strata). Both planes of overthrust are dipping about 30° to the north. The Sauris overthrust is merely a local phenomenon; it can be traced in E-W direction over a distance of 5 km, the easternmost point being the Monte Ruche, south of Sauris di Sotto (Section V).
In section VII this minor unit is no more present.
The Monte Bivera-overthrust is greater, extending over a greater width, also showing a greater structural overlap.
In section VII the Werfen strata overlie the Schlern Dolomite, in section VI a wedge of Bellerophon strata overlies the anisian reef limestones. According to the geologic map of Selli (1963) this overthrust extends in western direction over another 5 km, thus reaching outside the limits of the investigated area.
These two overthrust slices of sedimentary strata (section VI; in section V only the Sauris-unit, in section VII only the Monte Bivera-unit), are not connected with the two branches of the Ovaro-overthrust, mentioned above, because these curve southward at the Lake Maina. Section VI, if lengthened to the south, should cross a succession of four overthrusts (see fig.7).

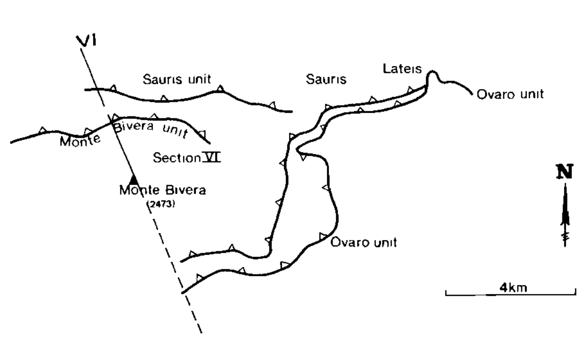

Fig.7. Situation of the various overthrust units near Sauris.

East of section IV and south of the Col Gentile and the Monte Veltri, the Ovaro-overthrust - the same as the major branch near Lateis - can be clearly traced. In the steep southern slopes of these mountains the plastic Werfen strata, dipping about 20° to the north, (Col Gentile, 2075 m) overlie the rigid Schlern Dolomite (1867 m).
At 3 km southeast of the Col Gentile the outcrop of the Ovaro-overthrust curves into a northern direction. This is caused by the topography (incision of the Rio Degano); near the village of Mione it reassumes an eastern direction. The overthrust plane can be observed directly south of Ovaro, along the road to Villa Santina, where Bellerophon strata overlie the Raibl Formation (Section II). The net amount of structural overlap here reaches at least 3 km.
From Ovaro to Zuglio (Enclosure sheet II), the presence of the Ovaro-overthrust can be stated at various places, showing a meandering path on the map, owing to the relief. The strata north of the line of outcrop have a maximum dip of 30° to the north.
The Ovaro-overthrust crops out one kilometer southeast of Zuglio along the road from Arta to Tolmezzo. In fig.8 some sketches are given; here again a northern minor branch is present. (See also section I). Both overthrust-units are moved to the southeast. The net structural overlap of the major, southern, branch of the Ovaro-overthrust amounts here to about 7 km. Still farther in eastward direction the track of the Ovaro-overthrust is covered by much younger tectonic movements, treated in paragraph H.
Other overthrusts, called Verzegnis-unit, Villa Santina-unit and Vinaio-unit, can be stated in the region Villa Santina - Tolmezzo. (Enclosure sheet II, sections I and II).

Section I cuts across the Villa Santina- and Verzegnis-overthrusts, south of the Torrente But. The Monte Spin is a klippe, which will be discussed in paragraph Hb. In this section the unstratified Schlern Dolomite is present, - at a distance of 3 km southwest of the village of Fusea, along the road from Villa Santina to Tolmezzo -, lying upon the Raibl Formation, which crops out in the valley of the river Tagliamento, at a lower topographical level. This is the Villa Santina-overthrust. About 1 1/2 km furtheron to the southwest northward dipping Raibl strata are lying upon the southward dipping Main Dolomite, showing the Verzegnis-overthrust.
The same picture is illustrated by section II, which cuts across three overthrusts, south of the Ovaro-unit. In the southernmost one - like in section I - the Raibl strata lie upon the Main Dolomite: this is the Verzegnis-unit. The second overthrust to the north is the Villa Santina - unit. Here again, like in section I, the Schlern Dolomite overlies the Raibl Formation. The next overthrust in northern direction has been called the Vinaio-unit; this unit could not be traced in the region of section I. Also in the Vinaio-unit the Schlern Dolomite overlies the Raibl Formation.

From the Verzegnis-, Villa Santina- and Vinaio-units the net structural overlap is difficult to estimate, especially in section II, where the Schlern Dolomite is thought to represent merely slivers of the entire formation. But the net structural overlap amounts to at least 1 1/2 km in the southernmost Verzegnis-overthrust, reaching a possible maximum of 4 km in the Villa Santina- and Vinaio-overthrusts.

It is useful to mention already here the differences between tectonic style of sheet I and sheet II of the geologic map enclosed.
In sheet II - apart from the northernmost Ovaro-overthrust - the tectonic pattern comprises only the middle- and partly upper-triassic parts of the sedimentary epiderm (Ladinian overlying Carnian, respectively Carnian overlying Norian).
In sheet I (sections III to VIII) the Ovaro-, Sauris- and Monte Bivera-overthrusts in the southern parts of the sections concern also the Permian and Lower-Triassic (Werfen strata overlying the Raibl Formation, respectively Bellerophon strata overlying the anisian reef limestones). This feature will be discussed in Chapter V.

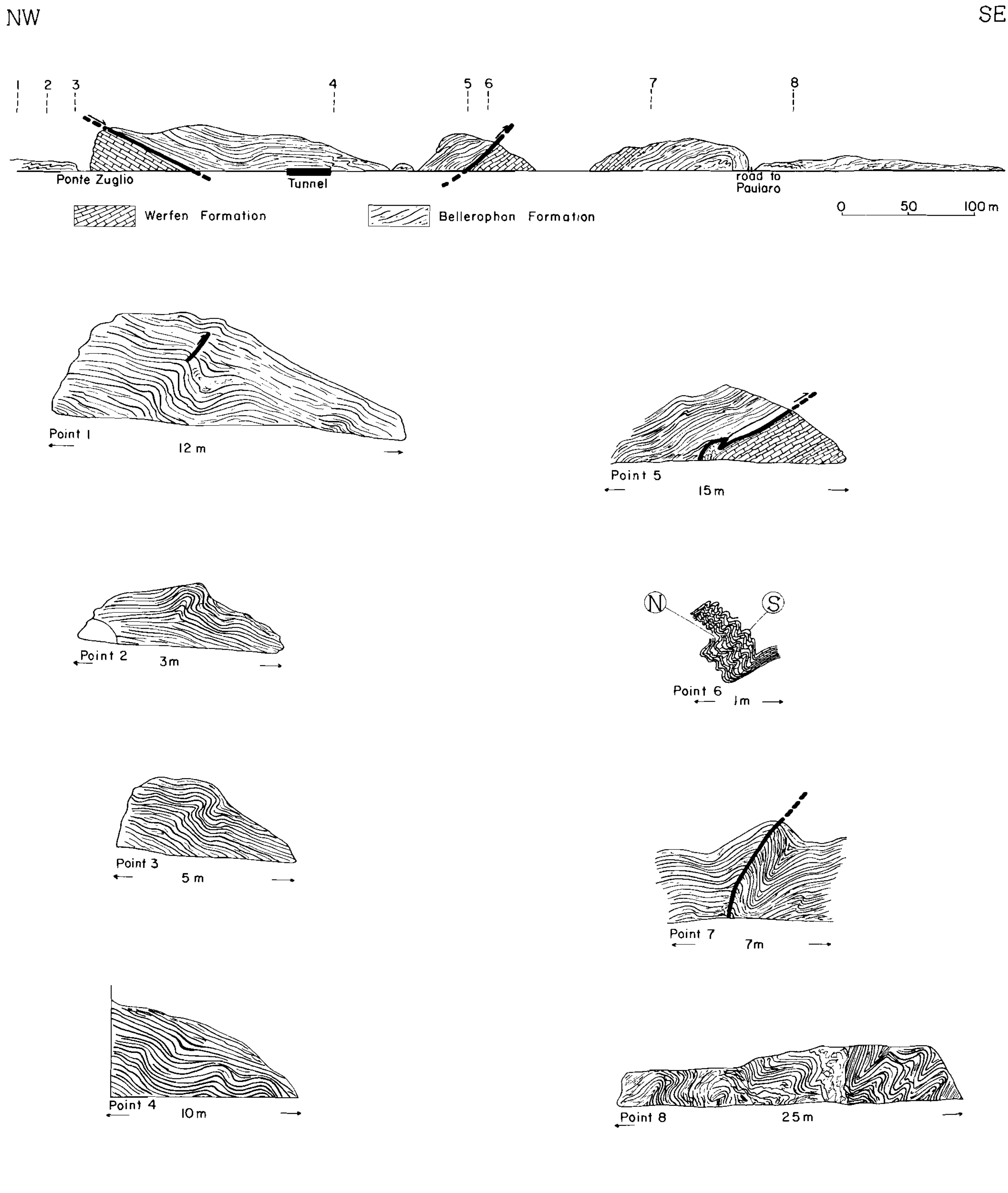

Fig.8. Sketches of a minor branch of the Ovaro overthrust near Zuglio.

C. THE BORDAGLIA-SAPPADA-TUDAIO GRABEN STRUCTURES

In the preceding chapters the tectonic phases 1 and 2 of the fig.9 and 10 are described. These phases, being the first ones in the region during the alpine secondary tectogenesis, have been dated as Lower Cenozoic (see tectonic map of fig.34). The overthrusts of phase 2 (see fig.9 and 10) have been succeeded by a third phase of tectonics in the area north of the overthrust front. This third phase produced a number of graben structures. The most important one extends over a distance of 33 km, from the Bordaglia region, NE of Forni Avoltri, to Vigo di Cadore in the westernmost part of the region. It consists of three major sections. The eastern part, NE of Forni Avoltri, has a NE-SW trend, pinching out northeastward over a distance of 9 km, and has been called the Bordaglia graben. The central part between Forni Avoltri and the Val Frisone trends WSW-ENE over a distance of 14 km, being about 5 km wide. This section has been called the Sappada graben. The western part of the graben extends in an almost E-W direction, over a distance of 10 km, being about 6 km wide. This part has been called the Tudaio graben.

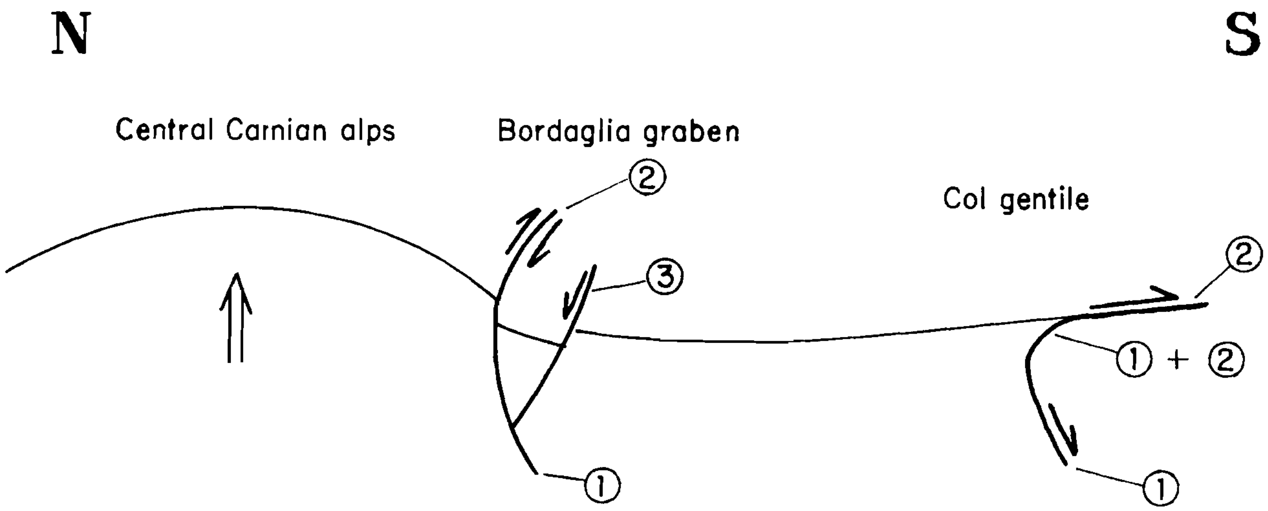

Fig.9. For explanation see text.

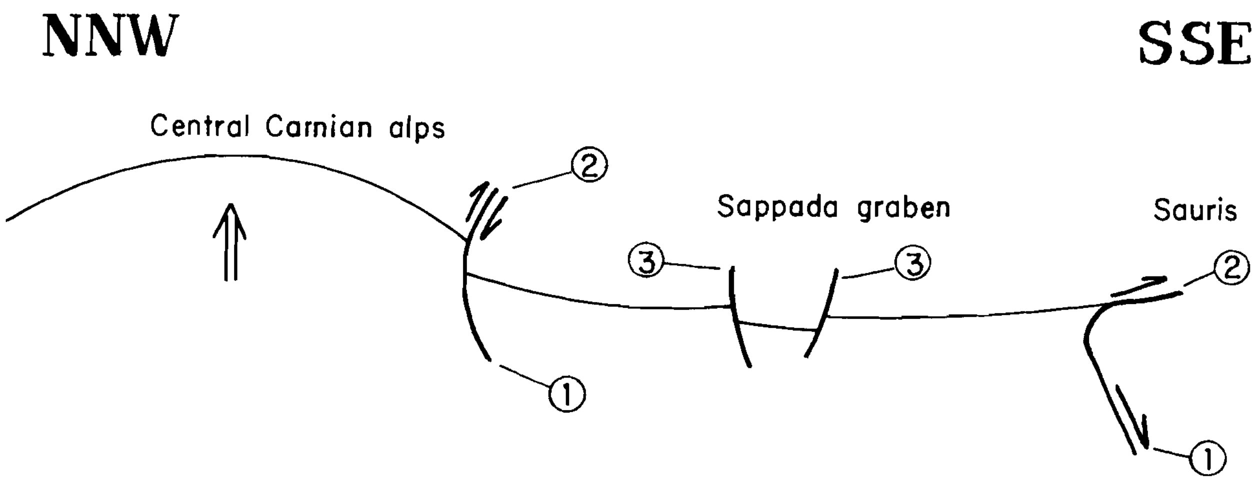

Fig.10. For explanation see text.

a. The Bordaglia Graben Structure

Fig.11, modified after Carloni (1967), gives a N-S section across the Bordaglia graben near Forni Avoltri. The southern graben fault has a vertical throw of at least some hundreds of meters, because higher parts of the Gardena Sandstone Formation have been brought into contact with rocks of the basement complex (e.g. Carboniferous). Carloni supposed that at the northern side of the graben a depositional unconformity exists between the basement complex (e.g. Ordovicium) and permian sandstones. In our opinion a normal fault is present. Gardena sandstones are in contact with Ordovicium; the vertical throw of this northern fault cannot be estimated, because the hiatus of the alpine unconformity is not known at this place. However, 3 -4 km farther in northeastern direction in a topographically higher level, near the frontier between Italy and Austria, the Bordaglia graben shows a much more pronounced picture (fig.12): Slightly tilted Werfen- and Bellerophon strata are lying upon a basement of brecciated Gardena Sandstones; these Gardena Sandstones contain blocks of the underlying paleozoic formations, as well as units of the Bellerophon Formation. One might describe it as a mylonitisation of all pre-Werfen rocks, which formed a kind of mega-breccia. This segment of the sedimentary epiderm, preserved as a wedge in the Bordaglia graben structure, might be the mylonitized base of the decollement, that occurred during phase 2.

The amount of vertical throw of both subvertical

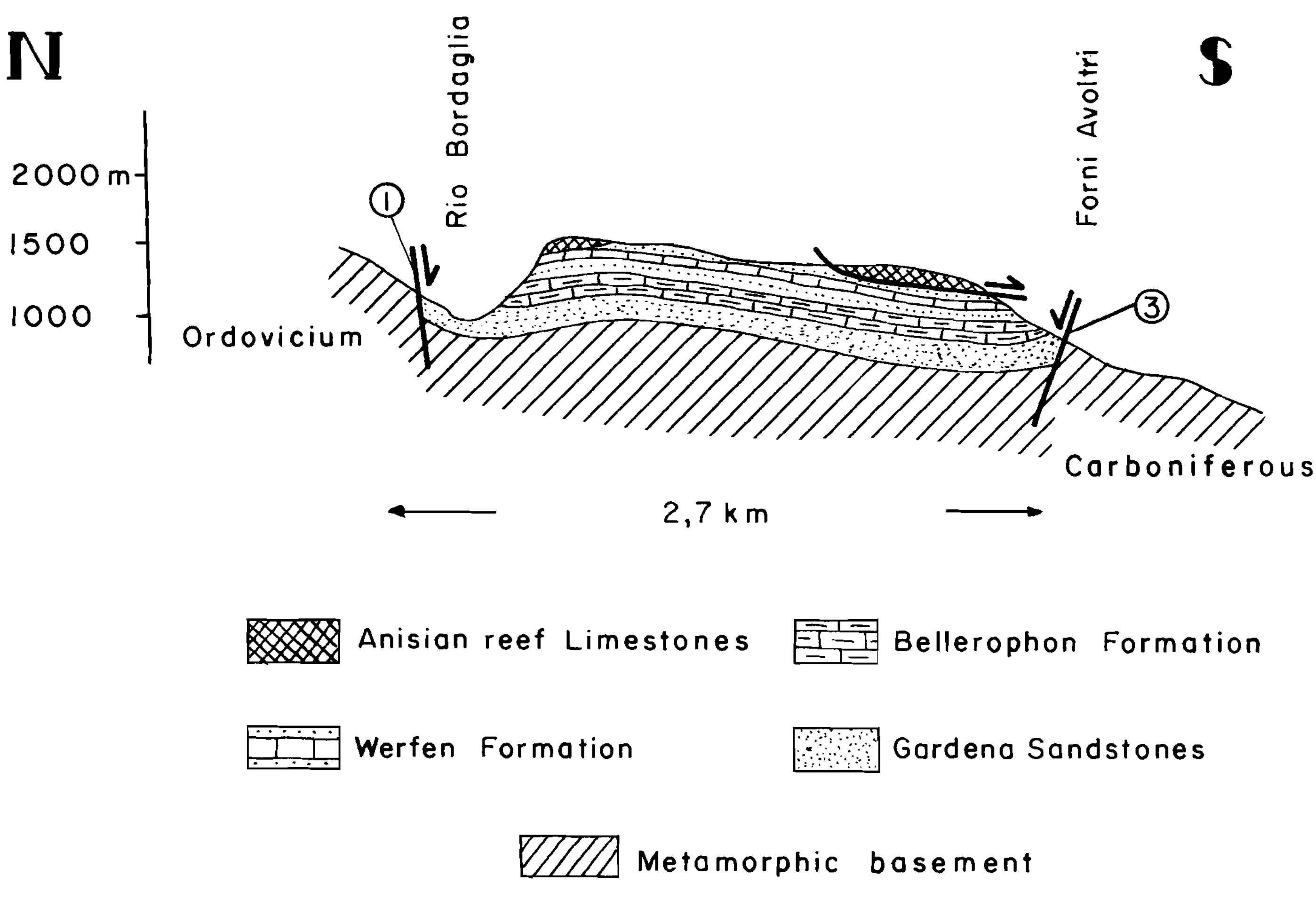

Fig.11. Section across the western part of the Bordaglia Graben.

