GEOLOGY AND PERMIAN PALEOMAGNETISM OF THE VAL-DI-NON AREA

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GEOLOGY AND PERMIAN PALEOMAGNETISM
OF THE VAL-DI-NON AREA

vH.

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PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE WIS- EN NATUURKUNDE AAN DE RIJKSUNIVERSITEIT TE UTRECHT OP GEZAG VAN DE RECTOR MAGNIFICUS DR. H. TH. FISCHER, HOOGLERAAR IN DE FACULTEIT DER LETTEREN EN WIJSBEGEERTE, VOLGENS BESLUIT VAN DE SENAAT DER UNIVERSITEIT IN HET OPENBAAR TE VERDEDIGEN OP MAANDAG 21 NOVEMBER DES N.M. TE 2.30 UUR PRECIES

DOOR

DICK VAN HILTEN

GEBOREN TE BREDA

1960

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

Aan mijn ouders

Aan mijn vrouw

Voorwoord

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Contents

Samenvatting

Gedurende de zomers van 1957–1959 werden geologische onderzoekingen verricht in het westelijk deel van de Dolomieten (zuidelijke Alpen), waar deze door de Judicariënbreuk gescheiden worden van de centrale Alpen.

Reeds lang voordat de hoofdbewegingen langs deze breuk plaats vonden – eind oligoceen – begin mioceen – was zijn aanwezigheid merkbaar als een zwaktezone (lineament); deze gaf aanleiding tot faciesverschillen (o.a. lombardische versus venetiaanse facies) aan beide zijden, vanaf het rhät.

Mogelijk zelfs is de permische grens Collio serie – vulkanische serie op deze zwaktezone terug te voeren.

In het Val-di-Non gebied bevinden we ons in een faciesbereik, dat veelal gecorreleerd kan worden met de bekende en veel onderzochte stratigrafie van de centrale Dolomieten. Tijdens het boven-krijt en het eoceen wordt de werkzaamheid van de Judicariënzone ook in dit gebied merkbaar, in de vorm van breccies en conglomeraten, die zich evenwijdig aan deze breuk ontwikkelden.

Het oorspronkelijk chaotische tektonische beeld toont verschillende plooiingsrichtingen, scheve en steile b-assen, benevens vlakke overschuivingen; het gehele gebied wordt doorsneden door breuken, die zeer verschillende verschuivingsmechanismen verraden. Ombuiging van breukvlakken en subrecente afglijdingsstructuren van grote afmeting komen herhaaldelijk voor.

Dankzij de gelukkige omstandigheid, dat de Judicariënbreuk in het Val-di-Non gebied niet evenwijdig loopt aan de strekkingsrichting van de midden-tertiaire alpine plooiingen, is het mogelijk de relatieve ouderdom van de verschillende deformatiefasen nauwkeurig te bepalen.

Drie midden-tertiaire orogene subfasen, met zeer uitgesproken eigenschappen, blijken ten grondslag te liggen aan het deformatiepatroon:

De eerste subfase laat een gravitatief afglijden zien van de sedimentaire epidermis naar het SSE, vanaf de zich verheffende centrale Alpen. Daarna ontstond de Judicariënbreuk als een steile afschuiving, waarlangs de zuidelijke Alpen afzakten ten opzichte van de centrale Alpen, die zelf tot grote hoogte oprezen. Kort hierna baande een tonalitisch magma zich een weg naar boven, voornamelijk gebruik makend van de juist ontstane Judicariënbreuk.

Ook in aangrenzende zuid-alpine gebieden zijn de gevonden drie subfasen te herkennen, ofschoon daar de peri-adriatische breuk – waarvan de Judicariënbreuk deel uitmaakt – over het algemeen evenwijdig loopt aan de alpine plooiingsrichtingen, waardoor de relatieve ouderdom der subfasen minder in het oog springt.

De aanname van een centraal alpine geanticlinale op welving, levert een mechanisch aanvaardbare synthese op van deze verschijnselen – en de volgorde waarin zij optraden. De opwelving werd veroorzaakt door de opstijgende kracht van een toenemende opeenhoping van relatief licht, mobiel materiaal aan de basis van de korst.

Dit levert een directe bevestiging op van het door van Bemmelen (1958, 1960b en 1960c) voorgestelde mechanisme der midden-tertiaire orogenese in de oostelijke Alpen; hij veronderstelde een primaire tektogenese (opwelving van de centraal alpine geanticline), die gevolgd wordt door een secundaire tectogenese op verschillende niveaux in de korst (gravitatief afglijden van de epidermis vanaf de geanticlinale flanken, afbreken van de zuidelijke Alpen van de centrale Alpen en zijdelings omhoogdringen langs deze breuk van het granitische magma, dat eerder de opstijgende tendens van de geanticline veroorzaakte).

De abrupte richtingsverandering die de Judicariënbreuk (NNE-SSW) in de peri-adriatische sutuur oplevert – hij onderbreekt het regelmatige E-W verloop ervan over een afstand van 80 km – verleidde vele tectonici tot de aanname van een sinistrale zijschuiving langs de Judicariënbreuk, waarbij het 'Dolomieten blok' verder noordwaarts vooruitgeschoven zou zijn dan de relatief achtergebleven 'Bergamaskische eenheid'. Van daarbij optredende (noordvergente) plooiingsverschijnselen, noch van enige sinistrale torsie langs de veronderstelde zijschuivingen is enig spoor in het veld aangetroffen.

Veeleer is deze richtingsverandering (Judicariënbreuk) in de peri-adriatische sutuur op te vatten als een locale aanpassing van deze sutuur aan een zwaktezone in de korst, die daar reeds sinds de trias aanwezig blijkt te zijn, gezien de sedimentaire voorgeschiedenis van de Judicariënzone.

De onder-permische vulkanische serie van Bolzano werd onderzocht op zijn paleomagnetische eigenschappen. Door progressieve demagnetisatie konden onstabiele magnetisatierichtingen in vele gevallen verwijderd worden.

De stabiele magnetisatierichting levert een onder-permische pool, gelegen op 118,6° westerlengte en 51,4° noorderbreedte, en verschilt dus aanzienlijk van de gemiddelde positie, zoals die uit andere Europese permische monsters is bepaald.

Dit verschil is mogelijk terug te voeren op geotektonische oorzaken.

Summary

During the summers of 1957 till 1959 geological investigations were carried out in the western part of the Dolomites (southern Alps), where these are separated from the central Alps by the Judicaria fault.
A long time before the principal displacements occurred along this fault – late oligocene – early miocene – its presence was indicated by a zone of weakness (lineament), which caused facies differences at both sides (e.g. Lombardian and Venetian facies) starting from the rhaetian. Even the permian boundary between Collio and volcanic series might be reduced to this zone of weakness.
The development of facies in the Val-di-Non area allows many correlations with the well-known and much studied stratigraphy of the central Dolomites.
During the upper-cretaceous and the eocene, the activity of the Judicaria zone is felt also in our area by breccias and conglomerates which developed parallel to this fault.
The originally chaotic tectonic picture shows different directions of folding, dipping b-axes, and subhorizontal overthrusting; the area is cut by faults which demonstrate many different mechanisms of displacement. Curving of fault planes and sub-recent collapse structures of great extension are frequently met with.
Thanks to the lucky circumstance, that the Judicaria fault is not running parallel to the trend of the mid-tertiary alpine foldings in the Val-di-Non area, an exact, relative dating of the various deformation phases could be established.