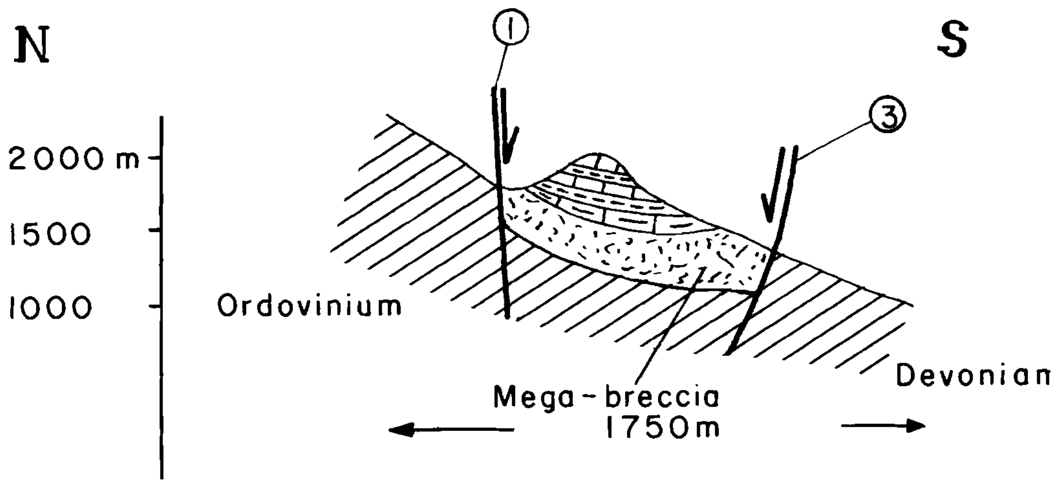

Fig.12. Section across the northeastern part of the Bordaglia Graben.

faults at this NE end of the Bordaglia graben structure cannot be exactly determined. The contacts between Werfen strata and Ordovicium at the NW side, and between Gardena Sandstones and Devonian at the SE side indicate that both faults have a vertical throw of at least 1 km. The horizontal distance between both faults amounts at the place of this section to only 500 m, and the subsided wedge terminated 2 km farther to the NE. Selli (1963) considers the southern fault ("Linea di Val Bordaglia") as a northward "Hercynian overthrust", which has been reactivated during the alpine orogenesis. In the field we could not find any arguments for this supposition.

b. The Sappada Graben Structure

Whereas in the Bordaglia graben also basement rocks are exposed, the adjacent Sappada graben shows mainly outcrops of triassic rocks. The example of the Bordaglia graben makes it probable that in the Sappada graben structure also the basement complex is involved. The general character of the Sappada graben can be seen in the sections III, IV, V and VI, enclosure sheet III.

Schematically the local situations are summarized in fig.13. The vertical throw of the graben faults becomes generally greater from east to west. This feature might have some relation to a change in the lithological character of the metamorphic basement. At various places in the field around section VI it can be stated that the basement is formed by the relatively plastic quartzphyllites, which are the major rock type underneath the Italian Dolomites. The basement in the area of the sections V, IV and III, however, is composed of the paleozoic rocks of the Carnian Alps. As mentioned in the chapter on stratigraphy, this Carnian basement behaved more rigidly during the alpine orogenesis (partly owing to the presence of great monolithic devonian reef units). In the eastern basement area of the Carnian type stepfaulting and graben structures occurred during the alpine orogenesis, whereas in the western basement area of the Dolomites more plastic deformations came into existence, such as those described by Agterberg (1961).

In the Sappada graben some minor faults occur (fig.13). However, besides these minor faults, another secondary fault system occurs in a direction of N 10° E.

The most important fault of this system is the one, which separates the Sappada graben from the Bordaglia graben. The southernmost fault of the Sappada graben can be stated clearly in the field between the Monte Siera and the Monte Creta Forata. Farther to the northeast this fault can be traced to the Monte Tuglia. This is a monolithic unit, existing of anisian reef limestones, that slid to the north and, consequently, it masks partly the connection between the southern Sappada graben fault and the one of the Bordaglia graben. Near Forni Avoltri the Bordaglia graben fault crops out. The border fault between both graben structures in a direction N 10° E shows, besides a certain amount of vertical throw, also a considerable left lateral horizontal component: during the alpine decollement of the sedimentary epiderm, the block west of this fault moved somewhat farther southward than the formations east of it. This wrench fault thus belongs to phase 2.

Three other normal faults with a negligable horizontal component, situated west of the Forni Avoltri wrench fault, have the same direction N 10° E. An E-W section from Cima di Sappada to the Monte Tuglia shows the pattern of fig.14, in which two of these three normal faults are involved.

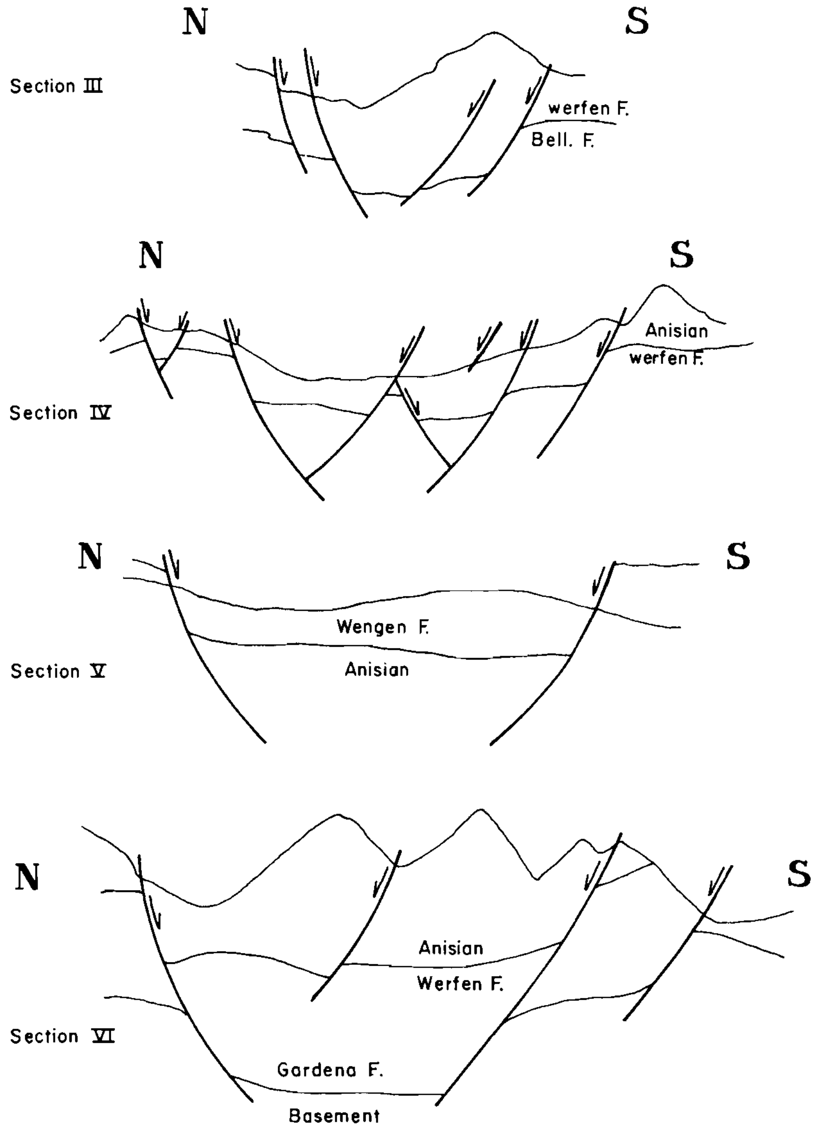

Fig.13. The Sappada Graben.

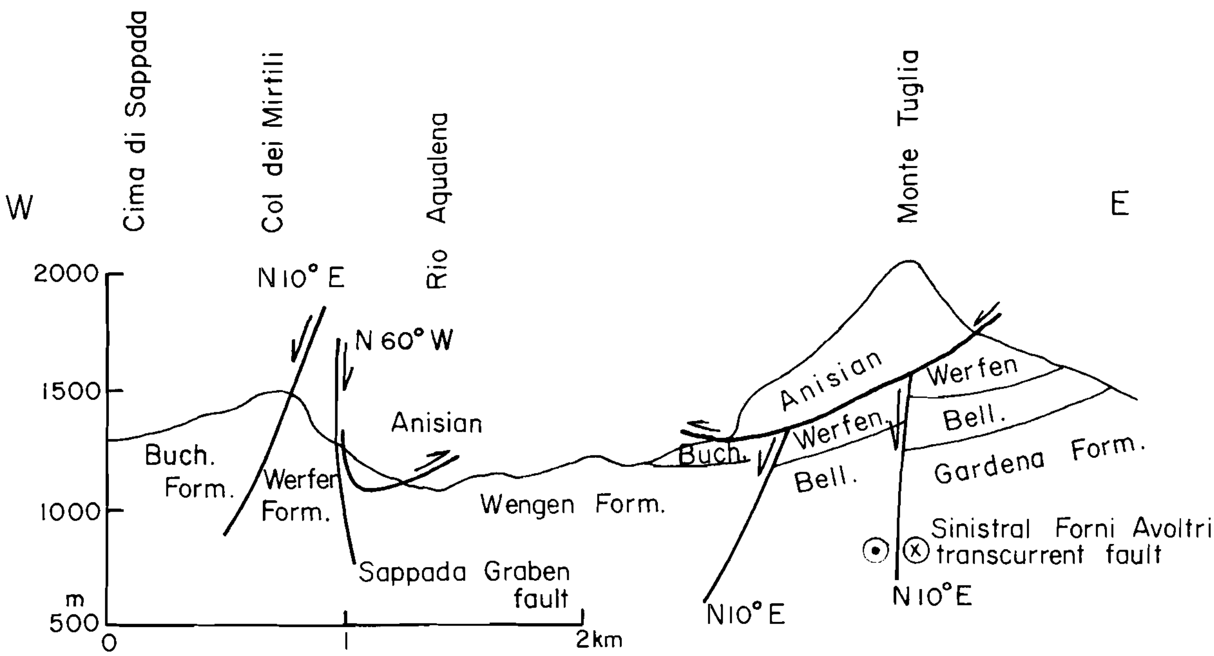

Fig.14. E-W section across the Sappada Graben.

c. The Tudaio Graben Structure

This western part of the series of graben structures cuts from NE to W across the area of study. It shows permo-triassic and jurassic rocks. It is 10 km long between Vigo di Cadore and the Val Frisone, and 6 km wide between Vigo di Cadore and San Stefano di Cadore. Its direction is almost E-W. The basement rocks are the quartzphyllites of Cadore. The marginal faults along the northern side of the Tudaio graben have been discussed already in chapter IV A, which treated the contacts between the Gardena Sandstones and the basement. These graben faults are younger than the phase of decollement (phase 2), so that they can be assigned to the third tectonic phase and not to the first one, which caused the fault contacts between the Gardena Sandstones and the basement complex at other places.

The situations can be studied in the sections VII and VIII of enclosure III. Schematically the situations are summarized in fig.15.

The major graben faults a and b, (respectively á and b́) are accompanied by many minor faults. The entire sedimentary wedge of the Tudaio mass, ranging in age from Permian (Gardena Sandstones) to the Jurassic, has subsided into this Tudaio graben structure.

The Tudaio graben also belongs to phase 3 of fig.9 and 10.

The overthrust structures of phase 2 are situated farther to the south, outside the investigated area. The more competent mass of the upper-triassic Main Dolomite and the jurassic limestones of the Monte Cridola Group played an important mechanical part during the alpine decollement (phase 2).

This Cridola unit slid southward over a base of plastic Bellerophon strata with gypsum, or over a base of plastic Raibl strata with gypsum. The latter crops out in the region of the Passo di Mauria, situated direct south of the investigated area. The Main Dolomite and the jurassic limestones of the Tudaio mass originally formed the rear part of the much greater Cridola unit. But during the southward decollement the Tudaio unit lagged behind and it was trapped in the graben structure.

In the Val Frisone, east of the Monte Tudaio mass, a small right lateral offset in the strike of the various formations can be observed along a N-S trending fault. This wrench fault of the Val Frisone might indicate that the Tudaio mass, sinking down in the Tudaio graben, contemporaneously somewhat rotated anticlockwise. Some structures south of the Tudaio mass can be explained in relation with such a rota-

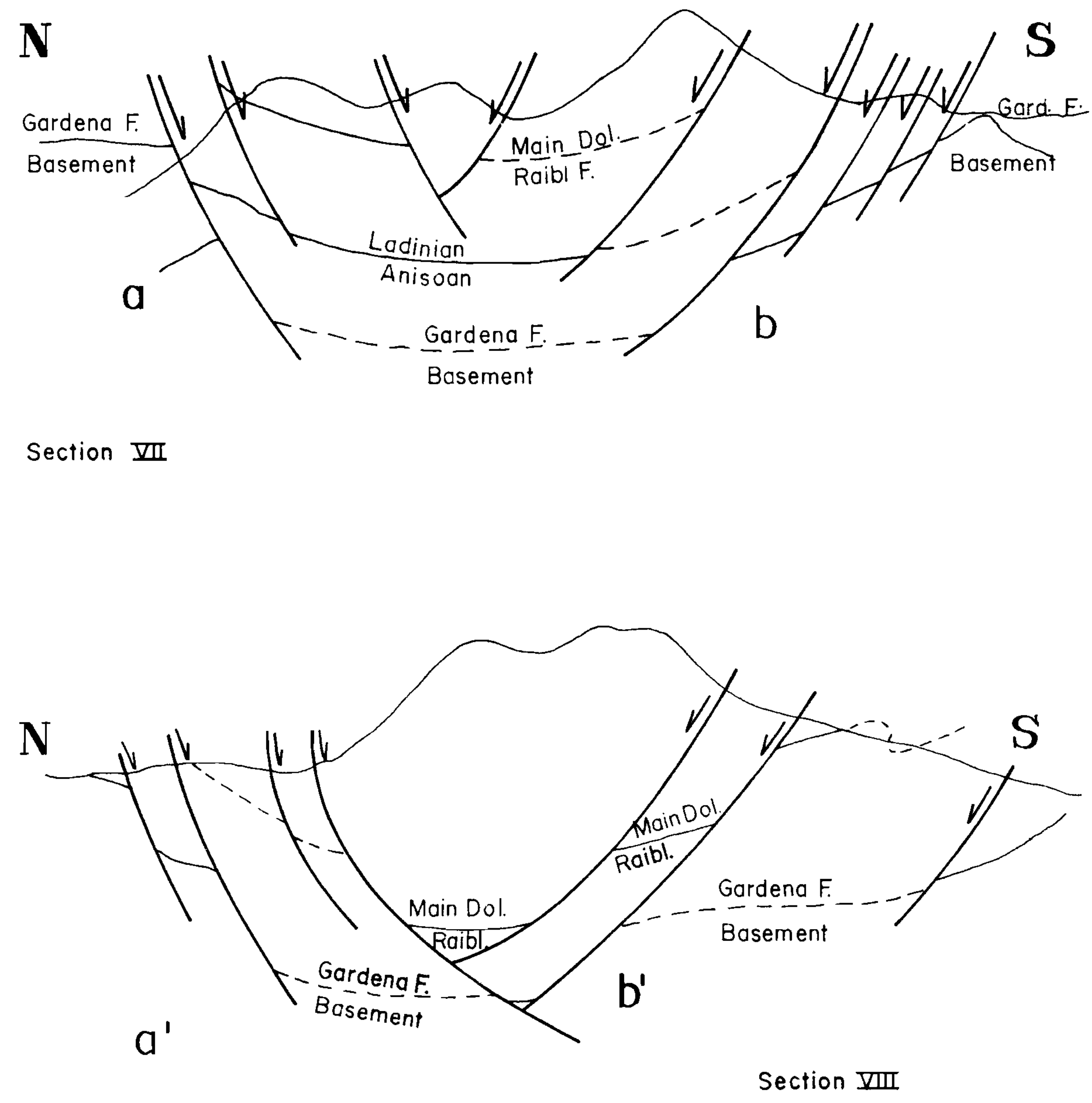

Fig.15. The Tudaio Graben.

tion. (see fig.16a and c).
Section VII shows south of the graben faults only some week folding of the Gardena Sandstones (Rementera anticline), whereas section VIII shows south of the Tudaio mass a series of strongly compressed, almost isoclinal folds with steeply northward dipping axial planes, which indicates movements to the south. Near Laggio di Cadore, west of section VIII, these folds are accompanied by two overthrusts. The supposed anticlockwise rotation of the Tudaio mass may have caused these additional overthrusts. The axis of the Tudaio rotation was located somewhat north of the Monte Popera Valgrande (Sasso Malpasso). Southeast of this point, (Col Rementera), no such compressive structures have been found (see fig.16b).

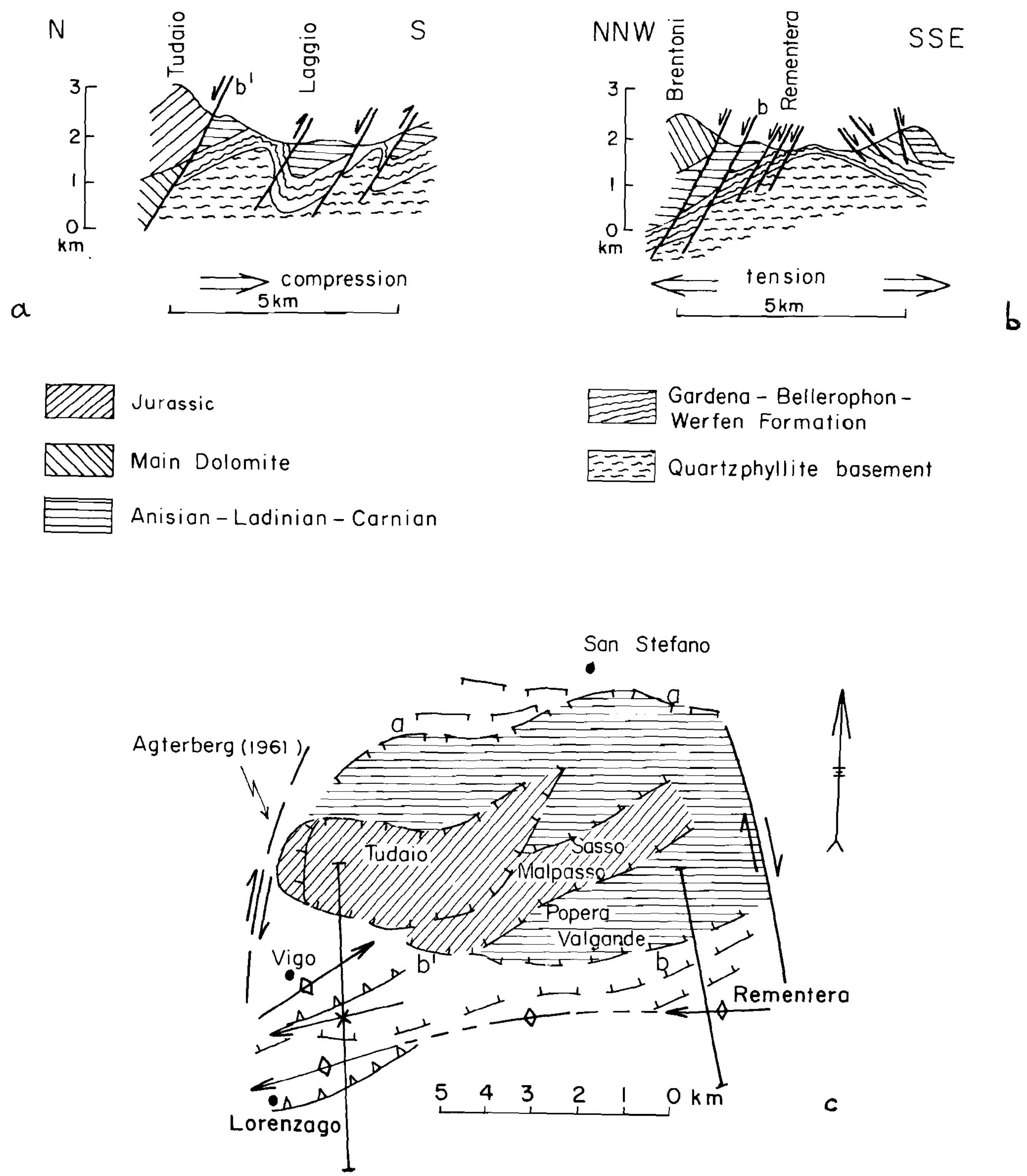

Fig. 16. Rotation of the Tudaio Mass.

D. THE VAL VISDENDE GRABEN STRUCTURE

In the northern part of the San Stefano area and the northwesternmost part of the area under investigation, Gardena Sandstones have been preserved probably as a small graben structure.
The stratification disappeared by the mylonitization, which occurred probably during the decollement of phase 2. This graben structure in the basement has a NW-SE direction (see also Agterberg, 1961, p.67 and section I of fig.50).
On account of a lack of outcrops no more detailed information can be given. See fig.17.