Three mid-tertiary orogenic subphases, with very marked characteristics, appear to be responsible for the deformation pattern.
The first subphase shows a gravitative décollement of the sedimentary epidermis from the rising central Alps towards the SSE.
Secondly, the Judicaria fault originated as a steep normal fault, along which the southern Alps sank relatively to the central Alps, which continued their rising to enormous heights.
Shortly after, a tonalitic magma made its way upwards, using mainly the previously formed Judicaria fault.
In the adjoining south-alpine regions too, these three subphases may be found again, though the peri-adriatic fault – which the Judicaria fault forms part of – runs generally parallel with the alpine trend there, by which the relative age of the subphases becomes less conspicuous.
The assumption of a central alpine geanticline offers a mechanically acceptable synthesis of these phenomena and their sequence. It was caused by the buoyancy of an increasing accumulation of relatively light mobile material at the base of the crust.
This directly affirms van Bemmelen's views on the mechanism of the mid-tertiary orogeny in the eastern Alps (van Bemmelen 1958, 1960b and 1960c); he proposed a primary tectogenesis (rising of the central alpine geanticline), followed by a secondary tectogenesis at various levels in the crust (gravitative décollement of the epidermis from the flanks of the geanticline, vertical shearing-off of the southern Alps from the central Alps, and the lateral intrusion along this fault of granitic magma, which previously caused the rising of this geanticline).

The sudden change of direction, displayed by the Judicaria fault (NNE-SSW) as a part of the peri-adriatic suture – the regular E-W extension is interrupted over a distance of 80 km – induced many authors to assume a sinistral strike-slip faulting along the Judicaria fault, by which the 'Dolomitic Unit' should have been shoved further northward than the 'Bergamasc Unit', which lagged behind. In the field, however, no traces are found of any accompanying (north-directed) foldings, nor of any sinistral torsion along the supposed strike-slip faults.
This change of direction (Judicaria fault) of the peri-adriatic suture is to be regarded rather as a local adaption of this suture to a zone of weakness of the crust, which appears to be present there since triassic times, as may be concluded from the sedimentary history of the Judicaria zone.

The paleomagnetic properties of the lower-permian volcanic series of Bolzano have been investigated. In most cases unstable directions of magnetization could be removed by progressive demagnetization.
The stable direction of magnetization furnishes a lower-permian pole, situated at 118,6° W and 51,4° N; this position deviates considerably from the average pole position, as obtained from other European permian samples. This deviation might be due to geotectonic causes.

Riassunto

Le seguente ricerche geologiche sono state eseguite durante i mesi d'estate dal 1957 al 1959 nella parte occidentale delle Dolomiti (Alpi meridionali), dove queste sono separate delle Alpi centrali dalla Linea delle Giudicarie.
Molto prima che i movimenti principali si svolgessero lungo questa dislocazione – fine Oligocene – inizio Miocene – la sua presenza era già percettibile come una zona d'instabilità ('lineament'); questa causava delle differenze di facies (fra l'altro facies Lombarde verso facies Venete) all'una e all' altra parte, cominciando dal Retico. Fors'anche il confine permiano tra serie di Collio e serie vulcanica è reducibile a questa zona d'instabilita.
Nella regione della Val-di-Non incontriamo uno sviluppo di facies, che spesso permette una correlazione colla nota stratigrafia molto studiata delle Dolomiti centrali. Durante il Cretacico-superiore e l'Eocene anche in questa regione l'attività della Linea delle Giudicarie diventa percettibile, nella forma di breccie e conglomerati, che si sviluppano paralleli a questa faglia.
L'immagine d'origine caotica dimostra diversi direzioni assiali, b-assi poco e ripidamente inclinati, come pure dei sovrascorrimenti suborizzontali; attraverso tutta questa regione si trovano delle dislocazioni, che rivelano delle traslazioni relative di una grande varietà.
Qui si incontrano frequentemente dei piani delle faglie che sono piegati e anche dei 'collapse structures' subrecenti di grande estensione.
Grazie alla circostanza favorevole, che nella regione della Val-di-Non la Linea delle Giudicarie non si estende parallela alla direzione delle pieghe alpine del Terziario medio, l'età relativa delle vari fasi deformative può essere determinata precisamente.

Evidentemente il disegno di deformazione risulta da tre fasi orogenetiche di vari proprietà spiccate, durante il Terziario medio:
La prima fase dimostra uno scivolamento gravitativo dell'epidermis sedimentaria dalle Alpi centrali emergenti verso il sud sud est.
Poi si formava la Linea delle Giudicarie come una faglia normale con una ripida inclinazione, lungo la quale scendevano le Alpi meridionali in quanto alle Alpi centrali, che da parte loro si alzavano a un'altitudine considerevole.
Poco doppo uno magma tonalitico si apriva il passo in alto, approfittando principalmente della Linea delle Giudicarie ora formata.
Anche nelle regione sudalpine adiacente si incontrano queste tre fasi, benchè lì la sutura periadriatica – della quale la Linea delle Giudicarie fa parte – si estenda in genere parallela alle direzioni assiali alpine, a causa della quale l'eta relativa di queste fasi e meno cospicua. Questi fenomeni – come pure l'ordine nel quale si presentano – sono riducibili a una sintesi accettabile dal punto di vista meccanico, cioè la supposizione di un sollevamento geanticlinale centro-alpino, provocato dalla spinta dell'accumulazione progressiva di materiale mobile e relativamente leggiero, alla base della crosta.

Questa sintesi dà una conferma diretta dei concetti di VAN BEMMELEN (1958, 1960b e 1960c) sul meccanismo dell'orogenesi medio terziaria nelle Alpi orientali; la sua supposizione era la tectogenesi primaria (sollevamento della geanticlinale centro-alpina), seguita da una tectogenesi secondaria (scivolamento gravitativo dell'epidermis dai fianchi genanticliali; lo staccarsi delle Alpi meridionali dalle Alpi centrali e lungo questa sutura l'emergenza laterale del magma granitico, che prima causava la tendenza sollevante della geanticlinale) a vari livelli della crosta.

Il cambiamento subitaneo della direzione manifestato dalla Linea delle Giudicarie NNE-SSO nella sutura periadriatica – cambia la direzione regolare est-ovest su una distanza di 80 chilometri – induceva diversi autori alla ipotesi di un movimento prevalentemente orizzontale (sinistrale) lungo la Linea delle Giudicarie, nella quale occasione 'l'unità Dolomitica' era spinta di più verso il nord che 'l'unità Bergamasca' relativamente rimasta indietro. Nel terreno non si è trovato una sola traccia di pieghe (con vergenza verso il nord) accompagnanti un tale movimento, nè di qualsiasi torsione sinistrale lungo questa faglia.
Il cambiamento di direzione (la Linea delle Giudicarie) nella sutura periadriatica può essere interpretato piuttosto come un adattamento locale di questa sutura a una zona d'instabilità nella crosta, che, visto gli antecedenti sedimentarii della zona Giudicaria, evidentemente si trova ligià fin dal Triassico.

I porfidi quarziferi del permiano-inferiore nella regione di Bolzano vennera studiati per la loro pro prieta paleomagnetica. In parecchi casi fu possibile rimuovere le direzioni della magnetizzazione instabili col mezzo di demagnetizzazione progressiva. La direzione della magnetizzazione stabile produce un polo permiano-inferiore , che si trova a 118,6° long. ovest e 51,4° lat. nord, e in tal modo differisce considerevolmente della posizione media, com'è determinata da altri campioni permiani in Europa. Può darsi che questa differenza risulti dai cause geotettoniche.

CHAPTER I

Introduction

The following study was set up for the tectonic analysis and interpretation of a part of the Judicaria fault, between Dimaro and S. Pancrazio. It was thought convenient to concentrate the investigations on the tectonics of the adjoining Southern Alps.
The Judicaria fault forms part of the well-known lineament – Insubric-N. Judicaria-Pusteria line – between the Central and Southern Alps. The interpretation of this line forms one of the many points of controversy met with in theories on Alpine orogenesis. Its tectonic meaning changes as rapidly as orogenic hypotheses are proposed and rejected.
Previous field studies on the Judicaria fault are often out of date or fragmentary; they hardly form a sound base for theoretical considerations. It is tried to throw some new light on the problem by means of a detailed tectonic survey of the Judicaria fault itself, and of the adjoining Val-di-Non area. Many kinds of – often small-scale – tectonic data were collected; they comprise such phenomena as schistosity, b-axes, directions and sequence of foldings, mechanism of faulting, deformation of fault planes, lineations and striations, jointing, and sub-recent collapse structures.

Moreover, a paleomagnetic survey was started on the permian effusives which reach a great extension in Northern Italy. This survey forms part of the investigations of the Geological Institute of Utrecht, which is particularly interested in this permian volcanism and the paleomagnetic poles, derived from it. (Rutten, van Everdingen and Zijderveld 1957; van Everdingen and Zijderveld 1959; Dietzel 1960; van Everdingen 1960; Nijenhuis 1960).

The studied area is situated in the northern Italian provinces of Bolzano and Trento (see outline map on enclosure I). More precisely its limits are formed by

46° 35′ 00″ and
46° 15′ 42″ N. latitude, and
10° 57′ 09″ and
11° 15′ 33″ longitude E of Greenwich.

Mapping was carried out on topographic maps (1:25.000) of the Istituto Geografico Militare, the sheets Bolzano and Trento.
The data were collected during the summers of 1957, 1958 and 1959.
All measurements in this thesis have been corrected for the magnetic declination.

Geological research of this area dates from 1558, though this first description was published in the form of a poem. The ultimate survey was carried out by Dietzel (1960) in an area immediately north of the present one, dealing also with the tectonic problems of the Judicaria and Nova faults.
The history of geological research in the Dolomitic region is unraveled in great detail by von Klebelsberg (1935, p. 1-33), who is referred to here.
The study of the literature on this area is hindered by a linguistic problem: because its unstable political position in the past, by which it was – alternatingly – attributed to german and italian speaking nations, most geographic items carry two – german and italian – names. Nowadays, the geographic maps only carry italian names, so it is in no way easy, to correlate the older literature – mainly austrian, using german names – with the present-day geography. A list, therefore, is added (chapter VII), in which a translation of the italian names into german ones is furnished, as far as they concern the studied area. In the present work only the italian names are used.

Stratigraphy and Petrography

a. GENERAL

Stratigraphically, the Southern Alps form a highly interesting region. Many publications and detailed studies are dedicated to its stratigraphy, in particular to the development of the triassic in the Dolomites.
In the Val-di-Non area the stratigraphic column is almost continuous, from the lower permian till the eocene, as shown in the columnar section of figure 1. Its base, the lower permian, overlies unconformably the quartz-phyllite series, which was previously folded during the variscan orogenic phase.
In our area fossilizations are relatively scarce. So in many instances the direct dating of its formations offers difficulties. By means of comparing them with well-known strata of surrounding areas, they mostly can be classified in a more indirect way. A complete treatment, however, of all stratigraphic features occurring in the surroundings is not to be expected, this being far beyond the scope of the present survey. Attention is to be paid though to such generalities, like the volcanic and dolomitic facies development during the ladinian, as they occur in our area too.
Similar considerations make it inevitable to ignore the problems connected with the development of a venetian and a lombardian facies in the Brenta area, immediately south of our area. These facies differences have been interpreted as the result of large-scale strike-slip faulting (e.g. Trevisan 1939 a); the influence of this faulting should be observable in our area too.

Because of a few factors, the studied area is not very well exposed. Firstly, the area was covered by the quaternary glaciations, which left, on their retreat, a locally thick morainic deposit. Secondly, extensive woods cover large areas, specially the triassic and older formations. The centre of the Foiana depression (see figure 5), a flat topography, mainly formed by the younger formations, is being used for fruit-growing and agriculture, and therefore badly exposed.
In close connection with this cultivation is the need of irrigation water. It is seen, thus, that practically all rivers and brooks are tapped, often quite near their source. Their erosive force is reduced considerably by this tapping, which causes many riverbeds – otherwise the geologist's favourite field of activity – to offer only occasionally good outcrops.
Furthermore, for purposes of energy production – generation of electricity and waterpower for sawing-mills – the rivers are canalized and barred (Lago di Cles, and the lake SW of S. Pancrazio), which does not promote their erosive action either.
Finally, the weathering of the dolomites – ladinian and norian – supplies enormous masses of scree material, which cover wide areas or build up huge talus cones at the foot of many a scarp.
Thus continuous stratigraphic sections are hardly met with in our area. It is striking that older papers on this region (e.g. Lepsius 1878, Fabiani 1919) report more complete sections and outcrops, which by now have often vanished. An extensive description, for instance, is given by Fabiani of the middle and upper eocene limestones and shales N. of Romallo, an area now covered by monotonous rows of apple-trees. Only some dispersed blocks of limestone, indicate the existence of the middle eocene north of Romallo.
During the field work no special attention was paid to the quaternary deposits, and they are not recorded on our geological map, except in the valley of the Adige river, where they reach a greater thickness.

Also petrographically the Val-di-Non area is an interesting region. Many papers are dedicated to its metamorphic – epizonal to katazonal – schists and the tonalitic intrusions, which are closely connected to the peri-adriatic line (i.e. the Insubric-N. Judicaria-Pusteria faults). The problems around the permian volcanic series revived again during the excursion of the german 'Geologische Vereinigung' in 1959.

b. THE CRYSTALLINE ROCKS OF THE CENTRAL ALPS

At the WNW-ern side of the Judicaria fault, and north of the Insubric and the Pusteria faults, the Central Alps are characterized by a wide zone, many hundreds of kilometres long, consisting mainly of metamorphic schists and gneisses. Petrographically speaking they show a great variety, though it is not impossible to group them in a number of more or less separate groups. (Klebelsberg 1935; Andreatta 1952 and 1953). The major trends of this metamorphic complex are represented in the geological sketch map of the Judicaria region (inset-map of enclosure 1). Andreatta, who worked in this region for many years, distinguish-