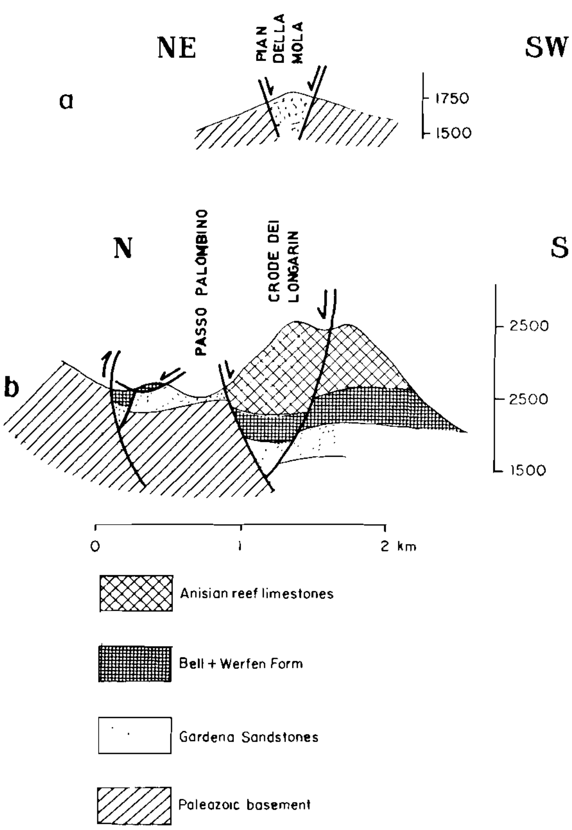

Fig.17. The Val Visdende Graben.

This NW-SE graben structure is considered to be the counterpart of the NE-SW Bordaglia-Sappada-Tudaio graben structure, which concerns also the basement of the Carnian Alps. By this reason the Val Visdende graben has not been treated in chapter IV A.
These graben structures have a diagonal trend, with respect to the Carnian uplift. Their mechanical meaning will be discussed in the next chapter IV E, and in chapter V.

E. MECHANICAL MEANING OF THE TECTONIC STRUCTURES OF PHASE 3

The Bordaglia-Sappada-Tudaio graben structures and the Val Visdende graben are phenomena of tension in the highest elevated parts of the Carnian Alps. These graben structures are younger than the phase of general southward decollement of the sedimentary epiderm (phase 2), because partly they cut across the rear parts of this cover of alpine sediments, and partly they are situated in the basement complex exposed by the corresponding tectonic denudation. These graben contain wedges of permo-triassic sediments (see also de Jong, 1967, fig.15 on p.769). In the Bordaglia graben mega-breccias are exposed at the base of the Permo-Triassic (chapter IV C), which might be caused by this decollement.

Van Bemmelen considers the Carnian Alps as a geanticline, formed by a primary uplift, parallel to the main crest of the Eastern Alpine Geanticline. (fig. 29, on p.439, 1966). This Carnian geanticline extends eastward from the line San Candido - San Stefano di Cadore - Vigo di Cadore. This line is the boundary with the structural unit of the Italian Dolomites to the west. Tension phenomena in the crest of this Carnian geanticline accompanied the arching up of the basement complex, causing a series of graben structures. The graben structures in the western part of the Carnian Alps, here under discussion, cut somewhat diagonally across this crest: the Bordaglia - Sappada - Tudaio graben has a NE-SW to E-W direction, whereas the Val Visdende graben has a NW-SE trend.
These aberrant trends might be related to the westward transition of the Carnian basement into the quartzphyllite basement of the Italian Dolomites. This relation between the Dolomites and the Carnian Alps will be discussed in Chapter V.
The Val Visdende graben is the northwestern end of the grabensystem on the crest of the Carnian Alps. The Bordaglia - Sappada - Tudaio graben intersects the Val Visdende structure at a sharp angle of 75° being the eastern end of the structural WSW-ENE trending Val Sugana lineament. (See chapter V).

The general picture of the structural situation is clear enough to come to the conclusion that these graben structures in the higher parts of the Carnian Alps are tensional features which developed during the uplift and/or tilting of the south flank of the alpine geanticline. Tilting was predominant in the Carnian Alps, so that a decollement could occur, whereas elevated blocks characterize the Dolomite unit to the west.
Considered in this way it is also clear that these

tensional features in the basement complex of the Carnian Alps occurred during the final stages of the southward decollement of the epiderm of alpine sediments, but that they also proceeded somewhat thereafter. It is conceivable that the decollement occurred in an early stage of the uplift, causing the E-W trending southward directed overthrusts downslope, whereas the tensional features of graben formation on the crest of the geanticline originated at a somewhat later stage of the arching up of the Carnian geanticline. Therefore, these graben structures and the decollement are not directly genetically related. They can not be interpreted as tension phenomena in the rear parts of the sliding sedimentary cover. Their genetical relation is indirect, because both phenomena are the result of secondary tectonic processes, namely the uplift of the Carnian geanticline and the tilting of the basement complex in its southern flank towards the Venetian - Adriatic depression in the south.

F. THE BUT-CHIARSO LINE

As already mentioned in chapter III on p. 19 the topographical and structural lineament Tolmezzo - Paularo, (Torrente Chiarso - Torrente But, see enclosure sheet II), forms the boundary between the Carnian - Bellunese Basin to the west, and the Julian Platform to the east.

The differences in thickness of all permo-triassic formations at both sides of this line, which have nevertheless the same facies, indicate that this line must have been an active fault or flexure during the deposition of these sediments. At the NW side of this lineament the alpine sedimentary column is relatively thick (about 5 km), whereas at the SE side almost all formations are thinner.

In our opinion these differences in thickness have had consequences during the alpine orogenesis, especially during the alpine decollement (phase 2). During the tectonic arching up of the Carnian geanticline, and the tilting of the basement complex in its southern flank towards the Venetian - Adriatic depression in the south, a decollement occurred (phase 2), both in the Carnian-Bellunese Basin and on the Julian Platform. However, the thick sequence of sediments of the basin moved farther southwards than the thinner sedimentary cover of the platform area.

The boundary between the basin and the platform (the But-Chiarso line), being a normal fault during the phase of alpine geosynclinal subsidence, acted during the orogenesis (phase 2) as a sinistral wrench fault.

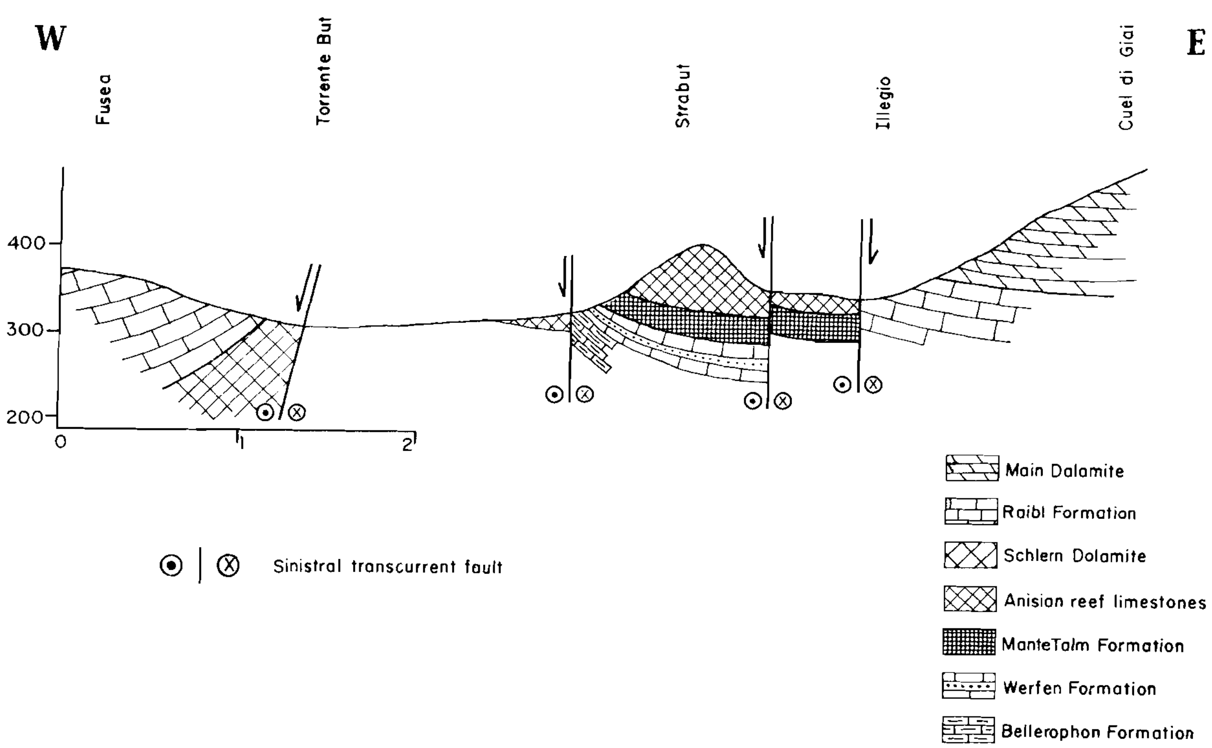

Fig. 18. E-W section across the But-Chiarsó line near Tolmezzo.

Along this transcurrent fault the basin sediments west of it moved some kilometers farther southward than the platform sediments east of it. In the area about 5 km north of Tolmezzo (see enclosure II) an array of four wrench faults can be stated. Fig.18 gives schematically a W-E section across these wrench faults, from the village Fusea to the Main Dolomite massives of the Julian Platform.

The direction of the But-Chiarso lineament is NNE-SSW. The line is partly masked over a distance of about 5 km, by the klippe structure of Cuel da Rinch, (treated in chapter IV H c).

G. DIAPIRIC PHENOMENA

This type of tectonic deformation occurs rarely in the area treated in this thesis.

a. In the central part of the Val Pesarina some outcrops occur, which indicate a diapiric upward piercement of contorted Bellerophon strata (fig.19).

After the rejuvenated erosion in the younger Cenozoic the plastic Bellerophon strata, partly gypsiferous, protruded upwards in the bottom of the valley near Culzei. This diapiric uptrusion was caused by the weight of the anisian and ladinian reef limestones and dolomites to the north and the Werfen Formation of about 1000 m thickness to the south of the valley. This diapiric structure coincides with the floor of the valley at least over a distance of 2 km. Upstream, in the higher part of the Val Pesarina, diapiric structures might also be present, but there the valley floor is filled by alluvial sediments, so that a lack of outcrops impedes direct observations in the field.

b. A lateral diapiric protrusion is present in the northern slopes of the lower part of the Val Pesarina, between Pesariis and Prato Carnico. At about 1400 m above sealevel (Casera Ruvin) and about 750 m above the floor of the valley the Gardena Sandstones occur, protruding between intensely contorted Bellerophon strata (fig.20).

In the higher levels of the Rio Fuina, northeast of Pesariis, the steep anticlinal structure of Bellerophon strata crops out, forming the centre of the diapiric structure. The axial plane dips northward. This lateral diapiric structure has been established over an E-W distance of 4 km. Its extrusion has been caused by the weight of the overlying anisian reef limestones, north of it, which form the upper part of the northern flank of the Val Pesarina. These limestones reach a maximum thickness of 1000 m in this area.

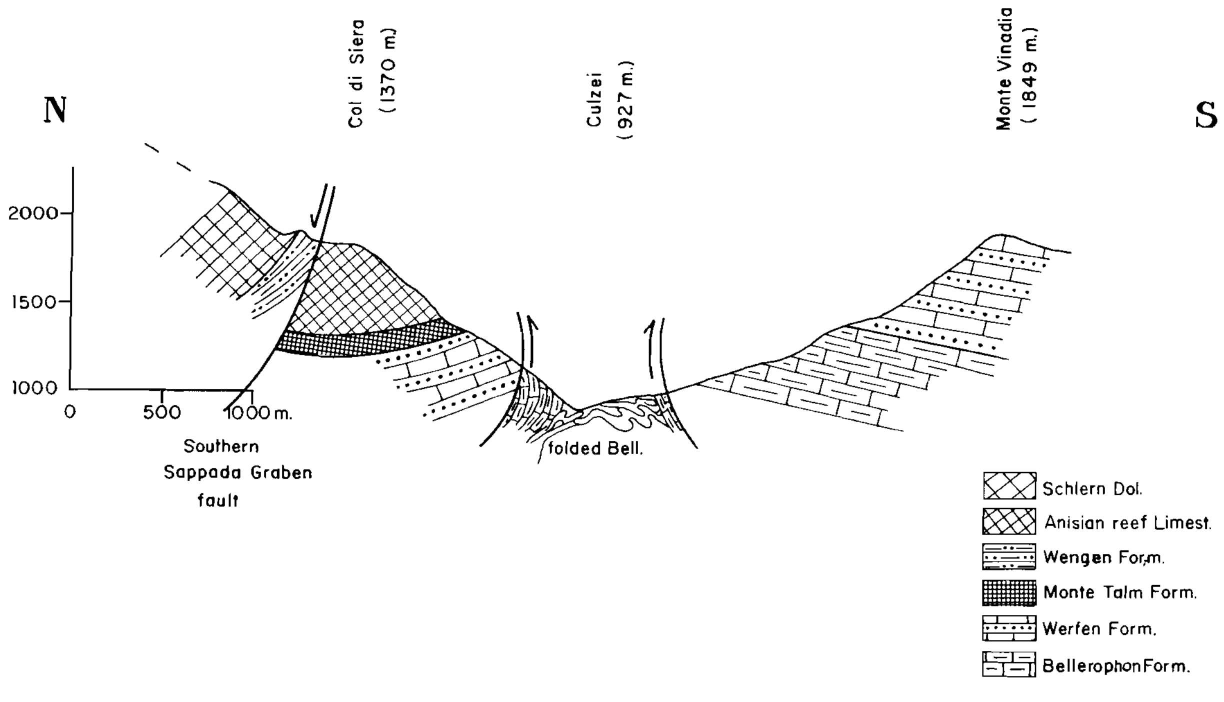

Fig.19. Diapiric phenomena near Culzei.

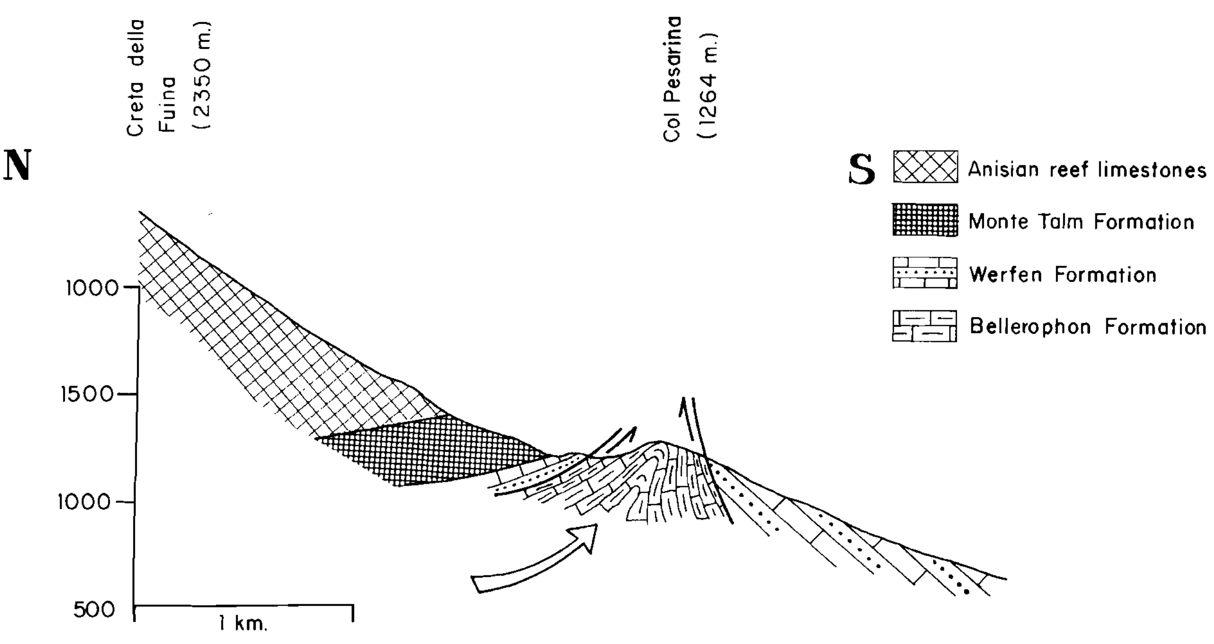

Fig.20. Lateral diapir in the northern slope of the Val Pesarina, between Prato Carnico and Pesariis.

c. The "Fuina-problem"

South of the lateral diapir, treated in the preceding paragraph, another diapiric structure is assumed. Fig.21 shows the real situation.

A competent series of Werfen strata dips about 60° to the south, overlain by strata of the upper member of the Bellerophon Formation, in about the same position. Finally, in the floor of the valley, outcrops occur in the eroded bed of the Rio Pesarina, which show the intensely folded gypsiferous lower member of the Bellerophon Formation. These two levels of diapiric protrusion (at about 1400 m near Casera Ruvin and at about 700 m on the valley floor) might represent successive stages of the upper-cenozoic erosion. The situation bears a strong resemblance to the lateral diapiric structures in the Italian Dolomites, described by Engelen (1963); Engelen found a clear correlation between the level of formation of lateral diapiric structures and the successive stages of progressing erosion (for instance, around the Buffaure Group, 1963, pp.73-76, which has also been discussed by van Bemmelen, 1966, pp.431-436). Elmi and Monesi (1967) explain the structural situation northeast of Pesariis, near the village of Osais, with a northward upthrust in the floor of the Val Pesarina. However, if that were the correct solution, the Bellerophon Formation should show an overturned position, the lower member lying upon the upper member of the formation.

Our field observations do not confirm their solution of the Fuina problem. This structure can be explained more consistently by the model of diapiric features.

During its diapiric extrusion in the bottom of the valley the gypsiferous lower member of the Bellerophon Formation was removed by the progressing erosion. At the northern side of the diapir a block of Werfen strata sagged into the potential void, tilting into a southward dipping position during this process. This mechanical interpretation has been accepted as being the most reasonable one during an excursion with Italian, Austrian and Dutch geologists. Minor folds in some strata near to the centre of the Werfen succession with axial planes indicating a southward displacement of the upper part with respect to the lower one, probably originated somewhat earlier, namely during the general southward decollement of phase 2 and before the attack of rejuvenated erosion. If northward upthrusts occurred in this place, as is suggested by Elmi and Monesi, these minor folds should indicate a reverse northward displacement of the upper part of the Werfen succession with respect to the lower one.

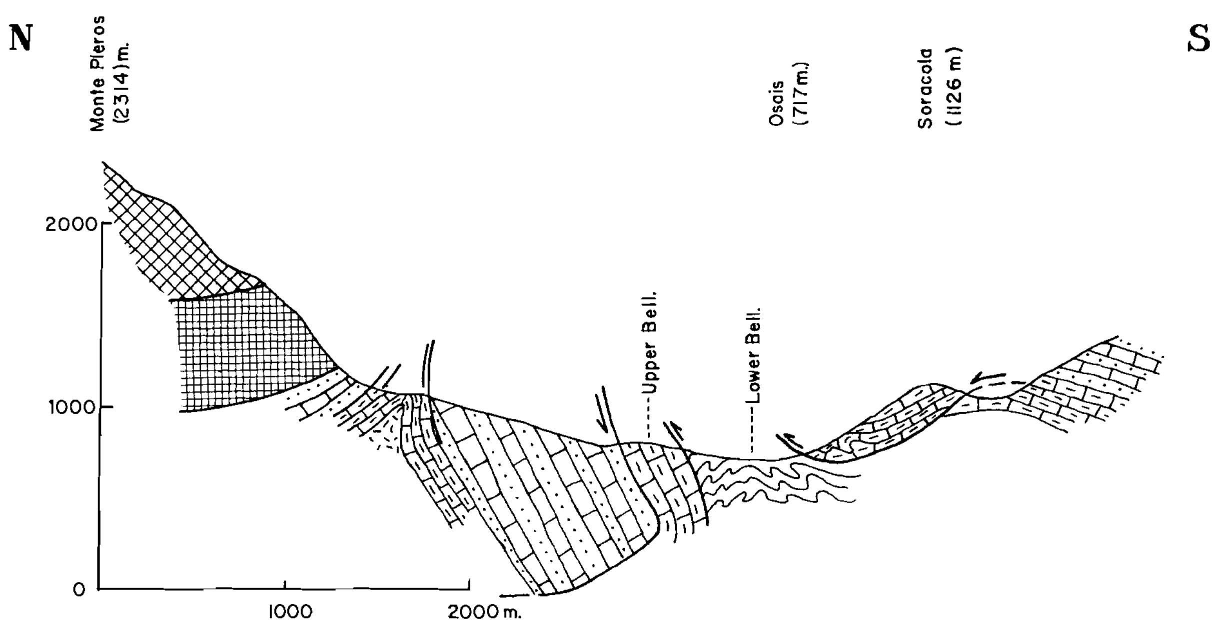

Fig.21. The Fuina diapiric structure near Osais.