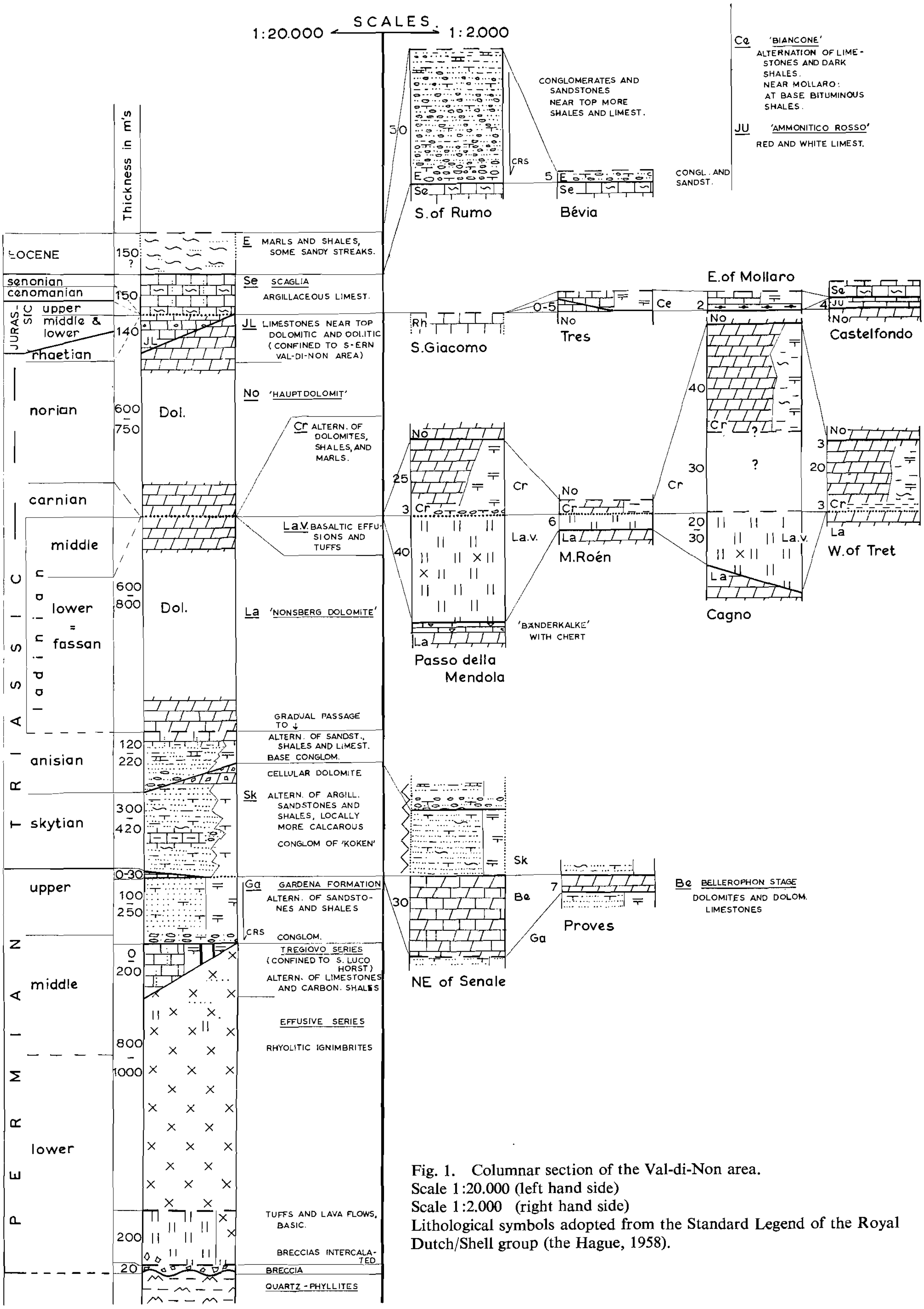


Fig. 1. Columnar section of the Val-di-Non area.
Scale 1:20.000 (left hand side)
Scale 1:2.000 (right hand side)
Lithological symbols adopted from the Standard Legend of the Royal Dutch/Shell group (the Hague, 1958).

ed three – epi-, meso-, and katazonal metamorphic – groups of rocks. The longest dimension of the outcrops of these groups show a clear preference for the NE-ENE direction.
Andreatta describes the epizonal quartz-phyllites between M. Cevedale and Merano (coinciding largely with the 'Marteller Quarz-phylliten' of Klebelsberg) as a broad syncline with gently dipping schistosity planes. This complex is underlain by mesozonal schists. The transition from epizonal to mesozonal metamorphosed rocks is a gradual one. Just as in the quartz-phyllites, the schistosity planes strike ENE and in the simple folds no great dips are met with. At its SE-ern side the mesozonal series is bordered by the Peio Line, a large mylonitic faultzone, discovered mainly by Andreatta (1948). Between the Peio line and the Judicaria fault the third group of rocks is encountered. In general these katazonal schists and gneisses still strike SW-NE, the inclination of the schistosity planes, however, is steeply dipping now, either to the NW or the SE. In this last group of rocks the phenomena, usually accompanying katazonal metamorphism are observed, e.g. igneous injections, metasomatic reactions, granitization and plastic deformations. A schematic NW-SE section over the metamorphic schists is shown in figure 2.

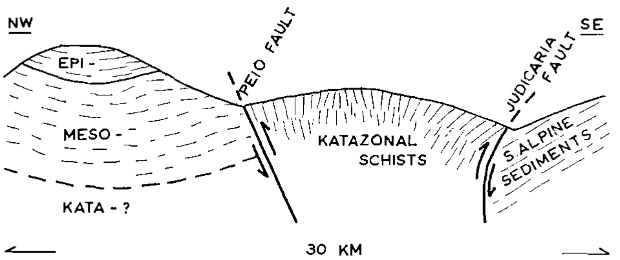


Fig. 2. Schematic cross section of the central alpine schists, based on sections and descriptions of Hammer (1902 b), von Klebelsberg (1935), Schmidegg (1936) and Andreatta (1948, 1952 and 1953).

Near the Judicaria fault we find a normal two-mica gneiss predominating. Dependent on the relative abundance of the quartz – feldspar and the biotite components, this gneiss may locally grade into a two-mica schist or into a muscovite-gneiss. South of Proves, lenses and pockets of garnet make their appearance, the individual minerals reaching a diameter of about 1-2 mm. It was observed by Hammer (1902 b) near the Mt. Pin that the appearance of the garnet is accompanied by a decrease of the mica content in the immediately surrounding schists. Confined again to these southern parts (e.g. near Rumo) lenticular intercalations of amphibolites and amphibolitic schists are found in the gneisses. Their width may range from 10 to 60 m.
Quartzites are abundantly present among the above-listed rocks, their dimensions diverge widely. Hammer (1902 b) mentions also the more rare occurrences of olivine-rocks, marble, graphitic schists and epidotegneisses.
Under the microscope cataclastic structures are not rare: undulating quartz and feldspar crystals, curved micas grading up to more or less complete kataclastic disruption of the crystals. A banded structure is formed by streaks of mica, with quartz or quartz-feldspar aggregates in between. The feldspar is oligoclase; the micas, biotite and muscovite, often are altered by chloritization, specially the former. Small garnets are common.
The tectonics of these crystalline rocks will be treated in chapter III.

c. QUARTZ-PHYLLITE SERIES

The quartz-phyllite series forms the oldest exposed rock in this part of the Southern Alps, SE of the Judicaria line. They can be correlated with the greater mass of epimetamorphic quartz-phyllites of Bressanone ('Brixner Quarzphyllit'). In the area under consideration they are elevated tectonically in the M. Luco horst. Farther to the south they are covered by the permo-triassic strata of the Dolomites, and they reappear again east of Trento, where they form the front of the Dolomite block (Sugana line).
Von Klebelsberg (1935: p. 276) suggests a relation of the quartz-phyllites of Bressanone with those of the Marteller zone in the central Alps. This Marteller zone extends from the Guardialta (2607 m) – i.e. about 10 km NW of the junction of the Valsura and Marano rivers – in a SW direction over at least 50 km. It is important to establish correlations between parts of the southern and the central Alps; they may enable us to state whether the correlated zones were separated from one another during the alpine orogenesis, and whether this separation is small or large.
In the studied area the quartz-phyllites are seen between the Judicaria- and the Foiana faults, covered by the permian effusives that dip moderately to the SW. The NE limit is formed by the intrusive mass of tertiary tonalites of the Mt Croce. Their schistosity planes are folded in a complicated way in different orders of amplitude; at least two phases of folding can be distinguished (see diagram 2, fig. 12). The field appearance is characterized by a grey-greenish phyllite, a changing coarseness of grain, often with large lenticular crystals of feldspar, parallel to the plane of schistosity, and local enrichments in quartz.

Under the microscope a coarse to medium grained rock with a foliated structure is revealed. The quartz lies together in small-grained streaks or in larger, single crystals, that often show undulating extinction. The feldspar – in larger crystals – is generally heavily sericitizised; encirclement by quartz is usual. The foliation is emphasized by streaks of muscovite-sericite, orientated in oblong crystals parallel to the plane of schistosity. Sometimes chlorite appears in a similar way. Opaque minerals and apatite form accessory constituents. According to von Klebelsberg (1935; p. 269) the original sedimentary status was one of shales and quartzitic sandstones, locally containing varying amounts of carbonaceous matter.

The quartz-phyllite series is cut by numerous – mostly aplitic – dikes, radiating from the tonalitic mass of the Mt Croce. The contacts with these dikes and with the tonalite itself are metamorphosed; the thickness of these contactzones varies greatly and is estimated a 300 m around the tonalite, diminishing to much smaller values around the dikes. The phyllites in the contact-zone offer a hornfelslike appearance – compact and dark – though the schistosity is not lost altogether. Many gradations are found between this hornfelsic-gneiss and the original quartz-phyllite; they are recognised by a tendency of the quartz and the feldspar to form larger crystals. A Na-rich plagioclase – albite-oligoclase – makes its appearance. Locally quartz is notably enriched, in other places biotite is encountered, though it is often totally chloritized. The presence of abundant sericite is a never failing phenomenon.

C. Andreatta (1937), in his study on the Mt Croce tonalitic intrusion, mentions the strong para- and postcrystalline deformation of the metamorphic zone of the phyllites.

From near the Passo di Plazzoles (E of Plazzoles) he describes a mylonitic hornfelsic gneiss, with a structure, orientated by postcrystalline movements (orientation of biotite; sericite on fracture-planes). Finally, after these movements, the deformed and fractured contact rocks suffered a hydrothermal stage of metamorphism, leading to an alteration of the feldspar and biotite into sericite, epidote, chlorite, magnetite and calcite (Andreatta 1937; p. 399). Andreatta does not express any opinion on the directions of the above-mentioned para- and postcrystalline orogenic movements, which would be of particular interest for the present tectonic study.

The quartz-phyllites form one continuous mass between the Mt Croce tonalite and the permian effusive rocks, though there might be one exception. About 800 m south of Bagni di Mezzo, at the E border of the Marano River some small outcrops can be found of a thinly laminated, grey to black carbonaceous mica-bearing schist; in places it has a graphitic character. The relations with the surrounding permian quartz-porphyry are obscured by a (ferruginous) sinter and vegetation. A spring above the sinter issues the whole-some waters of Bagni di Mezzo and built up the sinter. Blaas (1909) was the first to discover this outcrop and sought a connection with the Collio- and Tregiovo-series (middle permian, but post-effusive). The schists, however, have a slightly metamorphic appearance and they have stratigraphic planes that glitter by finely dispersed mica flakes; in the Collio-series these properties are unknown. Von Klebelsberg (1911 and 1935) correlates the micaschists of Bagni di Mezzo with intercalations in the quartz-phyllites which bear carbonaceous matter. Von Klebelsberg (1935: p. 269) cites at least seven places in the quartz-phyllites of Bressanone, where identical formations are exposed, so it seems reasonable to group them stratigraphically together with the quartz-phyllites. Its queer position amidst the quartz-porphyries will be discussed on page 17.

On both sides of the lower course of the Rio dei Prati, there are a number of galleries of abandoned mines. They are invariably penetrating mylonitic breccias of large faultzones, that cut through the quartz-phyllites. Formerly they were worked for ZnS-, PbS-, and $FeCO_3$- ores. The mineralizations in this district will be treated together in a separate chapter (VII c).

A more precise determination of the age than pre-permian is not possible. For the quartz-phyllites had been folded, brought to great depth, and risen up again before they formed a topography; only then the next-younger formation – the permian basal series – was laid down.

The tectonic details met in these series, will be elaborated in chapter III.

d. PERMIAN

1. The Basal Series of the Lower Permian

Separated from the quartz-phyllites by an angular unconformity a series of coarsely clastic sediments initiates the lower permian deposits. In the studied area they form a small strip between the quartz-phyllites (in the north) and the SW-dipping permian effusives (in the south). Outcrops, though, are rare because of a thick glacial deposit. But more to the east, e.g. near Ponte Gardena (between Bolzano and Bressa-none) and around Trento these initial deposits are better exposed.

Nowadays it is generally agreed upon (Trener 1933; Dozy 1935 a; Von Klebelsberg 1935; Giannotti 1958; Mittempergher 1958; Pichler 1959) that the series concerned was deposited under terrestrial and fluvial conditions, filling up a relief formed in the already

metamorphic and folded quartz-phyllites. It is composed of hardly rounded rockfragments and quartz pebbles derived mainly from the underlying quartz-phyllites (diameter sometimes more than 10 cm) in a matrix of mica-rich sand. This breccia, with a grey greenish or reddish colour, forms no continuous sheet, but may locally be absent, at other places it may reach a thickness of more than a 100 m. Intercalated in this breccia, increasing in thickness and frequency towards higher levels, are volcanic tuffs, tuffbreccias and a few lava extrusions, which represent the beginning of the well-known permian volcanism.
Fragments of the above described formations are found in the upper course of the Rio dei Prati. They confirm that the situation here did not differ in principle from that found more to the east. It is estimated that the breccias appear up to 20 m from the base of the uncomformity; at higher levels their place is taken completely by the effusives of the lower permian.

In many older publications the described basal series sometimes are called 'Verrucano', or 'Verrucano-like deposits'. This created the confusing situation that at least three, stratigraphically different formations are named 'Verrucano'. For this name is in use, too, for the conglomerates and sandstones on top of the Collio-series – i.e. the equivalents of the sandstones of Val Gardena (Grödner Sandstein) – in the Bergamasc Alps (Dozy 1935 a; de Sitter and de Sitter-Koomans 1949). Finally, the type locality of the Verrucano (Mt Verruca, near Pisa), was recently dated of carnian age by Trevisan (1955). Besides these differences in age of the 'Verrucano'-conglomerates, a distinction in depositional environment may be noted: the Verrucano-conglomerates of the type locality are products of the triassic transgression there. Von Wolff (1909) considered the basal series of the western Dolomites as the product of a marine transgression; nowadays, however, a regression of the hercynic sea is thought a more appropriate environment for the deposition of this series (Giannotti 1958; Pichler 1959).
It will be easily understood that in more recent literature it is strongly advocated to abolish the confusing term of 'Verrucano', at least to limit its use to deposits that are truely equivalent to the original – transgressive – conglomerates we find on the Mt Verruca.

2. The Perman Effusive System
('Bozener Quarzporphyr')

One of the most spectacular rocks in the Dolomitic scenery is formed by the extensive ($\pm$ 2500 km^2) permian effusive system. With their thickness often exceeding a 1000 m, these red to greenish coloured, hard rocks form the rigid underground on which the triassic strata were deposited.
The permian volcanism is not limited to this part of northern Italy. Similar phenomena are known from all over Europe: Lugano, the Estérel (S France), Nideck (NE France), Nahe (Germany), and Oslo. Volume 48 of the Geologische Rundschau (1959) dedicates a series of articles to this permian volcanism.

In the Val-di-Non area this formation is met with in two, tectonically different, positions: along the Adige river, from Lana to Termeno and in the 'Luco Horst'. The AGIP drilling of Mollaro reached this formation at a depth of 1612 m below sea level. This makes it probable that the permian effusives form a continuous layer under the Val-diNon area, making thus connection with the quartz-porphyries of the Val Rendena, SE part of the Brenta area.
The literature on the permian volcanism around Bolzano is voluminous. Numerous descriptions of detailed surveys exist; many efforts have been made to arrange the data in a convenient system. The following remarks are based on the recent literature (Von Klebelsberg 1935; Mittempergher 1958; Accordi 1959; Andreatta 1959, and Pichler 1959) and personal observations made during an excursion of the german 'Geologische Vereinigung' in 1959, under the leadership of Andreatta, Maucher, and Vardabasso, and which was dedicated to the permian volcanism of the Dolomites.
A division into a lower, more basic tuff series and an upper, more acid extrusive series is clear. The former, in its lower parts, is alternating with the conglomeratic basal series of the lower permian. Towards higher levels a steady decrease in the psephitic material and an increase in volcanic efflata is observed. The tuff series of trachyandesitic composition shows many explosive characteristics; its colour is dark or greenish-dark. Some rare melaphyric flows are intercalated. The thickness of this lower series ranges from about 200 m in the north to 800-1000 m near Trento in the south. On top of these more basic volcanic rocks, the bulky and extensive flows of the actual quartz-porphyries ('Bozener Quarzporphyrplatte') set in. The individual flows are often separated by crystal tuffs of relatively small thickness. Some properties of the rhyolitic flows, however, need some further examination.
The individual flows generally cover a wide area without noticeable differences in thickness and mineralogical and chemical composition. This thickness is mostly considerable, exceeding a 100 m. In the flows themselves stratification or flow texture is rarely found; they are of a particular homogeneity. Only in large outcrops (e.g. Alpe-di-Siusi and the steep – glacially U-shaped – banks of the Adige Valley), can the thickness of the flows be estimated. The constant thickness over many kilometres distance points to the fact that during their extrusion these rhyolitic masses spread out very easily, i.e. their viscosity was much

lower than the viscosity of a rhyolitic lava flow. Furthermore the characteristics of an ordinary lava flow, like irregular brecciated surfaces and tongue-like forms are completely lacking.