H. KLIPPE STRUCTURES AND LOCAL SLIDES

a. The Val Pesarina slide structures

In 1963 a geodynamic event, called "frana" (landslide) by the Italian geologists, occurred at Longarone, a little town near Belluno. After gathering impetus during a long preparatory phase, the Monte Toc slid within a fraction of a minute into the artificial lake of Vaiont. (Semenza, 1965, Rossi and Semenza, 1965, Selli, Trevisan, Carloni, Mazzanti and Ciabatti 1964).
The resulting catastrophal flood wave swept away half of the village of Longarone and about 2000 people perished.

Analogous slides occurred in subrecent time in the area described in this thesis.
In the Val Pesarina six hills, (or at least relatively more elevated points) occur, between Sostasio and Culzei, in the southern slope of the valley. This remarkable topography indicates the presence of subrecent sliding over a short distance, only some hundreds of meters (see tectonic map of fig.34 and the geologic map of enclosure I). A cross section is given in the southern part of fig.21).
Traces of brecciated strata, occurring in the tail or rear parts of these slides, have not yet been removed by erosion, which indicates the subrecent age of these slides.

b. The Monte Spin klippe

The hills in the Val Pesarina, mentioned in IV H a, are all composed of matter belonging to the lower and upper members of the Bellerophon Formation, and no structural overlap on younger strata can be stated. Therefore we cal them subrecent landslides. But a more important geodynamic process occurred farther east, between Arta and Tolmezzo (enclosure sheet II). Here a typical klippe, named the Monte Spin klippe, forms a mountain top of older strata on a base of younger ones (see also section I). A sequence of Werfen strata, Monte Talm Formation, anisian reef limestones and partly Wengen strata, all dipping uniformly to the northeast, is lying upon a base of relatively competent Raibl strata. The klippe unit (maximum altitude 915 m), of the Monte Spin is slid southward from the Monte Tersadia (maximum altitude 1959 m). The mutual distance between the summit of the Monte Tersadia and the Monte Spin is 9 km.

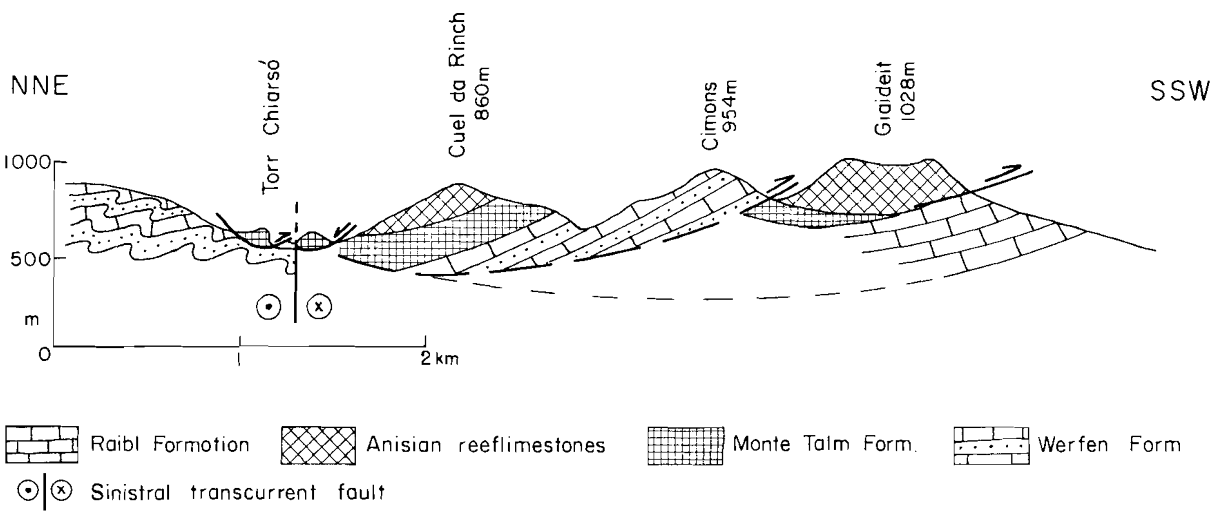

Fig.22.The Giaideit- and Cuel da Rinch-klippe structures.

c. The Cuel da Rinch klippe

Two isolated overthrust units, comparable to the Monte Spin klippe, are found at the eastside of the Torrente But, east of the latter (see tectonic map, fig.34 and fig.22).

Fig.22 shows a N-S section across these structures.

Northward dipping anisian reef limestones of the Monte Giaideit overly the Raibl Formation, forming the southern overthrust unit. Northeastward dipping Werfen and Monte Talm strata in their turn are thrust against the Monte Giaideit klippe, forming the Cuel da Rinch klippe. These two overthrust are relatively young, because they cover over a distance of about 5 km the But-Chiarso wrench fault, treated in chapter IV F. Like the Monte Spin klippe, the units of Giaideit and Cuel da Rinch also are local slides, detached from the southflank of the Monte Tersadia, north of it. They occurred in the young Cenozoic, after the phase of decollement and at the time, when the rejuvenated erosion had created quite local fields of relief energy with relatively strong stress gradients.

The klippe structures and local slides, discussed sub a, b and c are composed of permian and lower-triassic strata, up to the level of the Wengen Formation.

Moreover, all over the area of Sappada, (enclosure sheet I), slide structures occur, which are composed of more or less monolithic blocks of anisian reef limestones or ladinian Schlern Dolomite. A short survey of these slides follows in the next paragraphs (d - g).

d. The slide complex of Forni Avoltri

From a tectonic point of view the topographical depression, in which the villages Forni and Avoltri are situated, is structurally one of the most complicated features of the area under investigation.

The following tectonic lines come together at this place (fig.23):

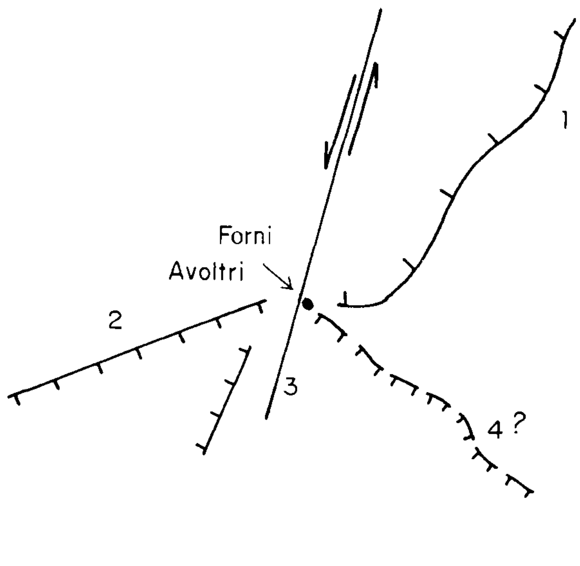

Fig.23. Structural lines, converging to Forni Avoltri.

1. The southeastern marginal fault of the Bordaglia graben (Chapter IV C a).
2. The northwestern marginal fault of the Sappada graben (Chapter IV C b).
3. The Forni Avoltri wrench fault (Chapter IV C b), which forms the boundary between both graben structures.
4. The NW-SE part of the Degano valley between Forni Avoltri and Comeglians. It is not certain whether or not this stretch of the valley represents also a tectonic line. Outcrops of the permo-triassic sediments are very scarce in this valley, but they include the sole representatives of the lower permian strata, characteristic for the south alpine facies (Kahler and Prey, 1963).

The numbers 1 -2 and 4 from fig.23 form the NE/SW - NW/SE branches of a cross, the mechanical meaning of which is discussed already in chapter IV E. A number of younger secondary units are superimposed upon this structural cross; taken together they are called the "Slide complex of Forni Avoltri". The slide complex of Forni Avoltri originated owing to the strong local field of gravitational relief energy, produced by the deep erosional depression of Forni Avoltri, where the floor of the valley is situated at 889 m above sealevel, whereas the surrounding mountains rise with steep slopes up to about 2500 m.

This Forni Avoltri slide complex exists of the following units, (see tectonic map, fig.34).

d1. T h e M o n t e T u g l i a is a unit existing of anisian reef limestones. It slid to the north over a distance of about 1 to $1\frac{1}{2}$ km; it now partly overlies the Forni Avoltri wrench fault, discussed in chapter IV C b.

d2. P i a n d i L u z z a
From Forni Avoltri to Cima di Sappada the northwestern Sappada graben fault has given rise to great local contrasts of relief energy. Along the steep slopes, originating from this fault, a "rock-glacier" of smaller blocks flowed, and perhaps partly is still flowing into the valley. At the scale of 1 : 227.000 of the tectonic map (fig.34) and 1 : 50.000 of the geologic map, only two units could be distinguished. The block, situated some hundreds of meters west from Forni Avoltri consists of anisian reef limestones, partly covered by Buchenstein strata. At the northwestern side of this block, near Pian di Luzza, some complicated structures can be studied.
After the relatively young phase of downsliding of this block a still younger movement of the Monte Chiadin and the underlying Werfen and Bellerophon Formations occurred. Fig.24 shows schematically these two subphases of the formation of this struc-

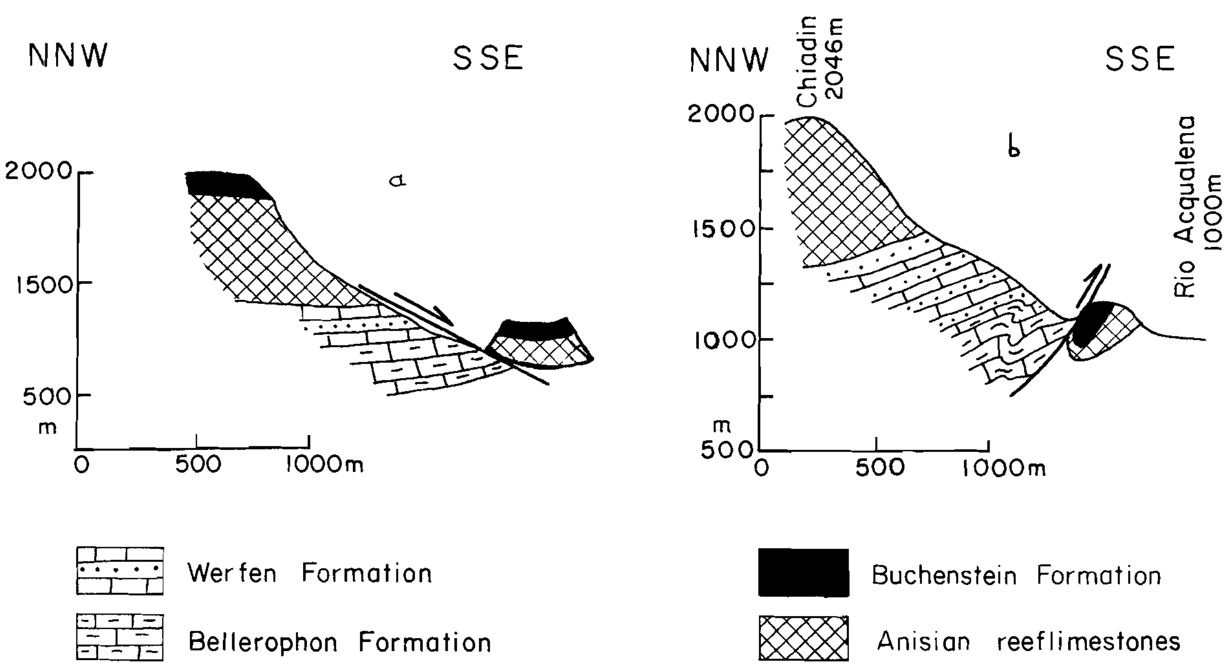

Fig.24. The origin of the structures in the Rio Bianco near Pian di Luzza.

ture.
After the downsliding of a block of about 1250 m length and 250 m width, consisting of anisian reef limestones and Buchenstein strata (fig.24a), the foot of the Monte Chiadin had still enough relief energy to be pushed against this block by a still younger phase of secondary tectogenesis. The second subphase deformed the gentle synclinal structure of the first slide into a steeply, compressive, isoclinal unit.
The fault contact between the Buchenstein strata and the Bellerophon Formation dips about 60° to 70° to the northwest. Drag folds with a displacement to the southeast testify to the southeastward direction of this upthrust; in other words, it is a local gravitational collapse structure, which tends to fill the topographical depression, formed by the erosion of the Degano river.
The strike of the synclinal axis in the Buchenstein strata is S 30° W and it dips about 20° in this direction.

d3. Cima di Sappada giant talus creep

The other major slide along the northwestern Sappada graben fault near Cima di Sappada consists mainly of greater and lesser blocks of anisian reef limestones, probably descending also from the Monte Chiadin. This talus masks the northwestern Sappada graben fault over a distance of about 1 km, and it is probably still slowly creeping towards the valley floor, as appeared during the abortive attempt in the years 1961-1966, to construct a highway through this scree unit.
Between the units of Pian di Luzza (paragraph d2) and this one many other smaller slide units occur, which are also composed of rocks, derived from the Bellerophon-, Werfen- and Monte Talm Formations. The entire northern flank of the dry valley between the pass of Cima di Sappada (at 1290 m) and Forni Avoltri (at 889 m) can best be characterized by the concept "Grosshanggleitung" of Kahler and Prey (1963).
This German term might be translated by the expression "Giant Talus Creep".

d4. Staipe di Buialecis

One kilometer northeast of Forni Avoltri a block of anisian reef limestones, about 1000 m in diameter, slid over a distance of about 100 m valleywards from the top of a gentle anticlinal structure in the Werfen- and Monte Talm Formations (fig.25).

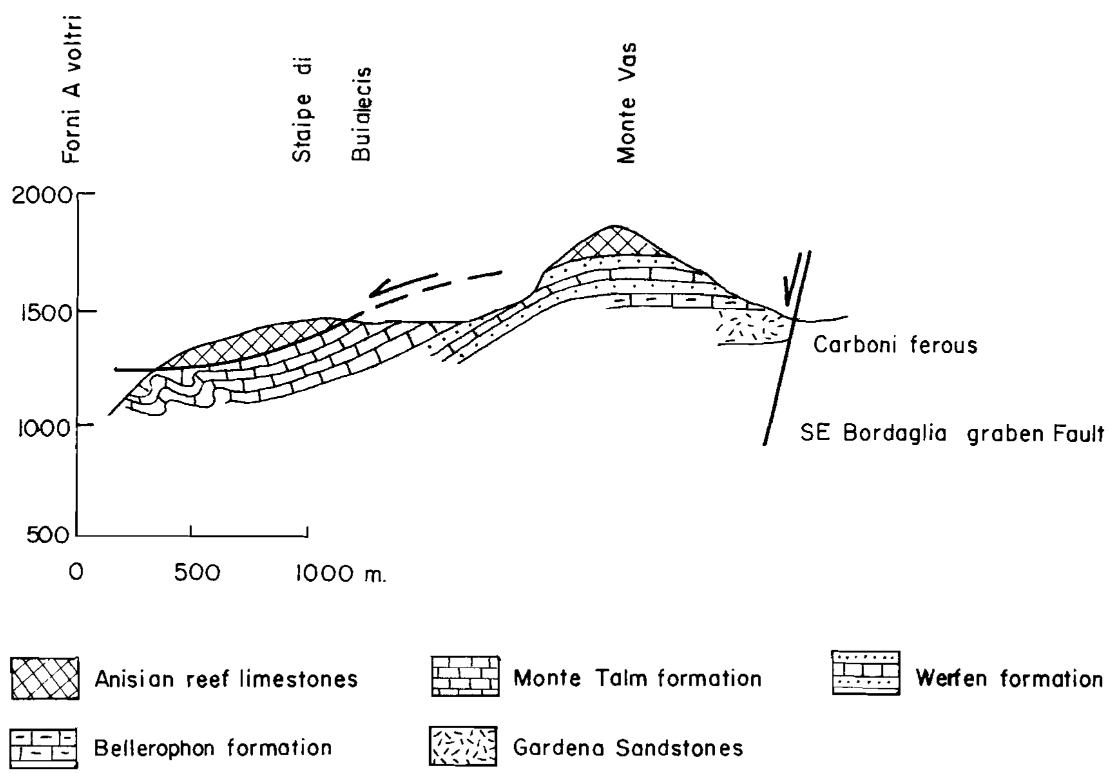

Fig.25. Staipe di Buialecis.

d5. The Monte Melescegn

About 3 km northnortheast of Forni Avoltri the Monte Melescegn slid in northwestern direction into the Bordaglia valley. The anisian reef limestones show an abnormal contact with the underlying Gardena Sandstones, which occupy the northwestern part of the Bordaglia graben.

d6. The Monte Lastroni (see section IV).

The Monte Lastroni, 5 km north of the village of Sappada, (sensu stricto), does not belong to the slide complex of Forni Avoltri, but is mentioned in relation with this group of slide blocks, because it is also a local slide in the area of this group, which originated according to the relief energy that accumulated during the late cenozoic erosion. After the general southward decollement the incision of the relief by erosion locally reversed the trajectories of the fields of relief energy to such an extent, that a rock unit of anisian reef limestones, about 800 m in diameter, slid nortward over a distance of about 200 m into the E-W valley between the Monte Lastroni and the Monte Peralba (see section IV).

e. The Monte Rigoladis (south of Sauris, see section VI).

A part of the anisian reef limestones of the Monte Bivera, south of the village of Sauris, 1500 m long and 750 m wide, slid to the north over the relatively plastic Wengen strata, which were exposed during the young cenozoic erosion. The slide unit of the Monte Rigoladis even comes into contact with the Bellerophon Formation. The Monte Rigoladis thus covers partly the outcrops of the Monte Bivera overthrust, treated in chapter IV B.

f. The Monte Tezza Seconda (also named the Monte Tezza Media, see section VI).

This unit, consisting of Schlern Dolomite and about 1500 m in diameter, slid southward until its further movement was obstructed by the Main Dolomite unit of the Monte Tezza Grande. The Monte Tezza Seconda was at first connected with the Monte Tezza Piccola, north of it, but owing to the local stress fields caused by the young erosion, the Monte Tezza Seconda slid southward, whereas the Monte Tezza Piccola descended north wards (next paragraph).

g. The Monte Tezza Piccola, the Monte Curie and the Monte Carro (around the entrance of the Val Visdende)

According to the geologic map by Selli and his collaborators (1963), the Monte Tezza Piccola consists of Schlern Dolomite; but P. Lagny, who investigated more closely the local stratigraphy and paleontology, - as geologist of the lead-zinc mine of Salafossa -, found indications for a slight emersion between the formation of the anisian reef limestones and the Schlern Dolomite (Lagny,1967). The distinction between the anisian reefs and the Schlern Dolomite on the geologic map of enclosure I is based upon Lagny's tentative observations. At the northern feet of the Monte Tezza Piccola, near the entrance of the Val Visdende, outcrops of an abnormal contact between the Schlern Dolomite and the Gardena Sandstones can be observed in exposures, formed by the activity of the lead-zinc mine.
The Gardena Sandstones form a mylonitic zone, in which drag folds are found, showing clearly a displacement to the northeast. These outcrops are a proof for the concept that the Monte Tezza Piccola block slid northeastward over its base of permo-triassic strata, exposed by erosion, towards the floor of the valley.
Fig.26 shows two sketches (fig.26a made from San Stefano di Cadore in eastern direction and fig.26b from Cima di Sappada in western direction), demonstrating that the sliding of the Monte Tezza Piccola did not occur in one movement, but in a series of movements along northwest-, north- and northeastward dipping slide planes.

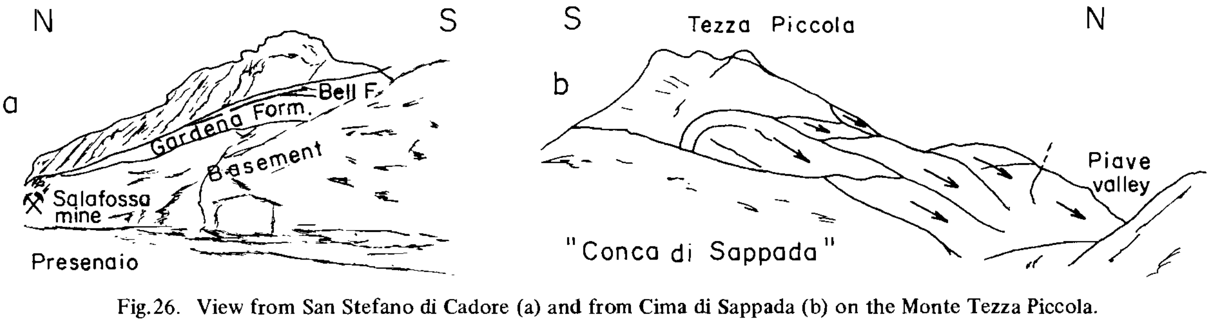

Fig.26. View from San Stefano di Cadore (a) and from Cima di Sappada (b) on the Monte Tezza Piccola.