From these simple field observations it can be concluded that the rhyolitic masses flowed out in a fluidized, two-phase condition. This accounts for the essential mobility during the extrusion, necessary for the fast spreading-out over wide areas, in thick sheet-like layers of a homogeneous composition. After its spreading-out the two-phase system (solid-gas) will have lost much or all of its gascontent and it becomes by then an ordinary, hot lava. After the cooling down the quartz-porphyry may show under the microscope ignimbritic features (Mittempergher 1958). Considering a fluidized rhyolitic flow after its deposition and after its having lost most of its gascontent, it is possible that the upper parts of such a sheet will be less pressed together than the lower parts, because the former lack the compressive stresses of a heavy load on top. In other words, the upper parts of the sheet will have many characteristics of tuffs.

Consequently, the question whether an extrusion took place in a fluidized state cannot be solved in general by microscopical criteria, but must primarily be decided on field-geological data. Only the latter enable us to reconstruct the conditions during the extrusion. The physico-chemical conditions during the cooling-off process of an ignimbrite may more or less obliterate the microscopical structures and textures, that are thought critical (Marshall 1935) for an ignimbritic effusive status.

During periods of volcanic inactivity the upper parts of the last flow will be subjected to erosion and reworking. All these phenomena are met with at different levels in the quartz-porphyry series. At many places typical unsorted lahar deposits make their appearance.

Mittempergher (1958) was the first to draw attention to the ignimbritic habitus of the quartz-porphyries in the Dolomitic region. It may be noted here that many other permian effusives in Europe (Estérel, Oslo, Nideck) are looked upon as ignimbrites nowadays. In spite of the field evidence in favour of Mittempergher's views, Andreatta (1959) does not mention the possibility of a fluidized extrusion of the rhyolitic masses. Pichler (1959) thinks that the criteria for calling these series ignimbrites are absent, basing his considerations on the classic descriptions of Marshall (1935).

Another interesting aspect of the permian volcanism is seen near Trento, at the southern end of the quartz-porphyry plate. NE of this town the permian effusives are still present in great thickness. SE of Trento, however, this formation is completely lacking; there the quartz-phyllites are directly covered by a conglomerate which starts the deposition of the Val Gardena sandstones. This and similar rapid changes in thickness show that the effusives filled up a pronounced topography.

A simple volumetric consideration will render it obvious that this relief is greatly accentuated by contemporaneous faulting. The enormous volumes of volcanic matter which are brought to the surface are compensated by collapse structures, thus forming a volcano-tectonic depression. So the effusions are restricted indirectly to an area limited by a – roughly circular – faultzone. This point of view is taken also by Accordi (1959), who compares the Dolomitic volcano-tectonic depression with the one of Lake Toba, Indonesia, described by van Bemmelen (1930).

Sofar we have described the permian effusives east of the Adige river; at the western border the outcrops would not permit us to describe the formation in so much detail. In the area immediately bordering the Adige river, between Tesimo and Termeno, we constantly dwell in the uppermost part of the series, formed by the hard quartz-porphyries, coloured monotonously dark-reddish, locally dark-grey. Only from a greater distance may a faint stratification be observed, dividing these quartz-porphyries into layers of over a 100 m thick; a layer of a slightly less solid constitution, may – by selective erosion – be cut out a trifle more, than the over- and underlying ones. In general the formation lies undisturbed, dipping only 10°-15° to the S or SSW. The volcanic formation is covered here by the Val Gardena sandstones.

The geological map (Sheet Nr. 10, Bolzano, of the Carta geologica delle tre Venezie) shows locally porphyritic tuffs, like lenticular intercalations in the quartz-porphyries. The criteria for their distinction from the surrounding ignimbritic quartz-porphyries, however, seem to be rather dubious and subjective. The deposition of each massive quartz-porphyry flow, looked upon as an ignimbrite, was one paroxysmal extrusion, rather than a series of eruptions, interrupted by numerous violent explosions of tuffaceous material. In an ignimbrite the appearance of unconsolidated, tuffaceous looking portions is an easily understandable phenomemon.

Furthermore, an airborn tuff is not expected to give a stable direction of magnetisation. Paleomagnetic research on these rocks showed that they were deposited at temperatures, well above the Curie-point of iron-oxyde, i.e. 300-600° C. This research, which will be discussed later in chapter V, pleads for the spreading-out of the quartzporphyries in a hot and fluidized state, together with their tuff-like intercalations.

The quartz-porphyries form a compact and hard rock. To the tectonical stresses it responds by jointing and fracturing; folding occurs only as slight bending on a very large scale. Joint- and fault patterns in this formation are represented in the diagrams 3, 7, and 8. Macroscopically phenocrysts of quartz, feldspar and biotite are easily recognized. The quartz may show its typical six-sided bipyramidal form. The colour of the feldspar is going from white to grey, with often lightly reddish or yellow variations. The groundmass is generally dark-red, ranging to violet and occasionally green varieties.

Under the microscope the rhyolites show a porphyritic texture with phenocrysts of quartz, plagioclase, orthoclase, and biotite. The quartz crystals occur in dipyramidal forms, though they are generally corroded, showing embayed outlines; kataclastic fracturing of the minerals is much observed. The feldspars suffered heavy sericitization. Oligoclase is present in greater amounts than orthoclase, though the determination of the relative quantity is hampered by the abundant sericite. Perthitization of the orthoclase is frequent. The biotite is mainly altered into chlorite and opaque minerals (iron-oxydes?), even in fresh samples. In the rare cases of unaltered biotite it appears often in bended laths. Pleochroism is strong, from olive-brown to total absorption.

The groundmass is felsitic, probably composed of quartz and feldspar and chloritizised dark constituents. In some cases a fluidal structure is to be seen. Accessory minerals are scarce; apatite and zircone were found. Opaque minerals occur in various quantities.

Chemical analyses of the quartz-porphyries – and of the basal tuff series – were published by Mittempergher (1958) and Andreatta (1959). It is emphasized by Mittempergher that the chemical composition of the rhyolitic rocks is particularly homogeneous throughout the dolomitic region.

In the Luco horst again the top of the quartzporphyries is exposed. As may be seen in sections I, II, III, and VII this is due to the cylindrically arched roof, which is formed by the rigid porphyry plate in this horst. Only on the northern slopes of the Mt Luco do we meet with the lower parts of the permian effusive system.

At their base, a sharp limit with the underlying breccias of the basal series cannot be drawn, as pointed out above (p. 15). The volcanic activity starts with its most basic member, mainly trachyandesitic tuffs and lavas, intercalated in the breccias. The chemical composition of the tuffs is less basic than their dark-green and -red colour makes suspect; it changes from trachyandesitic to quartzlatitic, in higher levels. A detailed description of the sequence of the eruptions in the Luco horst cannot be given, because exposures in these basal tuff series are scarce and of a dubious kind. A glacial deposit covers much of the series and at other places, e.g. the eastern slope of the Mt Luco, north of the Passo delle Palade, coarse scree material prevents an accurate examination of the formation. It is estimated that the basic, basal part of the permian volcanic system in the Luco horst reaches a thickness of about 200 m. In higher levels the more acid effusives of the quartz-latites and rhyolites appear; their thickness is thought to reach here about 1200 m. Because of the inaccessible and dubious outcrops of the basic series in this part of the Dolomites, reference was made to the more complete and extensive descriptions of this series by Mittempergher (1958), Andreatta (1959) and Pichler (1959).

On the NW-side of the Mt Luco, near the Marano river the stratigraphic sequence of the permian volcanic series is obliterated by an other complication. Here we are very near to the Judicaria fault-zone, and there are indications that the volcanic formation here is cut by some NNE-SSW striking faults.

The presence of the quartz-phyllitic outcrop amidst the permian quartz-porphyry, south of Bagni di Mezzo, along the Marano river needs still further notice. At least three different explanations for this occurrence may be advanced, now that we are better informed on the effusive character of the rhyolitic series:

1. The quartz-phyllite of Bagni di Mezzo formed a mountain during the effusive stade of the rhyolites and was washed by them like an island.*)
2. The quartz-phyllites are bordered by faults belonging to the system of the volcano-tectonic depression.
3. The quartz-phyllites are bordered by faults belonging to the Judicaria system.

3. The Tregiovo-Series

Near Tregiovo and Lauregno, on top of the effusives and covered by the Val Gardena sandstones, we meet with a deposit, which is generally known as the Tregiovo Series. Its extent is limited and its thickness is irregular, reaching a maximum of about 200 m south of Tregiovo. The series is formed by an alternation of dark to black, bituminous limestones and shales. The thickness of the individual limestone layers ranges from about 5 cm, near the base of the series, to a 20 cm in the higher levels. In many instances the limestones show a more sandy or marly composition; then they are less compact, exhibiting a thin layering. On the bedding planes fossil plant remains are abundant, but they are badly preserved and do not permit an easy determination. Heritsch (1939 b) – quoting Vacek (1882 and 1911) – mentions the following flora of the Tregiovo Series:

Baiera digitata HEER
Ullmannia frumentaria SCHL.
U. cf. selaginoides BRGT.
Walchia piniformis SCHL. and
W. filiciformis SCHL.

*) This interpretation is schematically shown in section VII.

Though the contact with the underlying permian effusive rhyolites is not directly exposed, the Tregiovo series is thought to be deposited without angular unconformity.
Some sedimentary parts of the so-called Collio Series of the Bergamasc Alps show a great facial resemblance to our Tregiovo series (Dozy 1935 a; Giannotti 1958). In the Bergamasc Alps and near the town of Collio (S of the Adamello massif), this series does, however, not form a continuous sedimentary deposit like near Tregiovo, but intercalations of sandstones, and volcanic tuffs and flows occur frequently. Giannotti assumes the Collio series to be deposited under unstable coastal conditions, where marine and continental sedimentation and volcanic activity follow one another in rapid succession. The volcanism around Collio and in the Val Rendena is the same as met with in the Val-di-Non area (described in the preceding part). The outcrop in the Val Rendena (E of the Adamello Massif, along the Judicaria fault) is of particular interest to us because here the Collio series overlies the permian effusives, being thus in an identical stratigraphic position as found near Tregiovo. Both Dozy and Giannotti mention the occurrence of fossil plant remains, mainly *Walchia*, in the Collio series.

Reviewing the sedimentary and volcanic cycles, we find the SW-ern offshoots of the permian volcanism intercalated in the Collio series. Farther to the NE, in the Val Rendena and ultimately near Tregiovo, the volcanic series is more continuous and the Collio series is present only in isolated occurrences on top of it.
In the studied area the Tregiovo series appeared to extent a few kilometres farther to the north, than was indicated on the italian Carta geologica (Foglio Bolzano). Some unquestionable outcrops were found along the upper course of the Rabiola river. Near the Foiana fault another isolated exposure was found (not indicated on the enclosed geological map). The tectonic complications connected with this occurrence will be discussed in chapter III b 4.

4. The Gardena formation
('Grödener Sandstein')

On top of the permian effusive series or – when present – on top of the Tregiovo and Collio series the continental deposit of the Val Gardena sandstones (Grödener Sandstein) sets in. Throughout the Dolomites and the Bergamasc Alps these clastic deposits are met with. It was remarked above, that the Val Gardena sandstones directly overlie the crystalline basement near Trento, where the effusive series is lacking. In the Val-di-Non area the thickness of the formation ranges from 100 to 250 m.

At their base the sandstones are coarse and clearly show that they are composed of reworked material of the underlying rhyolites. In the field it is often difficult to tell the rhyolites and the sandstones apart: both may lack stratification and show the same reddish – violet colours. Rounding of the particles may be completely absent in these lower parts of the sandstones. The reworking of the underlying rocks is clearly demonstrated in those outcrops where the sandstones overlie the Tregiovo series. Here it is repeatedly seen that the sandstones contain sharp-edged black pebbles, derived from the Tregiovo limestones (See figure 3).

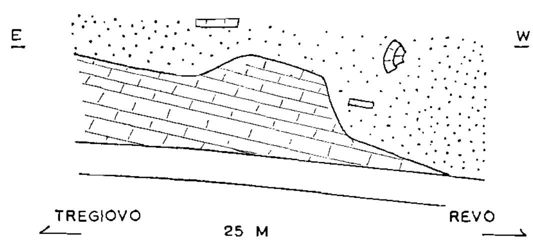


Fig. 3. Reworking of the Tregiovo series by the Gardena sandstones (dotted). 1 km SW of Tregiovo, along the road to Revo.

Towards higher levels a more distinct bedding sets in. The reddish – violet colours of the mostly thick sandstone layers may change locally to reddish – grey and grey. The grain size of the coarse, often conglomeratic, basal layers rapidly diminishes to medium and fine, intercalations of red pelites make their appearance. The terrestrial characteristics are furnished by the red colour, cross-bedding, ripple marks and the lack of fossils. Only fossil plant remains, which are badly preserved, are more or less frequently found. These remains may locally be present in so great an amount, that thin coal seams originate. North of Proves, near the Passo di Castrin such a carbonaceous intercalation was encountered. More occurrences are reported by Von Klebelsberg near Tesimo and Caldaro.
Near the top of the Gardena formation some dolomitic and gypsum-bearing layers are met with. In general it may be remarked that in the Val-di-Non area the highest levels of this formation are less coarse and may be entirely composed of, mostly red-coloured, pelites.

Leonardi (1949) reports near Redagno (10 km east of Termeno) an important fossiliferous locality in the Gardena formation. Footprints are found of tetrapodes, amphibians and reptiles; according to this author (Leonardi 1949 and 1955) they may be attributed to the following species:

Nasopus (?) *grimmi* n. sp.
Ichnium cf. brachydactylum PABST.
Eumechichnium gampsodactylum PABST.
Thecodontichnus sp.
Prochiroterium permicum LEONARDI
Ornithoidipus (?) *perwanferi* n. sp.
Onychichnium escheri DOZY

Moreover, the following fossil plants from the same locality could be determined:

Lepidodendron cf. sternbergi LINDL. and HUTT., **or** *Schizolepis permensis* HEER
Lepidodendron cf. veltheimianum ST.
Lebachia (*Walchia*) *laxifolia* FLORIN.

Quoting Gümbel (1877), Tedesco reports near Egna (eastern bank of the Adige river, opposite Cortaccia) the occurrence of

Baiera digitata HEER
Ullmannia bronni GOEPP.
U. geinitzi HEER
Voltzia hungarica HEER
Carpiolithes sp.
Calamites sp.
Equisites sp.

Mutschlechner (1933) is the sole reporter of a marine fauna in the Gardena sandstones. In an outcrop near Redagno, remains were found by him of the species listed below:

Orthoceras sp.
Pleuronautilus sp.
'*Nautilus*' sp.
Mojsvaroceras sp. and
Parapronorites sp. ?

This local occurrence of marine sedimentation might be taken for the first sign of the advancing triassic transgression.

A detailed sedimentological study on the Val Gardena sandstones – in particular those of the Val Rendena (N. of Tione, along the Judicaria fault) – was published by Tedesco (1958). Table 1 shows some data on the sandstones, which are of interest for the study of the Val-di-Non area, as these samples were collected near Terlano, Ora (3×) and Meltina (7 km NE of Tesimo). In the columns I-VI the composition of the sandstones is reproduced, divided in quartz (Q), feldspar (F) and residual components (R); these items are subdivided according to the rock (v or s) from which Q, F and R are derived. Only two source-rocks appeared to exist: the volcanic (v) rocks of the permian effusive system and the schists (s) of the quartz-phyllite series. Under the microscope the distinction between e.g. quartz grains derived from volcanic rocks and those derived from the phyllites is easily observable. The former show the same characteristics as the quartz minerals of the described ignimbrites: uniform extinction, traces of corrosion and resorption. The quartz grains derived from the quartz-phyllites consist mainly of aggregates of small crystals; grains, formed by only one crystal, generally show strain shadows. Similar considerations permit the other (F and R) components to be subdivided according to their source-rock.