An abnormal contact too exists at the south foot of the Monte Curie, where anisian reef limestones come into contact with the quartzphyllites of the basement complex of Cadore.
The Monte Curie slid in southeastern direction in the Piave valley between San Pietro di Cadore and Sappada.
Also in outcrops at the south foot of the Monte Carro, near the entrance of the Val Visdende into the Piave valley, some features are found which indicate a sliding of the Monte Carro towards the base of the valley. Those features occur over a distance of about 2 km upstream the Val Visdende and also over about 2 km upstream the Piave valley. The rugged topography of this mountain complex with its many erosion channels, resulted probably from the presence of crushed zones in the reef body. The Monte Carro disintegrated into three or four parts which slid downwards, some parts into a western direction (Val Visdende) and some parts into a southern direction (the Piave valley between the Salafossa mine and Sappada).

East of the Monte Tezza Piccola unit, two other smaller rock units occur, composed of anisian reef limestones; the general topographic situation suggests that these units also slid downward into the valley of the Piave near Sappada.
Fig.27 schematically illustrates the general situation.

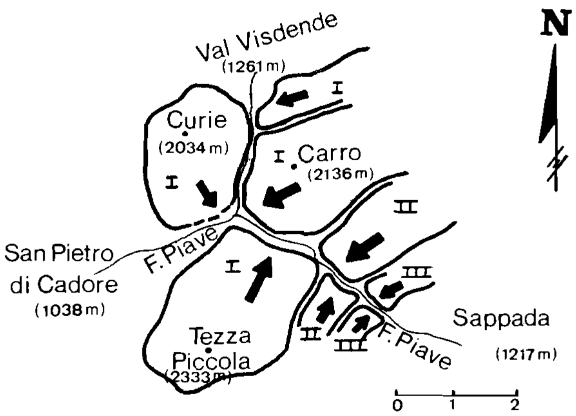

Fig.27. Slide movements around the entrance of the Val Visdende.

The cause of these movements must be a progressive erosion of the valley. During this process the older, more plastic formations (Werfen-, Bellerophon- and Gardena Formations), more and more had to bear the load of the massive reefs. At other places in the area investigated the equilibrium was restored by lateral diapirism (see for instance, p.36 the Ruvin lateral diapiric structure). In this case, however, the competent reef blocks had a tilted base, owing to the warping of the preceding tectonic phases. When the late cenozoic erosion gave them some free board in a lateral downslope direction, sliding occurred until newly encountered obstructions brought them to a halt, (such as the colliding against the neighbouring reefs, as occurred in the Piave valley, near the Salafossa mine).
This clustering temporarily forced up the waterlevel upstream. In the wide Sappada valley upstream (the "Conca di Sappada") various terraces are present.at three different levels, respectively 1280-1300 m, 1250-1275 m and 1210-1230 m (Fig.28).
These terraces are partly deltaic cones which spread in a lake.
Fig.29 shows a sketch of foreset beds in the terrace at 1275 m, north of the military barack near Cima di Sappada. Southdipping clay and silt layers alternate with layers with sand and grit. After the drainage of the lake, these lake deposits were unconformably covered by a coarsely conglomeratic layer of alluvial deposits with a thickness ranging from 1-6 m. Some terraces are partly covered by younger deltaic cones of debris, which were formed after the retreat of the water. Still younger erosion channels intersect these alluvial deposits. An E-W cross section over the Conca di Sappada and the mountains west of it is given in fig.30 a and b.
Also in the Val Visdende a lake terrace is found at 1300 m, corresponding in altitude with the highest Sappada terrace. The following succession of events of alternating incision by erosion and sliding probably occurred: (see also fig.30).
The sliding and collision of the reef blocks of the Monte Tezza Piccola, Monte Curie and Monte Carro, membered I on fig.27, around the confluence of the Val Visdende and the Valley of the Piave, forced up the water, up to a maximum level of 1300 m (both in the Val Visdende and in the Conca di Sappada).
During an interval of erosion the obstruction was removed and these lakes disappeared.
Thereafter the sliding of the blocks II on fig.27 caused a new barrier in the Piave valley and in the Conca di Sappada a second lake came into existence. During an interval of erosion also this lake disappeared. The phenomenon was repeated for the third time, when the valleywards sliding of the blocks III on fig.27 occurred. This latest subphase of sliding again forced up the water to the level of the terrace at 1225 m, This succession of events seems to be the most likely. A reversed succession, however, could also be a possibility.

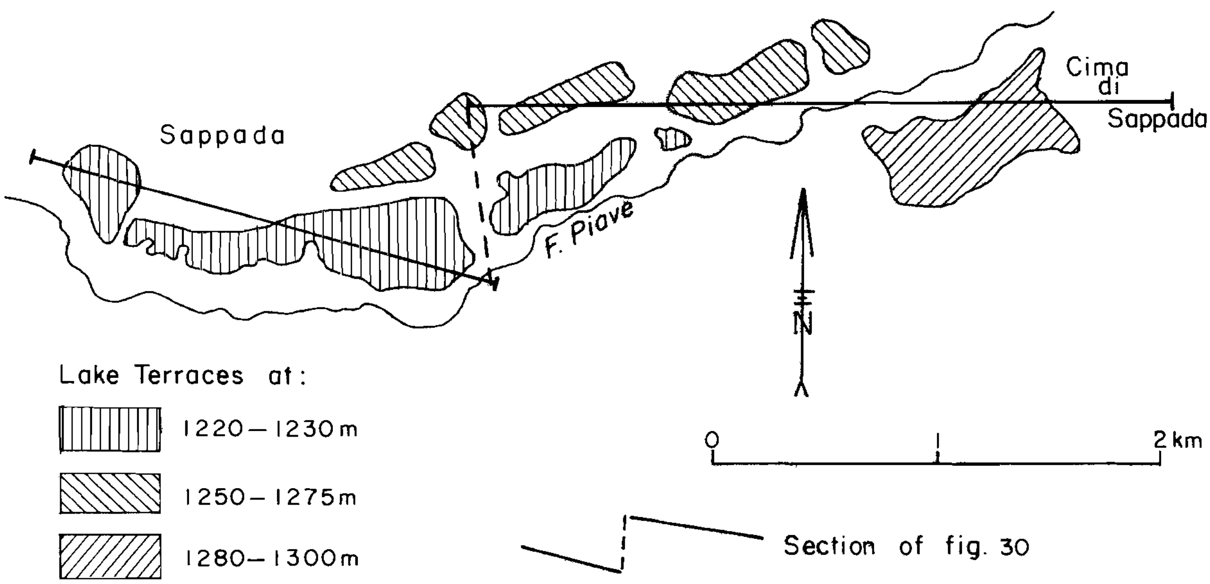

Fig.28. Lake terraces in the "Conca di Sappada".

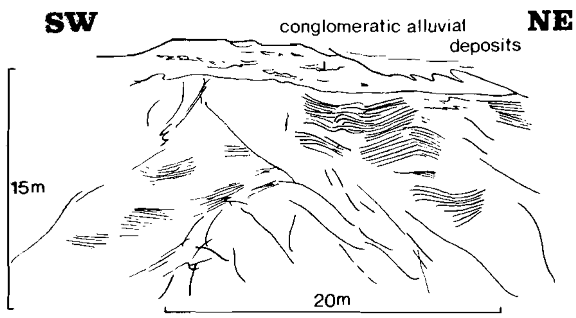

Fig.29. Sketch of foreset beds in the lake terrace at 1275 m in the "Conca di Sappada".

All these slide phenomena are the youngest very localized manifestations of gravity tectonics. They occurred during the Plio-Pleistocene. It is questionable to what extent glaciers may have played a part during the damming up of the water in the Val Visdende and the Conca di Sappada. Typical U-shaped valleys are not present. If they were formed their glacial character was destroyed by the valleywards sliding of the blocks. Glacial morainic deposits have not been observed, neither upstream (in the Val Visdende and the Conca di Sappada), nor in the region farther downstream (near San Pietro and San Stefano di Cadore).
Consequently, the hypothesis can be dismissed that glaciers obstructed the drainage pattern and caused the forcing up of lakes upstream.

h. The Colle Spina (in the higher western part of the Val Visdende, see section VI of enclosure III)

A huge block of a paleozoic reef, 2500 m long and 500 m wide, according to the geologic map by Selli (1963) of gotlandian age, slid southward from the higher crest of the Central Carnian Alps, into the western part of the Val Visdende. This block slide covers the fault contact between the Gardena Sandstones and the metamorphic basement complex over a distance of about 2½ km.

J. GRAVITATIONAL SPREADING OF MOUNTAIN CRESTS ("GEBIRGSZERREISUNG")

Besides the valleywards sliding of greater units of anisian reef limestones, respectively Schlern Dolomite, as described in the preceding paragraphs, another feature of gravitational disintegration of massive reef units is represented by a phenomenon, called "Gebirgszerreisung" in the German literature. By this process a mountain crest of competent limestones and/or dolomites, carved into topographical isolation by the erosion, tends of disintegrate into smaller blocks, which start sliding downslope toward the valley floor (fig.31).
Such a phenomenon can be observed, for instance, at the northwestern mountain crest of the Val Visdende region, the Crode dei Longarin (fig.32).
Similar features are found at the eastside of the

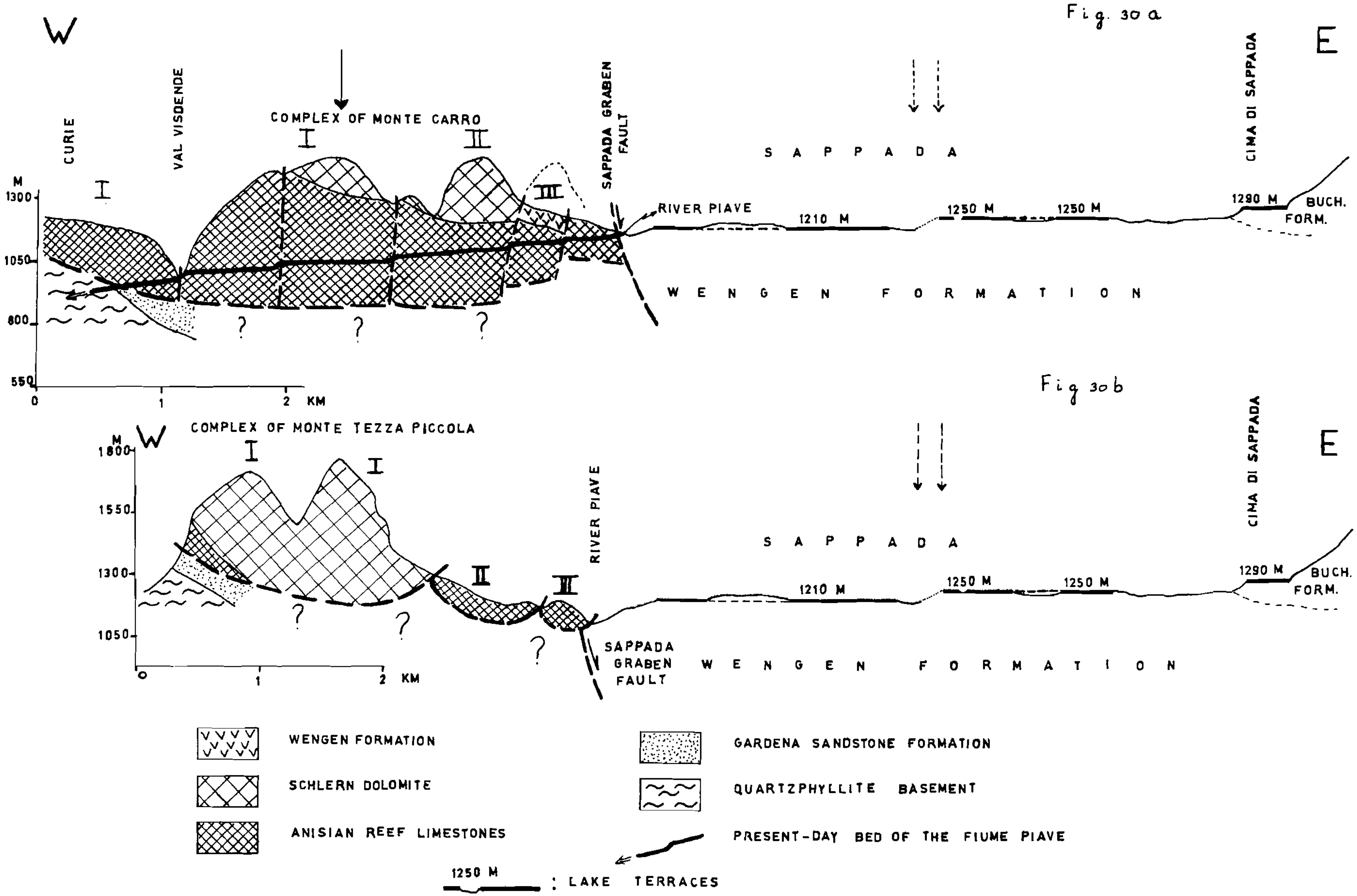

Fig.30. E-W sections across the "Conca di Sappada" and the mountains west of it. Fig.30a is constructed north of the Piave valley, (across the complex of the Monte Carro), fig.30b south of the Piave valley, (across the complex of the Monte Tezza Piccola).

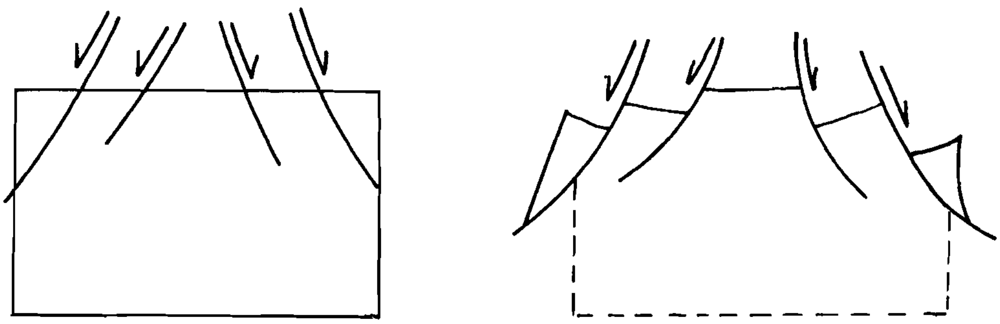

Fig.31. Schematic illustration of the gravitational spreading of mountain crests.

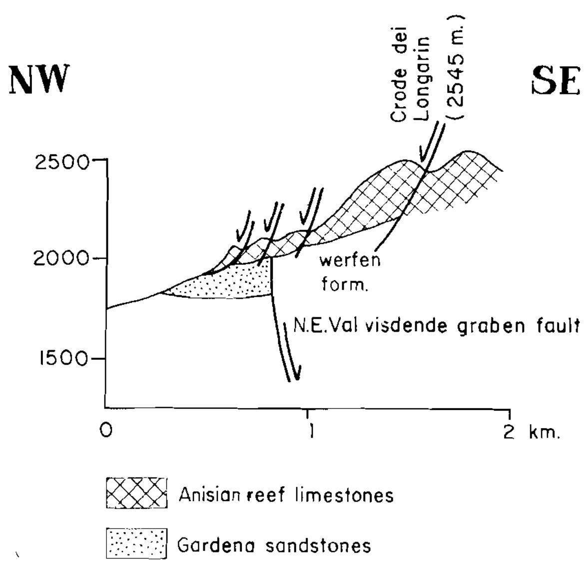

Fig.32. Gravitational spreading of the northwestern crest of the Crode dei Longarin.

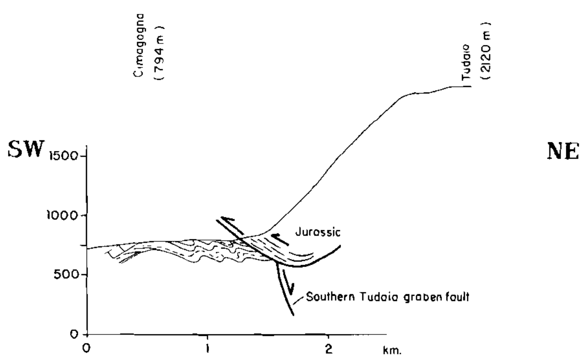

Fig.33. Advancing blocks of Jurassic limestones, narrowing the floor of the Piave valley near Cimagogna.

Monte Chiadin, northeast of Cima di Sappada.

Also at the westside of the Monte Tudaio region in the valley of the Fiume Piave the process of "Gebirgszerreisung" can be studied (fig.33). Abnormal contacts between the jurassic limestones of the Monte Tudaio Formation, which forms the mountain crest, and the folded Werfen strata exposed by the erosion near the floor of the valley, are also an indication for "Gebirgszerreisung". The valley of the Fiume Piave is gradually or intermittantly narrowed by the advancing blocks of jurassic limestone from the crest. The erosion thus has to cope not only with the supply of detrital matter by mountain side creep of decomposed rock strata, but also with blocks of greater size, derived from the crest by "Gebirgszerreisung".

CHAPTER V

THE STRUCTURAL EVOLUTION

After the description and analysis of the various regional and local structural units a reasonable synthesis can be given on the succession of tectonic events during the alpine orogenesis.
The structural history of the area under discussion (illustrated by fig.34) may form also a basis for the interpretation of the tectonic development of the surrounding areas of the Carnian Alps and the Cadorian Dolomites.
Before treating the successive orogenic phases we will explain some essential differences in the tectonic style existing between the areas of the enclosures I and II.

The sections I and II of enclosure III are constructed across the area of enclosure II. They show a tectonic style which is totally different from the sections III-VIII constructed across the area of enclosure I. For convenience, the latter will be called the "Sappada-Sauris area" and the area of enclosure II the "Tolmezzo area".
In both areas the sections show great southward overthrust structures, (Sauris-, Monte Bivera-, Ovaro-, Vinaio-, Villa Santina- and Verzegnis-overthrust units).
However, in the sections III-VIII across the Sappada-Sauris area the overthrust units are composed of relatively older formations (Bellerophon- and Werfen Formations) in comparison to the formations that built up the overthrust units of the sections I and II in the Tolmezzo area (Schlern Dolomite, Raibl Formation and Main Dolomite). There is one exception to this rule, namely the Ovaro overthrust unit which extends over a W-E distance of 25 km from Sauris to Arta.
The Vinaio-, Villa Santina- and Verzegnis-overthrust units are composed near the surface of the younger, relatively massive, triassic formations and their deeper parts consist probably of the older, more plastic, Werfen- and Bellerophon-Formations.
The Ovaro-, Sauris- and Monte Bivera-overthrust units are formed near the surface by the relatively plastic Werfen- and Bellerophon-Formations, whereas in their deeper parts probably the quartz phyllite-basement and partly the Gardena Sandstone Formation are involved. The reason for these differences in tectonic behaviour of both areas of enclosure I (Sappada-Sauris) and enclosure II (Tolmezzo) can be found in the mechanical properties and the relative depth of the basement complex underneath the alpine sedimentary column.

The quartzphyllite basement occurring in the Central Dolomite Region and in Cadore can be traced eastward to:
a. the westernmost part of the Val Visdende Graben and the quartzphyllite region of San Stefano di Cadore.
b. the easternmost part of this region is the Pb-Zn mine of the Salafossa, 2 km east of San Pietro di Cadore, where outcrops occur in the quartzphyllite basement.
c. the Col Rementera, SE of the Tudaio-Brentoni region (encl.I).

The basement complex of the Carnian Alps has a quite different character. It is exposed in the W-E mountain chain that forms the main crest of the Central Carnian Alps. These paleozoic rocks have mechanically a much more rigid character than the rather plastic quartzphyllites of Cadore. The Carnian basement complex is composed apart from schists, also of rigid gneisses, and marbles of the monolithic devonian reef-blocks (Monte Peralba 2693 m. Monte Avanza 2489 m. Monte Coglians 2780 m).
The quartzphyllites are one of the more plastic formations of the entire area of study.
Arguments for this thesis are:
a. the south- and southeast-ward overturned folds situated along the southern margins of the Tudaio region, between Laggio di Cadore and the Col Rementera (see also section VIII and fig.16), in the cores of which highly tectonized quartzphyllites are exposed.
b. another argument for the plasticity of the quartzphyllites bears an actualistic character. These regions, formed by exposures of quartzphyllites, were always badly hit by local landslides during periods of heavy raining in the last three years. Also in the parts of the Carnian basement, farther to the east, which are built up of phyllitic schists, local landslides are common, for instance between Forni Avoltri and Comeglians; but these landslides cannot be compared, in their extent with those, occurring in the Piave valley in the

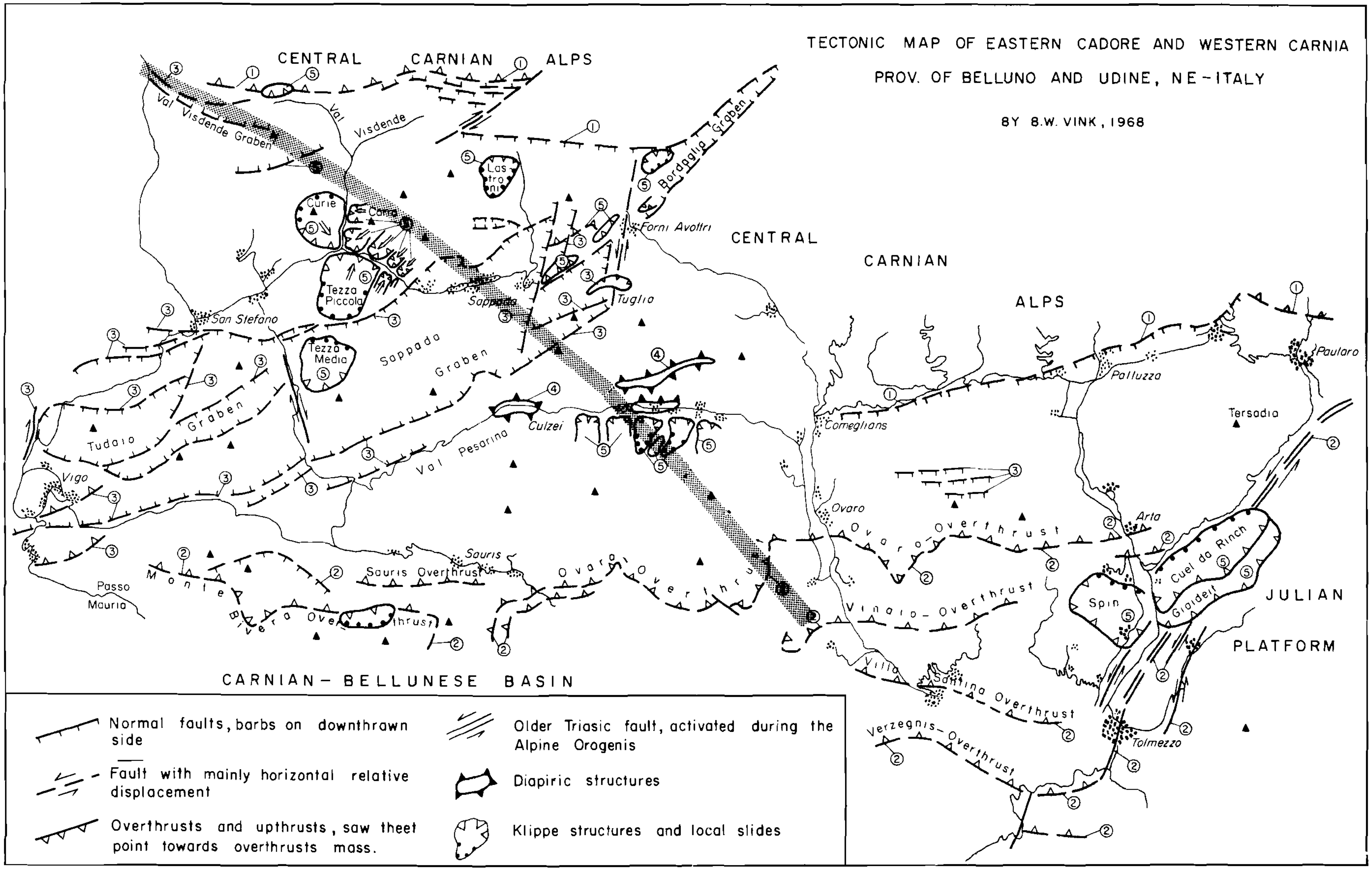

Fig.34. Tectonic map of the area of study. The NW-SE zone, indicated with dots, represents the supposed transition of the quartzphyllite basement in Cadore into the Carnian basement in Carnia.

surroundings of San Pietro and San Stefano di Cadore. These villages are built upon the quartzphyllites.
During the catastrophal rains of 1966, for instance, an evacuation was envisaged of the village Costalta, situated some hundreds of meters higher than San Pietro, on the northern slope of the Piave valley. It is still feared that during one of the next periods of heavy raining the whole village will slide into the Piave valley (personal communication by G. Carniel, secretary of the municipality of San Pietro di Cadore, in 1967).

The presumable zone of transition from the relatively plastic quartzphyllites into the more rigid Carnian basement is also indicated on fig.34. This boundary probably has a NW-SE direction: the westernmost part of the Val Visdende graben is a place where this boundary can be observed in the fieldexposures at 1500 m above sealevel. Near the Salafossa Mine, 2 km E of San Pietro di Cadore, outcrops in the quartzphyllites occur at 1020 m above sealevel. On the Col Rementera a small outcrop from quartzphyllites reaches a level of 1800 m above sea. The sections III and IV indicate that near Sauris the basement consists of quartzphyllites, because according to the construction of those sections the basal plane of the Ovaro-overthrust extends northward into the basement rocks.

The Raibl Formation and the Main Dolomite, south and southwest from Tolmezzo, occur at an altitude of 400-500 m above sealevel. Taking into account the thickness of the sedimentary column underneath these formations one comes to the conclusion that in the Tolmezzo Area the basement is situated much deeper than in the Sappada-Sauris Area.
Fig.35 shows a schematical W-E section across the basement extending from Lorenzago di Cadore (902 m) and the Col Rementera (1800 m), where outcrops of quartzphyllites are found, to the region of Villa Santina - Tolmezzo, where the Carnian basement is supposed to be situated at depths of $3\frac{1}{2}$-4 km beneath sealevel.
The differences in tectonic style due to the differences in plastic behaviour between the basement in the Sappada-Sauris Area and the Tolmezzo Area are also illustrated by fig.37 a and b, which give an outline of the tectonics of the SE Alps, from the Gailtal Alps (c.q. Lienzer Dolomites) in the north, to the Venetian-Adriatic depression in the south.
The W-E section across the basement (fig.35) shows the rapid transition from the quartzphyllite basement of the Sappada-Sauris Area into the Carnian basement of the Tolmezzo Area. It is possible that a basement fault is present, hidden at the surface by the younger tectonic movements of the sedimentary epiderm, which caused the Ovaro-overthrust: the latter is not interrupted by a contingent older basement fault underneath. How much older such a basement fault might be, however, cannot be determined. Faulting, transcurrent movements and rotation of basement blocks have also been established for the basement complex of the Vicentinian Alps (de Boer,1963).

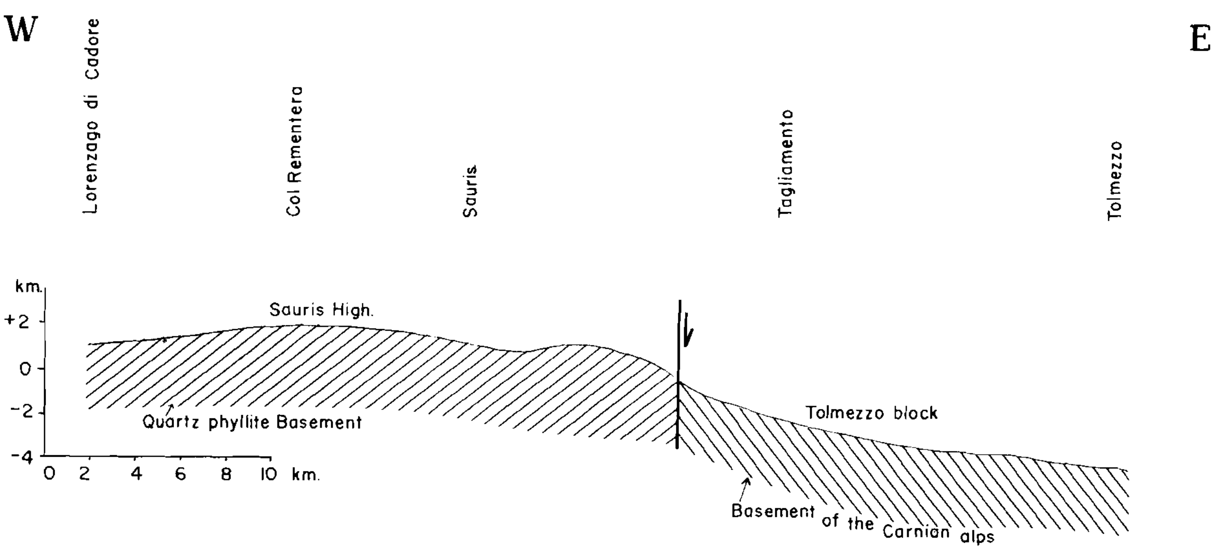

Fig.35. E-W section across the basement complex (Lorenzago-Sauris-Tolmezzo).

Fig.36 is a schematical map of the area of study with contour lines on the top of the crystalline basement, thus giving also the position of the unconformity between the basement complex and the Gardena Sandstone Formation, above or beneath sealevel.
This map is based upon a relatively small number of direct observations. Direct data are the boundaries between the basement and the Gardena Sandstones along the northern margins of the area of study, which boundaries are treated in chapter IV A. Also direct data are the occurrence of quartzphyllites near the Salafossa Mine and on the Col Rementera and in the surroundings of Lorenzago di Cadore, respectively 1100 m, 1800 m and 902 m above sealevel.
Besides direct observations on the outcrops of this unconformity, indirect information about its position can be gleaned too from the sections I-VIII of enclosure III. These sections have been extrapolated to the boundary between the basement complex and the Gardena Sandstones.
Consequently this map must be considered as a prognosis, merely giving some suggestions about the positions of the top of the basement complex in depth.

The general picture is the relatively high position of the basement in the Sappada-Sauris Area and its lower position in the Tolmezzo Area. Between both areas a N-S trending basement fault is probably present, such as is indicated on this map (fig.36) and on the section (fig.35). This fault is older than the Ovaro-unit discussed above.
In the relatively high quartzphyllite basement complex and in the basement complex of the relatively high Carnian Belt (the area of encl.I, the Sappada-Sauris Area), some depressions occur which are both faulted graben structures (Bordaglia-Sappada-Tudaio graben and the Val Visdende graben, see chapter IV C and IV D). These graben, however, are the result of younger tectonic phases, corresponding in age with other graben structures in the crest of the Carnian Alps, such as the Pontebba graben, described by Guicherit 1964. See also p.34, chapter IV E.
The lower position of the crystalline basement of the Tolmezzo Area cannot be explained by tensional graben formation on the crest of the tertiary Carnian geanticline. This low position of the Tolmezzo block was caused by down faulting of the southern flank of this geanticline. It can be assumed that during the uplift of the Carnian geanticline some areas in its southern flank were not only tilted southward, but also longitudinal southward sloping normal faults came into being, causing a lag in the uplift of the southern flank.

The relative altitudes to which the blocks of the crystalline basement have been elevated result from primary differentially vertical movements. Their uplift caused phenomena of gravitational spreading, called secondary tectogenesis. At first a general decollement of the sedimentary epiderm over horizons of great plasticity occurred. This general decollement cannot be established in our restricted area of study. It has been illustrated by de Jong (1967, fig.13c).
The decollement treated in chapter IV B, and called phase 2 in this thesis, is a younger phase of decollement.
The first decollement affected especially the younger formations (Cretaceous and Jurassic), which now are situated south of the area of study. But also the permo-triassic formations slid somewhat southward during this first decollement. The only indication in our area of study for this first phase of decollement is the mega-breccia in the Bordaglia-graben (see p.28). This breccia probably originated by frictional movements between the basement complex and the Permian during the initial decollement. It subsided into the Bordaglia graben during a later phase of orogenesis.

During the further uplift of the Carnian geanticline the tilted southern flank of basement rocks broke into blocks in regions where these basement rocks are relatively plastic. The blocks are separated by step faults. On fig.37b four of such step faults in the relatively plastic basement complex of quartzphyllites are indicated, and only one north of Sappada, in the more rigid Carnian basement. Also on fig.37 a across the Tolmezzo area, only one step fault occurs. This type of step fault in the Carnian basement is discussed in chapter IV A on the contacts between the basement complex and the Gardena Sandstones. See especially fig.5g.
In our area of study these step faults are the oldest tectonic phenomena of the alpine cycle of orogenesis. For this reason they are called phase 1 in this thesis.

The relief energy created by this stepfaulting has given a renewed impetus for decollement. This new phase of decollement is called in this thesis phase 2. In the Tolmezzo Area this phase 2 can be divided in some successive subphases: the oldest one (subphase 2a) caused the Verzegnis-overthrust, the next one (subphase 2b) the Villa Santina overthrust, then (during subphase 2c) the Vinaio overthrust came into being; finally (during subphase 2d) the Ovaro overthrust terminated this retrogressive sequence of imbrications. During subphase 2d the decollement af-

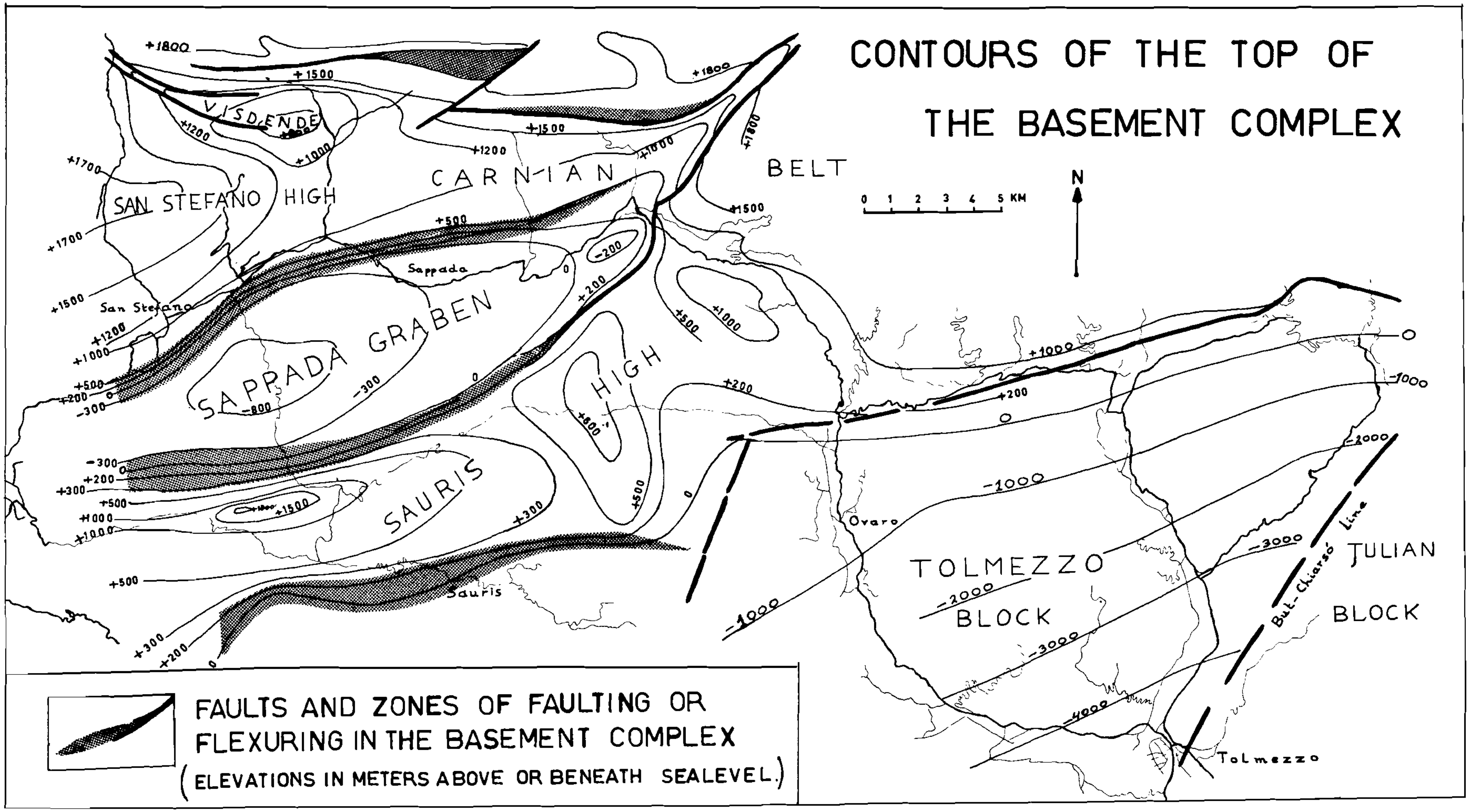
CONTOURS OF THE TOP OF THE BASEMENT COMPLEX
VISDENDE
SAN STEFANO HIGH
CARNIAN
BELT
SAPPADA GRABEN
HIGH
SAURIS
TOLMEZZO
BLOCK
JULIAN
BLOCK
But-Chiarsò Line
San Stefano
Sappada
Sauris
Ovaro
Tolmezzo
0 1 2 3 4 5 KM
N
FAULTS AND ZONES OF FAULTING OR FLEXURING IN THE BASEMENT COMPLEX
(ELEVATIONS IN METERS ABOVE OR BENEATH SEALEVEL.)

Fig.36.

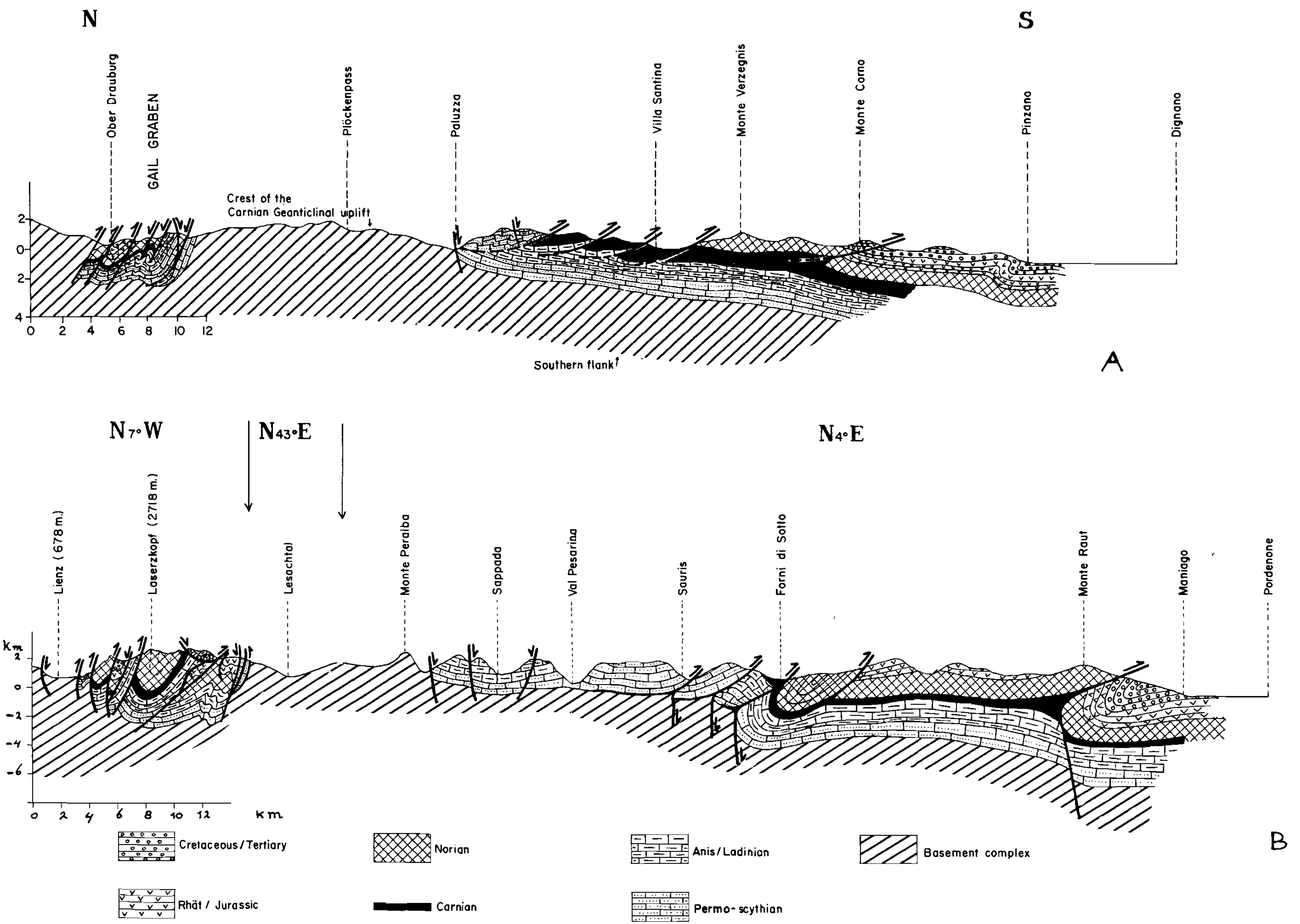

Fig.37. Two sections across the Southern Alps.
Fig.37a across the Gail Graben (Austria), the Central Carnian Alps and the Tolmezzo Area to the Venetian-Adriatic depression.
Fig.37b across the Lienz Dolomites (Austria), the Central Carnian Alps, and the Sappada-Sauris Area to the Venetian-Adriatic depression.

fected also the top part of the quartzphyllitic basement of the Sappada-Sauris Area. The Ovaro overthrust unit can be traced westward to Sauris. The Monte Bivera- and Sauris overthrusts occurred probably simultaneously.

The decollements of phase 2 were much more intensive in the Tolmezzo Area than in the Sappada-Sauris Area - one can speak of an imbricate structure at a rather large scale -. This can be explained by the relatively greater depth of the basement in the Tolmezzo Area, which caused stronger stress gradients of the potential energy field in the southern flank of the Tolmezzo section of the Carnian geanticline than in the Sappada-Sauris section. Each impulse of primary uplift of the Carnian geanticline caused a new subphase of secondary gravitational reactions, namely decollement of sedimentary units in the Tolmezzo Area. In the Sappada-Sauris Area it was apparently only after subphase 2c (which caused the Vinaio overthrust in the Tolmezzo Area) that the slope of the southern flank of the Carnian geanticline was great enough to cause the Ovaro-Sauris-Monte Bivera-overthrust units.

It can be said that the relatively higher- and lower positions of the crystalline basement resulted in first instance from the primary tectogenesis (differential uplift). After the first arching up of the Carnian geanticline the secondary tectogenetic reactions had the character of a decollement of the higher levels of the alpine epiderm of sediments. During further stages of the primary tectogenesis the Carnian geanticline was dissected by longitudinal step faults (phase 1). This induced a second phase of secondary tectogenesis, namely the decollement of phase 2, which was more active in the Tolmezzo Area than in the Sappada-Sauris Area. This phase 2 can be divided into four subphases in the Tolmezzo Area, the youngest one causing the Ovaro unit. This unit extends westward to the Sappada-Sauris Area, where it is the major downslide of the sedimentary skin, together with the more local Sauris- and Monte Bivera-overthrust units.

It appears from the previous paragraphs - and it is important to mention this with a special stress - that the tectonic phases treated so far, occurred more or less simultaneously. The primary tectogenetic geanticlinal rise caused almost immediately the secondary tectogenetic reactions, mentioned above. But also after the secondary tectogenesis of the phases 1 and 2 the uplift of the Carnian geanticline continued.

Phase 3 was the direct consequence of the continuing uplift of the Carnian geanticline. This phase 3 caused the tension phenomena in the higher parts of the Carnian geanticline, such as the Val Visdende graben structure and the Bordaglia-Sappada-Tudaio graben structures (see p.27). Their mechanical meaning has been treated already in chapter IV E.

These graben structures are indicated also on the contour map of the basement (fig.36). These graben are characterized by relatively lower wedges of the crystalline basement amidst higher situated parts. This internal differentiation into highs and lows of the Sappada-Sauris Area is the result of phase 3. Thus the relatively lower position of the crystalline basement in the graben structures on the crest of the Carnian geanticline came into being in a later phase of orogenic evolution than did the relatively low position of the Tolmezzo block.

The Bordaglia-Sappada-Tudaio graben and the Val Visdende graben are phenomena of tension in the higher elevated parts of the Carnian Alps and they can be compared with the longitudinal gräben system on the crest of the Carnian geanticline, farther east, between Paularo and Tarvisio, described by Guicherit (1964). These graben structures are younger than phase 2 of the southward decollement, because they cut partly across the rear parts of this cover of sediments, and partly extend downward into the basement complex, which was initially a more or less southward tilted slope for the downsliding sedimentary cover (decollement).

The Carnian Alps are bordered at their northern side by the graben system of the Drau zone, the Lienz Dolomites and the Gailtal Alps, described by van Bemmelen, 1966 (see table 11 on p.440 for the structural history of this part of the SE Alps).

The Carnian Alps are bounded at their western end by the line San Candido - San Stefano di Cadore - Vigo di Cadore. This line is the boundary with the Italian Dolomites, farther west.

In the area studied by Guicherit (1964) the graben structures are more or less parallel to the crest of the Carnian geanticline, but the graben structures here under discussion (Val Visdende graben and Bordaglia-Sappada-Tudaio graben) cut somewhat diagonally across the crest of this geanticline.

These aberrant trends might be related to the westward transition of the Carnian basement into the basement of the Dolomites. The Italian Dolomites are a major structural unit in the southern flank of the alpine geanticline, occupying the corner formed by the echelon-displacement of the eastern part of the Peri-Adriatic line (Pusteria-Gail-Drau-fault system) with respect to its western part (Tonale-Insubric fault system). Both parts are united by the NE-SW trending Iudicaria fault.

This Dolomite block is surrounded by faults, as has been described by Engelen (1963, chapter V, pp.31-38). The Pusteria fault along the northern margin of the Dolomite block, forms, together with its antithetic faults, also a graben (described by Agterberg, 1961), which trends WNW-ESE. Between San Candido and Sillian this graben links on to the major, W-E trending graben system of the Drau zone, but a minor graben system branches off in SE direction, forming the graben near Candide, which is filled with Gardena Sandstones (Agterberg, 1961, p.67-69 and fig.50), and those of the Val Visdende described in chapter IV D of this work.

The Val Visdende graben forms a structural link between the graben system on the crest of the Carnian Alps and the one that surrounds the Dolomite block at its NE side. The northern border fault of the Val Visdende graben curves from a NW-SE direction eastward into a more W-E trend (north of the Crode dei Longarin).

The Bordaglia-Sappada-Tudaio graben intersects the Val Visdende graben at a sharp angle of about 70 degrees, trending (E)NE-(W)SW. This graben system forms a northeastward extension of the Val Sugana lineament bordering the Dolomite block at its southern side. The western part of this Val Sugana lineament is formed by the well-known Sugana fault and its adjacent Borgo graben (see Agterberg, 1961, p.94 and fig.83). The eastern part of it, between Fiera di Primero and Vigo di Cadore, has not yet been reinterpreted in the light of van Bemmelen's concept on the structural evolution of the Southern Alps (1966). But at Vigo di Cadore the Val Sugana lineament which forms the southern boundary of the Dolomite unit, links on to the Bordaglia-Sappada-Tudaio graben, which has the same direction, cutting obliquely across the crest of the Carnian geanticline. The transition of the Dolomite unit into the unit of the Carnian Alps lies in the Cadore region where the northeastern and southwestern boundaries of the Dolomite unit converge, forming the Val Visdende and the Bordaglia-Sappada-Tudaio graben structures, which cut diagonally across the W-E trending Carnian unit.

These graben structures are tensional features the formation of which began during the final stages of phase 2 of the southward decollement, and continued somewhat during the later stages of the Carnian uplift. The graben structures of phase 3 and the southward decollement of phase 2 are thus not directly related, but indirectly: both phenomena are the result of secondary tectonic processes occurring in relation to one and the same tectonic process, namely the uplift of the Carnian geanticline and the tilting of the basement complex in its southern flank towards the Venetian-Adriatic depression in the south.

Thus, the phases 1, 2 and 3, causing the structural units of greater extent, are directly related to the primary tectonic uplift of the Eastern Alps in general, and - more specially - to the Carnian geanticline in the southern flank of the Alps.

A number of local tectonic phenomena occurred during the vigorous erosion and denudation resulting from this uplift and its related secondary tectogenetic processes. These later and more local effects of gravity tectonics are superimposed on the structural situation, acquired during the phases 1, 2 and 3.

The diapiric features in the Val Pesarina discussed in chapter IV G are classified as phase 4, whereas phenomena of klippe structures and local slides described in chapter IV H, are the latest (phase 5). The more local phenomena of gravity tectonics occur all over the area of study.

It is reasonable that a strict time relation between the phases 4 and 5 cannot be found. Even phase 5 can be divided into sequences of local sliding, such as those which caused the ponding up of the Sappada-lakes. But a time relation between such local sequences of sliding cannot be established, because these structures have no mutual relation. Only with regard to the slide structures around the entrance of the Val Visdende can a speculative picture of the succession of events be given. These slide structures probably are postglacial phenomena. Assuming that also this area in the Alps has been covered by glaciers the slide movements of the Monte Tezza Piccola, Monte Carro and Monte Curie occurred during the retreat of the ice. In this region neither a typical morphology nor the presence of morainic deposits has been established. If there has ever been a glacial morphology (U-valley and the like) this morphology has been subsequently deleted. It was destroyed by the sliding movements of the reef units of the Monte Tezza Piccola, Monte Curie and Monte Carro, which originally formed the flanks of the U-valleys and then closed them, obstructing the drainage pattern.

Finally a remark on fig.37 a and b, which illustrate the general tectonic structure of this part of the SE Alps. The section of fig.37a is constructed across the Drau zone near Oberdrauburg, the Carnian uplift, the Tolmezzo area, extending southwards to Dignano in the Friulian lowland (the Venetian-Adriatic depression). The section of fig.37b is constructed across the Drau sone near Lienz, the Carnian uplift, and the Sappada-Sauris area, extending southwards to Pordenone in the same pre-alpine lowland.

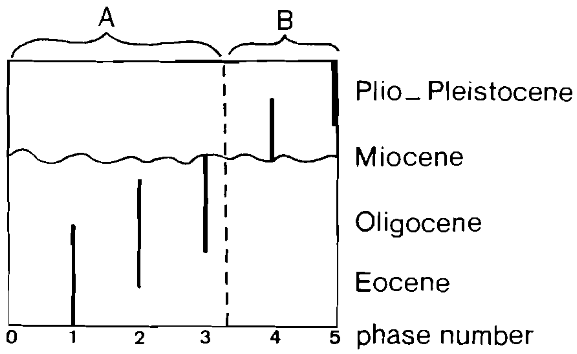

Fig.38. Speculative time relation between the phases 1-5.

These sections clearly show the effects of the general tectonic phases, called phase 1, 2 and 3: the step faults in the basement (phase 1), the decollement of the sedimentary epiderm (phase 2) and the tension phenomena resulting in graben structures in the crest of the Carnian geanticline (phase 3). A speculative time relation between the phases 1-5 is given in fig.38. Fig.39 (after de Jong, 1967, fig.13c) gives three genetical sections which illustrate schematically the tectonic evolution of this part of the Southern Alps.

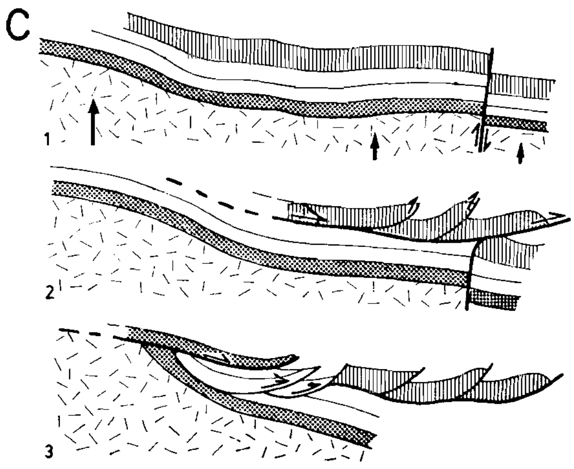

Fig.39. (after de Jong,1967), genetic sections across the southern flank of the Carnian geanticline.

CHAPTER VI

NOTES ON THE GEOCHEMISTRY OF LEAD

I. ANOMALIES IN THE GARDENA SANDSTONES

In the early sixties the presence of Pb-Zn ores was detected in the Val Piave, near its bifurcation into the Val Visdende. The ore body occurs in the Schlern Dolomite at the base of the Monte Tezza Piccola reef. The occurrence is nowadays worked by the Societá Mineraria e Metallurgica di Pertusola in a mine, called Salafossa. Some data on this mine are given in the next section.
Here some results are discussed of a small scale geochemical investigation of the lead content of the anisian and ladinian reef bodies in this area. Samples were also taken from the total succession of sediments, from the Gardena Sandstones up to the jurassic Monte Tudaio Formation. From each formation an average of three samples was taken, at different places in the area of study. The sampling occurred in such a way that from various places of one exposure about ten smaller samples were taken, and the mean lead content of these ten samples was taken as the average content of the occurrence.

Analytical Procedure:
The Pb-content of finely ground powders of sediments was measured with a Philips PW 1540 X-ray fluorescence spectrometer, by comparison with artificial standard samples on a SiO_2- and a $CaCO_3$-bulk composition, containing small amounts of lead. The essay values of the standard series were 0, 10, 20, 40, 60, 80, 100, 500, 1000 and 10.000 ppm Pb.
The samples from the field were compared with these standard series, sandstones with the Pb in SiO_2, and limestones with those of Pb in $CaCO_3$.
In the case of dolomite samples (from the upper member of the Bellerophon Formation and from the Schlern Dolomite) a correction was applied for the $MgCO_3$ in the bulk composition.
According to Wedepohl (1956) the mean value of lead as trace element in sandstones is 7-9 ppm, and in limestones and dolomites 10-12 ppm. Most of the results of these measurements of the lead content in sediments were negative: almost all samples had lead content that did not rise above the normal background value. For this reason too it was not necessary to make a special standard series of lead in dolomite, to obtain the correct lead content of the dolomite samples: a comparison with standard series of lead in $CaCO_3$ matrix, although incorrect, showed that in the dolomite samples no anomalies were present.
Only two samples showed anomalous Pb-values of 40-50 ppm. Both samples came from the Gardena Sandstone Formation. This enabled us to carry out a sampling programm of the Gardena Sandstones during the next summer of fieldwork, sampling and measuring in the manner described above. The results of the investigations are given in Table I.

TABLE I

number of sample	location of sample	lead content (ppm)
67–1	sources of River Piave	43 ± 5
67–2	Forcella di Lavardet	20 ± 4
67–3	Pierabeck	24 ± 4
67–4a	1 km E of Ravascletto	36 ± 5
67–4b	”	19 ± 3
67–4c	”	29 ± 5
67–4d	”	14 ± 2
67–5	Cercivento	50 ± 5
67–5a	”	23 ± 3
67–6	Ligosullo	47 ± 6
67–7	Villamezzo	40 ± 5
67–8	Povolaro	20 ± 4
67–9	NE of Forni Avoltri	15 ± 3
67–10	Temerat	42 ± 5
67–10a	”	32 ± 5
67–11	SW of Rigolato	34 ± 4
67–12	Prato Carnico	38 ± 5
67–13	Col della Varda	30 ± 4
67–14	Costa Bruna	15 ± 3
67–15	Rio Dolmi	40 ± 5
67–16	NW end of Val Visdende Graben	60 ± 7
67–17	between Pelos and Lorenzago	68 ± 8
67–18	S of San Stefano di Cadore	64 ± 8
N15	Col Rementera	47 ± 6
N26	W of Pian di Casa	47 ± 6

Table I. Lead contents of samples of the Gardena Sandstone Formation. For location of samples see also fig.40.

Almost all Gardena Sandstones appear to contain anomalously high Pb-values, from 20-70 ppm. In two occurrences, one SE of Forni Avoltri and one near Ravascletto, the sampling occurred systematically for some layers of sandstones. Each layer showed an anomalously high lead content, which indicates a rather uniform distribution of the lead through out this sandstone formation.
Fig.40 gives the location of the sampling points of these sandstones.

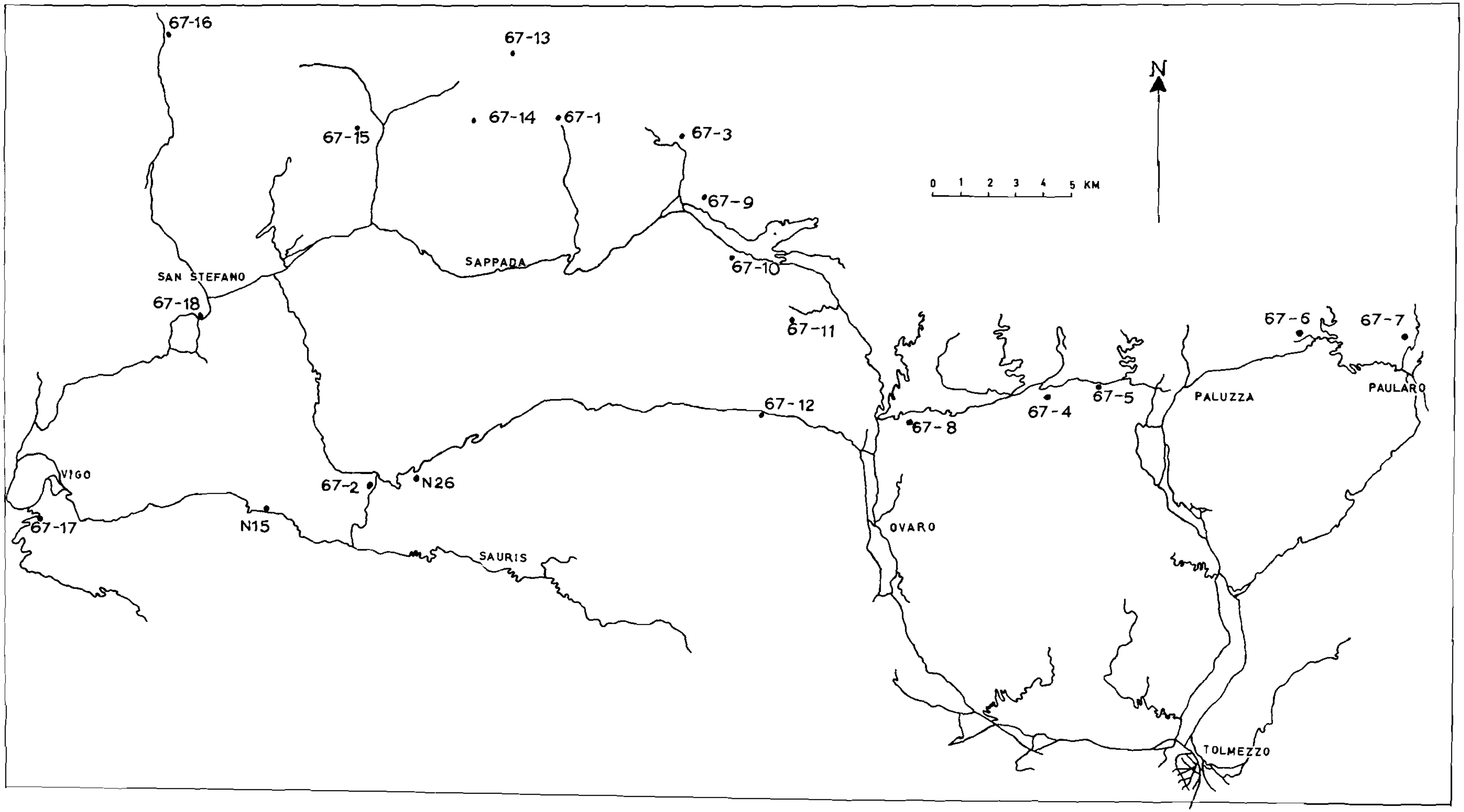

Fig.40. Sampling points of Gardena Sandstones in the area of study.

Since all other formations from the permian Bellerophon Formation up to the jurassic Monte Tudaio Formation, did not show any anomalous Pb values, the anomalies of the Gardena Formation have no geochemical relation to the lead-zinc concentration in the ore body of the Salafossa Mine found in the Schlern Dolomite. The metallogenic concentration in the Gardena sandstones must have its own geochemical history; a secondary redistribution and local concentration of the lead content of the Gardena Sandstones during the growth of the ladinian Schlern Dolomite reefs seems highly improbable, as in the interjacent Bellerophon-, Werfen- and anisian-formations no anomalous Pb values are found.

Little is yet known about the process of local concentration into an ore-body. On the other hand, something can be said on the cause of the lead anomalies of the Gardena Sandstones.

In the Permian of the Southern Alps various lead-zinc mines occur. Maucher (1959) is of the opinion that the origin of these geochemical culminations of Pb-Zn is related to the volcanism of the Bolzano area, well known for its ignimbritic volcanism, the so called Bolzano-quartz porphyries. The syngenetic ores originated either by the exhalative and/or hydrothermal activity of this volcanism, or by redistribution of the metal content of the effusive and cataclastic volcanic rocks on weathering. Mostler (1966) found conglomerates of porphyries with Pb-Zn ores in the Tregiovo-series, intercalated between the porphyries and the Gardena Formation. In the carbonatic and marly strata of this Tregiovo series there are Pb-Zn ores of clearly synsedimentary character (Mostler, 1966). In this case the ore minerals are most probably derived from the porphyries, by means of their weathering and chemical lixiviation.

In the same area lead- and zinc minerals have been observed in the Gardena Formation in places where these sandstones overlie directly the porphyries (though the mineralisation does not give rise to workable quantities). The quartz of the sandstones is released from the permian quartz porphyries during their weathering and erosion; so there is evidently a relation between these sulphidic Pb-Zn minerals and the original lead-zinc content of the permian volcanics. In this area Pb-Zn minerals do also occur in the Bellerophon Formation, namely in those places where this formation overlies transgressively the permian porphyries. Such positions of transgressive overlap occur frequently, because the Gardena Formation was deposited in a number of depressions, relics of the preceding Hercynic orogenesis. For instance, in the Sextener Dolomites, NW of San Stefano di Cadore, the thickness of the Gardena Sandstones ranges from zero to 2000 meters.

The groundwater lixiviated the volcanic sequences of the Lower Permian and penetrated into the sediments that filled the depressions, thus causing their mineralisation and in places ore deposits (Mostler, 1965).

The situation in the area of our investigations is quite comparable with that of the Dolomites and the Bergamasc Alps, so that the anomalously high Pb values in the Gardena Sandstones, tabulated in Table I, are most probably a synsedimentary feature. On the other hand, the Bellerophon in this area lies nowhere transgressively directly upon lower permian volcanics, or on the basement complex.

Consequently, no anomalously high Pb values have been found in it.

It might be asked whether the Pb anomalies in our area of study result from lixiviation of the lower permian volcanics or from the Hercynian basement complex of the Carnian Alps and the quartz phyllites of Cadore.

The easternmost occurrence of permian porphyries is in the Padola area, some 8 km NW of San Stefano di Cadore, an area immediately bordering on our area of study; but this does not eliminate the possibility that the sandstones of the Gardena Formation were derived from the lower permian volcanics, occurring in the surroundings. One of the criteria for answered this question is the mineral composition of the Gardena Sandstones, indicating its provenance. Gianotti (1958) accepted without reserves that all Gardena Sandstones are composed of detritus from the quartz porphyries.

A detailed petrographic investigation was executed by Tedesco (1958), who found in thin slides the following mineral components of the Gardena Sandstones: monocrystalline quartz grains, plagioclase from 0-20% An, sanidine and biotite (all components of the quartz porphyries) and mosaic quartz grains, albite and sericite (components of the quartzphyllites). The portion of the volcanic detritus diminished with the distance from the Bolzano centre of ignimbritic quartz porphyries. Samples of Gardena Sandstones, taken about 5 km east of Laggio di Cadore, south of the Monte Popera Valgrande, (see enclosure sheet I), contain, according to Tedesco, 63% of porphyry components and 37% of phyllite components. We made no sedimentpetrographic investigations on the composition of the Gardena Sandstones in our area. But following the outcome of Tedesco's study, the prognosis might be given that their content of porphyry components will be lower still in eastern direction, because they are farther away from the Bolzano centre of lower permian volcanic activity.

Therefore, the direct influence of this centre of volcanism on the composition of the Gardena Sandstones in our area of study will probably be small (this centre is situated about 100 km west of our area of study). It should be realized that a lead content of 20-70 ppm is too low for the formation of discrete grains of galenite. The measured amounts of lead in the Gardena Sandstones probably occurs in the red pigment enveloping the grains of these sandstones.

The important fact is that the lead content all over our area of study, which measures about 45 km W-E and 25 km N-S, have everywhere the same order of magnitude. There are two possible ways for explanation:

.1. The lead anomalies are the result merely of mechanical weathering. If so, the older volcanic formations, or the metamorphic basement complex should have had also a lead anomaly.

2. The lead anomalies are the result of chemical weathering and lixiviation of the source area.

The fact that the lead anomalies of the Gardena Sandstones have an almost constant level, suggests that the second possibility provides the best explanation. The groundwater and surface water solutions with a relatively high concentration of lead ions, permeated the deposits of sandstones, producing intergranular films of iron-oxide with a relatively high lead admixture.

The supposed source area, the lower permian centre of the Bolzano quartzporphyries, was situated some 100 km to the west of our area. Thus it seems quite unlikely that the original solutions, produced by chemical weathering of this volcanic Bolzano area were still present at such a distance. This leads to the assumption that the lead anomalies in the Gardena Sandstones have a synsedimentary character, but that nevertheless the lead content is entirely or partly derived from the metamorphic basement complex nearer; also the basement of the Central Carnian Alps might have been involved, as is indicated, for instance, by the anomalies near Paularo, at the eastern end of our area of study.

The occurrence of the lead anomalies in the Gardena Sandstones is conform to the opinion of Krauskopf: according to Krauskopf (1955, p.449) the "red bed" environment is an ideal environment for concentration of heavy metals. The red beds are often pictured as regions of semi-arid plains, supplied with coarse to fine-grained detritus from adjacent high land regions. Groundwater and surface water from the high land regions partly evaporated and became concentrated on the plains, dropping their heavy metal content where precipitating agents are present. In our area of study the Bolzano quartz porhyries and the peneplain-shaped metamorphic basement have formed the high land areas. In local basins and troughs between these areas the Gardena Sandstones have been deposited. Thus evaporation in the surrounding and more humid high lands and precipitation in the local basins are the geochemical factors responsible for the lead anomalies found in the red beds of the Gardena Sandstone Formation.

II. THE ORE BODY OF SALAFOSSA

The Salafossa Mine worked by the "Societá Mineraria e Metallurgica di Pertusola" is situated in the Val Piave, near its bifurcation into the Val Visdende (Enclosure sheet I). The ore-bearing formation is the ladinian Schlern Dolomite, and the reef unit wherein the ores occur, is the Monte Tezza Piccola. The tectonic structures of this reef are treated in Chapter IV H, paragraph g.

P. Lagny, geologist of the mine, kindly gave some stratigraphic and economic information to the present author.

The ore-body near the base of the reef occurs in a sedimentary breccia formed during the growth of the reef in ladinian time. In the lower part of the breccia the ores are not concentrated; only in the upper part do they occur frequently in economic concentrations. During a short excursion into the Salafossa Mine in 1965, P. Lagny pointed out to R.W. van Bemmelen, G. Hazeu and the present author the synsedimentary character of the mineralisation of the ores in the upper part of the breccia. In the contact zone of the breccia with the unstratified reef dolomite some synsedimentary slide folds occur.

The principal ore minerals are galenite, sfalerite and chalkopyrite. Cl, Br and F occur as trace elements in the sulphides.

In the centre of the ore breccia about 10% of the rock consists of pure sulphidic ore ($PbS + ZnS + CuFeS_2$); in the margins of the ore body about $1\frac{1}{2}$-2% sulphides.

The production of the mine in 1966 was 1500 ton/day, with an average sulphidic ore content of 6 %.

Though the ores of the Salafossa Mine clearly have a syngenetic character, there are yet two different possibilities for their origin:

1. Exogenic: the ore has been supplied by exogenic processes, namely by erosion of older ore bodies and descending solutions.
2. Endogenic: the ore has been supplied by endogenic processes, by ascending hydrothermal and/or exhalative solutions.

In the Southeastern Alps a number of workable Pb-Zn mineralizations occur (fig.41). These ore depo-

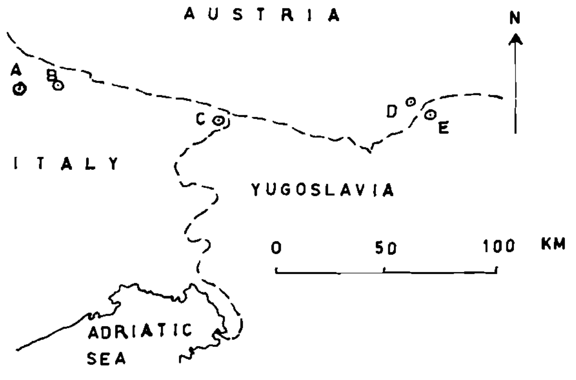

Fig.41. E-W zone (geofracture or geosuture) in the Southeastern Alps, with the situation of the various Pb-Zn occurrences.
A = Auronzo; B = Salafossa (San Pietro); C = Cave del Predil; D = Bleiberg; E = Mezica.

sits are situated along an E-W directed zone, which extends over a distance of 250 km from the Gailtal Alps in the west to Slovenia in the east. In this zone the ore bodies of Mezica (Slovenia), Bleiberg (Carinthia), Cave di Predil (NE Italy) are the most important.

The Salafossa Mine is also situated in this zone; so is another Pb-Zn occurrence near Auronzo, some 15 km west from San Stefano di Cadore in the region bordering to our area of study to the west.

All these Pb-Zn occurrences are probably of synsedimentary character, all of them being situated in ladinian and/or carnian formations. In the case of the Cave di Predil Pb-Zn mine a redistribution of the ore occurred later on during the alpine orogenesis. The ore went into solution and was reprecipitated near fault zones (Guicherit, 1963, p.69). This alpine redistribution is the cause that some authors (including di Colbertaldo, 1948,1958) were of the opinion that this ore body was formed epigenetically by ascending alpine hydrothermal solutions.

Considering the correlation between an E-W zone and a number of ladinian and/or carnian Pb-Zn (and partly also Cu) mineralisations, a genetical relation between the geological history of this lineament and the ore deposition probably existed.

Maucher (1959) points out that many ore deposits in the Alps are related to volcanic activity. The spatial dependence of mineralisation on volcanism is not related to the geosynclinal and/or orogenic features, but to long belts of fault lines, which gave rise to the volcanic activity. Such lines are called geofractures in Mauchers nomenclature.

Though in our area of study the volcanic character of the ladinian Buchenstein- and Wengen-Formations is not very clear (pure tuffs and/or effusive rocks do not occur), nevertheless these formations are undoubtly influenced by the ladinian volcanism.

In the basin-areas (Carnian-Bellunese Basin and the Lombardic Basin) a relatively thick sedimentary epiderm presumably suffocated volcanic extrusions (see chapter III, p.19). However, a volcanic origin by hydrothermal and/or exhalative solutions, ascending along fault lines during the triassic time of reef building, seems to be possible.

The E-W zone in the Southeastern Alps (fig.41) is a typical example of such a geofracture or geosuture. This triassic lineament gave rise to the ladinian volcanism, which was the most active on the platform- and somewhat less active in the basin-areas.

With regard to our area of study the Monte Chiaine with its Ugovizza breccias, 1 km NE of Cima di Sappada (Enclosure sheet I), can be mentioned as an indication for a syngenetic fault formed in anisian (and perhaps already in scythian) time. See pag.13.

In the same area of Cima di Sappada the ladinian Buchenstein Formation, which bears witness that volcanic activity occurred at that time, reaches its maximum thickness of 350 m.

Summarizing it can be said that the Salafossa Mine with its Pb-Zn-Cu ores is probably related to the anisian faulting and the ladinian volcanism. The syngenetic synsedimentary Pb-Zn-Cu ores are endogenically formed, by ascending hydrothermal solutions, which caused sulphidic precipitations on reaching the sea-bottom near or at the foot of the reef.

An alpine redistribution of the ore minerals, such as occurred at the Pb-Zn ores of Cave di Predil, did not occur in the Salafossa Pb-Zn-Cu ores. If the ore minerals had been transported and concentrated during the alpine orogenesis, traces of Pb-Zn-Cu should be present in the surrounding triassic reef formations. Our investigations on the lead content in the anisian and ladinian reefs of the Monte Curie, Monte Carro and Monte Tezza Piccola, all surrounding the Salafossa Mine, showed that no anomalously high Pb values occur in these limestones and dolomites.

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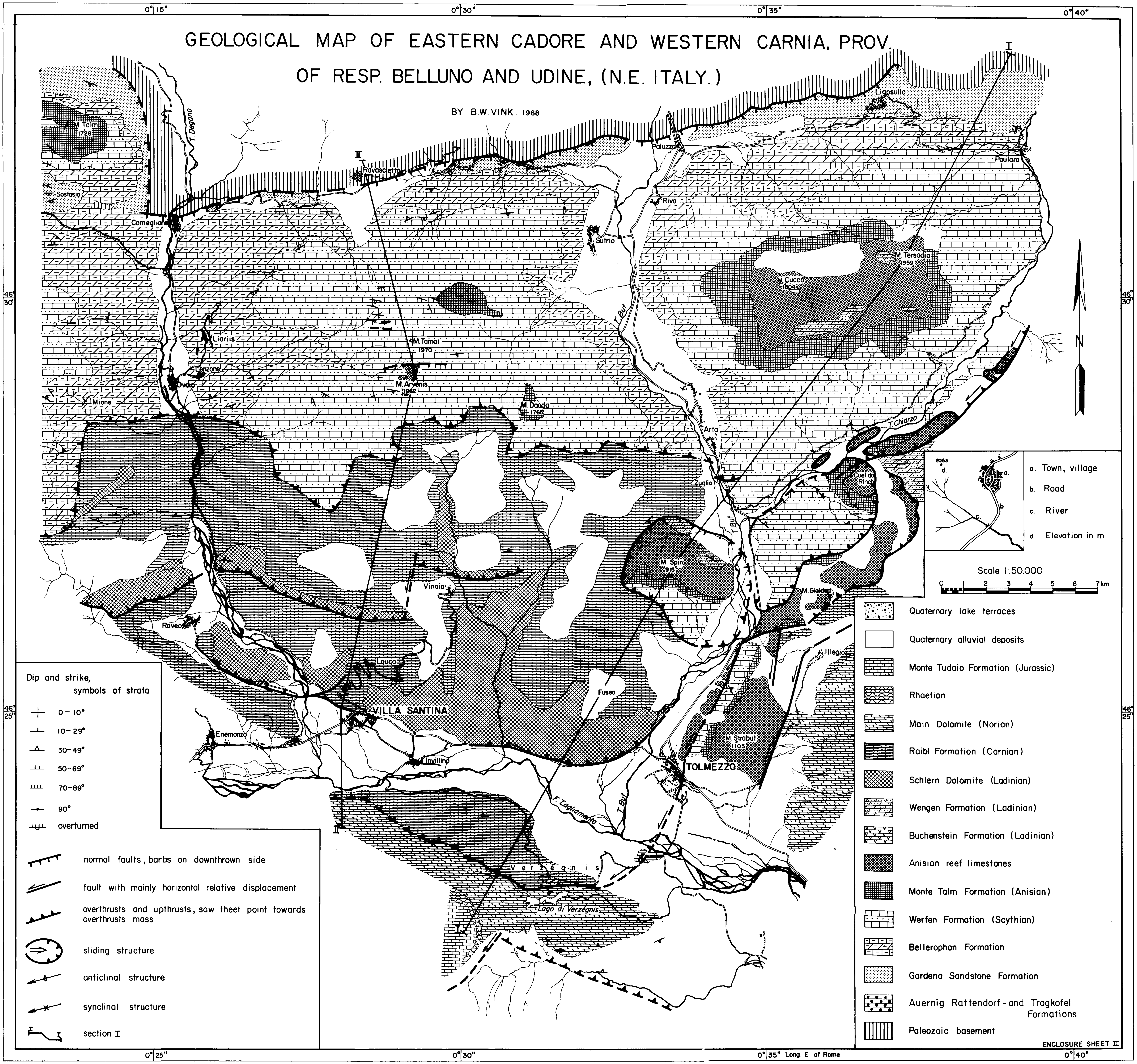
CURRICULUM VITAE

Op verzoek van de Senaat der Rijksuniversiteit.

Schrijver van dit proefschrift behaalde in 1959 zijn diploma gynmanisumβ aan het Chr.Gymnasium te Utrecht. De studie in de geologie werd hetzelfde jaar begonnen. Het candidaatsexamen (j) werd afgelegd in februari 1963, het doctoraalexamen (hoofdvakken geologie en geochemie, bijvak petrografie) in december 1966.
Vanaf oktober 1963 is de schrijver werkzaam op de afdeling geochemie van het Vening Meinesz Laboratorium voor Geofysica en Geochemie, tot het doctoraalexamen als assistent, daarna als wetenschappelijk medewerker.


GEOLOGICAL MAP OF EASTERN CADORE AND WESTERN CARNIA, PROV. OF RESP. BELLUNO AND UDINE, (N.E. ITALY.)
BY B.W. VINK. 1968
0°15"
0°30"
0°35"
0°40"
0°25"
0°35" Long. E of Rome
46° 30'
46° 25'
M. Talm 1728
Sostasio
T. Degano
Comeglians
Ravascletto
Paluzza
Ligosullo
Paularo
Rivo
Sutrio
M. Tersadia 1959
M. Cucco 1804
T. But
Liariis
Ovaro
Mione
M. Tamai 1970
M. Arvenis 1962
M. Dauda 1765
Arta
T. Chiarzo
Zuglio
Cuel da Rinch
M. Spin 915
M. Giaidet
Vinaio
Raveo
Lauco
Illegio
Fusea
VILLA SANTINA
Enemonzo
Invillino
M. Strabut 1103
TOLMEZZO
F. Tagliamento
Verzegnis
Lago di Verzegnis
a. Town, village
b. Road
c. River
d. Elevation in m
Scale 1:50.000
0 1 2 3 4 5 6 7km
N
Quaternary lake terraces
Quaternary alluvial deposits
Monte Tudaio Formation (Jurassic)
Rhaetian
Main Dolomite (Norian)
Raibl Formation (Carnian)
Schlern Dolomite (Ladinian)
Wengen Formation (Ladinian)
Buchenstein Formation (Ladinian)
Anisian reef limestones
Monte Talm Formation (Anisian)
Werfen Formation (Scythian)
Bellerophon Formation
Gardena Sandstone Formation
Auernig Rattendorf- and Trogkofel Formations
Paleozoic basement
Dip and strike, symbols of strata
0 - 10°
10 - 29°
30 - 49°
50 - 69°
70 - 89°
90°
overturned
normal faults, barbs on downthrown side
fault with mainly horizontal relative displacement
overthrusts and upthrusts, saw theet point towards overthrusts mass
sliding structure
anticlinal structure
synclinal structure
section I
ENCLOSURE SHEET II


GEOLOGICAL MAP OF EASTERN CADORE AND WESTERN CARNIA, PROV. OF RESP. BELLUNO AND UDINE, (N.E. ITALY). BY B.W. VINK 1968
Scale 1:50.000
0 1 2 3 4 5 6 7 km
AUSTRIA
CENTRAL CARNIAN ALPS
Cortina d'Ampezzo
CADORE
CARNIA
Tolmezzo
Tagliamento
Zwitz.
Austria
Yugoslavia
France
ITALY
Roma
N
0°00"
0°5"
0°10"
0°15"
0°20"
46° 35'
46° 30'
0°15" Long. E of Rome
C. di Aiareda
C. Spina
Col. della Varda
Crode dei Longarini
M. Schiaron 2244
M. Peralba 2694
M. Avanza 2475
Bosco Bordaglia
VISDENDE
M. Lastroni 2449
M. Melescagn
M. Curie
M. Rinaldo 2473
M. Carro
M. Chiadin
Forni Avoltri
M. Chiaine
Piani di Luzza
Costalissoio
S. Pietro
Campolongo di Cadore
S. Stefano di Cadore
M. Terza Piccola 2334
Cima Sappada
Sappada
M. Tuglia 1931
M. Siera 2443
M. Pleros 2314
M. Creta Forata 2462
M. Terza Media
Siera
C. Ruin
DOLOMITI PESARINI
M. Terza Grande 2586
Creton di clap grande
M. Tudaio
M. Cornon 2370
Culzei
Pesariis
Prato Carnico
VAL PESARINA
M. Brentoni 2548
M. Popera Valgrande 2520
F. Piave
Vigo di Cadore
Laggio
Forc. di Lavardet
M. Vinadia 1843
Col Rementera 1910
M. Losa 1953
Lorezago di Cadore
Col Gentile 2075
M. Pallone 2018
Casera Razzo
Sauris di sopra
Sauris di sotto
M. Tiarfin 2413
M. Ruche
M. Veltri 2003
M. Rioda
M. Cloros 1738
Lago di Sauris
M. Bivera 2474
M. Lagna
ENCLOSURE SHEET I

SECTIONS BELONGING TO THE GEOLOGICAL MAP OF EASTERN CADORE AND WESTERN CARNIA. (N.E. ITALY)

BY B.W. VINK 1968

ENCLOSURE SHEET III