Column VII presents an index of provenience, given by Q_v/Q_{tot}.. The indices clearly show the fact that the Gardena sandstones in the Val-di-Non area are mainly built up by material derived from the underlying rhyolitic ignimbrites. Tedesco (1958) produces a map of N. Italy, on which curves have been drawn, connecting points with the same index of provenience with one another. A regular pattern is found, showing the highest indices in the centre (near Ora), decreasing gradually outwards in all directions. Thus the highest index is found near what might be called the centre of the permian effusive series; towards its borders the index of provenience decreases, i.e. the portion of the material, supplied by the quartz-phyllite series increases. This means, as from all sides quartz-phyllitic material is furnished, that the Val Gardena sandstones were deposited in a *depression*. A similar condition – a volcano-tectonic depression – was thought to control the effusion of the underlying

TABLE I

Site	% of composition						$\frac{Q_v}{Q_{tot}}$	$\frac{Q}{Q+F}$	Q_{tot}	Cement	Grain size	Sorting	Angularity
	Q_v	Q_s	F_v	F_s	R_v	R_s							
Terlano	48	39	9	2	2	–	0,55	0,89	87	Limonite, clay, quartz	$\frac{1}{2}-\frac{1}{4}$ mm	+ (good)	–– (angular)
Ora 1	82	7	10	1	1	–	0,92	0,90	89	Calcite, limonite	$\frac{1}{4}-\frac{1}{8}$ mm	– (little)	– (subangular)
Ora 2	70	17	2	–	11	–	0,80	0,98	87	Calcite	$\frac{1}{2}-\frac{1}{4}$ mm	+	–
Ora 3	65	19	10	–	6	–	0,77	0,89	77	Calcite	$\frac{1}{4}-\frac{1}{8}$ mm	–	–
Meltina	55	30	4	1	8	2	0,65	0,94	85	Limonite, quartz, SiO_2	$1-\frac{1}{2}$ mm	–	○ (rounded)
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII

Sedimentological data on the Val Gardena sandstones in the Val-di-Non area, after Tedesco (1958). Explication in the text.

ignimbrites (see p. 16). The depression, in which the Val-Gardena formation was deposited, may be taken for the last stage of the volcano-tectonic depression; its bordering faults were not reactivated after the effusion of the volcanic material had come to a standstill.
The bulk of the Gardena sandstone formation is to be classified as 'feldspatic sandstones', as is demonstrated by Tedesco, who uses the classification of Heinrich (1956). Only accidentally the composition of the samples of Terlano, Ora 1 and 2, and of Meltina diverges a trifle, so they are rather classified as – respectively – graywacke, quartzite, quartzite, and subgraywacke.
The much cited studies of Mittempergher, Accordi, Giannotti and Tedesco on the palaeozoic formations in N. Italy were stimulated by the 'Comitato Nazionale per le Ricerche Nucleari' (CNRN). This interest is due to the fact that the Val Gardena sandstones showed to be uraniferous. The sandstones being largely made up of reworked palaeozoic rocks, the CNRN initiated the investigations of these series. More detailed descriptions of the mineralizations have been published by Mittempergher (1958 b and c).

5. The Bellerophon Stage

In the central parts of the Dolomites, this formation, about 150 m thick, is covering the Val Gardena sandstones. Their deposition took place during the subsidence of this part of the alpine geosyncline below sea level. The lower parts of the Bellerophon Series show the first signs of an advancing sea: in the marly shales intercalations of gypsum become more frequent. Towards higher levels cavernous limestones make their appearance. On top of them black, bituminous limestones grade upwards into the more oölitic, compact limestones, which contain – in the Val Gardena for instance – *Bellerophon*, the fossil after which this zone is named.
Thus sedimentary conditions changed from continental (Val Gardena formation), via paralic (evaporites of the lower half of the Bellerophon zone), towards neritic open sea conditions, represented by the upper half of the series (Accordi 1959).
More towards the SW, near Bolzano and Trento, it is seen that the Bellerophon Stage is formed by a less thick – about 60 m – rock series. Here, facies changes demonstrate that the transgression arrived later.
Still farther to the SW, Trevisan (1939 a; p. 18) reports from the Val Rendena, that usually the triassic strata directly overlie the Gardena sandstones. Only at one locality an intercalation, a few metres thick, is found between them. It is composed of impure, cavernous, dolomitic limestones, or oölitic strata and thin bedded limestones. This occurrence is considered as the most western one, for in the Bergamasc Alps the Bellerophon series was not deposited; it is known (Dozy, 1935 a) that marine sedimentation started there not earlier than during lower triassic times.
The fossil content of this series enabled Accordi (1959) to date the transgression accurately. He found the change to marine conditions to have taken place during the middle of the upper permian in the central Dolomites. Near Bolzano and Trento this happened on the turn of permian to triassic time. In the Bergamasc Alps, near Lugano, the transgression is dated as upper skythian. By these observations the direction of the transgression is clearly demonstrated, proceeding from ENE to WSW.
This introduction was given for a better understanding of the position of the Bellerophon rocks in the Val-di-Non area. Here the thickness of the series diminishes rapidly from 60 m, E of Bolzano, to 10-20 m on the western bank of the Adige river. There are indications that at many places, farther to the north and west, the Bellerophon Zone has never been deposited. This is understandable in the light of the notable thinning-off of the Bellerophon Zone in westward directions. Locally, however, the absence of the formation may be due to tectonic complications.
In our area fossilizations are extremely scarce, both in the Gardena sandstones and in the Bellerophon Zone and also in the overlying skythian formation. It was important, therefore, to state that in our area the marine transgression took place on the turn from permian to triassic time. It enables us, by lack of fossils, to determine the age of the Bellerophon beds.
In the studied area the Bellerophon Zone forms morphologically a conspicuous layer, as it consists of a harder rock than the enclosing beds. When not hidden by scree material, it forms an easily observable ridge at many places in the steep western slopes (cuesta) of the Adige river.
Its composition is one of compact, often dolomitic limestones or dolomites, the individual beds being some 20-60 cm thick. The thickness of the Zone ranges from 10 to 20 m, locally reaching a maximum of 25 m, e.g. N of the Passo delle Palade. The colour is light-grey or yellowish in wheatered state, dark-grey or brownish on fresh ruptures. In some beds quartz grains are dispersed and undeterminable particles of fossils are met with. Towards higher levels small plant remains are found on the bedding planes, and thin, intercalated marly limestones announce the gradual passage to the lower triassic beds.
This description suggests that in the Val-di-Non area a rock series was deposited, much like the upper parts of the Bellerophon formation in the central Dolomites, as reported by Accordi (1959).
Along the Foiana fault, near the Passo delle Palade

and north and south of Senale, the Bellerophon layers are steeply dipping towards the ESE, because of the drag, there, along this fault (see sections I and II and the sections of Fig. 15). Here it is seen that at several places (see geological map) the Bellerophon Zone is lacking, or appears in reduced thickness (Passo delle Palade). We can only guess which process is responsible for the partly or complete reduction of the series:

a. The tectonic deformation along the Foiana fault, the drag of the strata of the ESE-ern block is of considerable importance. Near the Passo delle Palade a tectonic reduction of the thickness of the permian and mesozoic strata is observed. It is understandable that the competent Bellerophon beds are broken and torn apart during this deformation, so that only locally pieces of these rocks, amidst the imcompetent formations, were dragged up along the Foiana fault.
b. Near Prisciano and Tesimo, – a tectonically undisturbed area – the Bellerophon Zone has not been deposited. This does not surprise us, knowing that the series is thinning off in a western direction. In the Pescara valley, too, near Mione, the Bellerophon Zone is locally absent.

The local absence of the Bellerophon series along the Foiana fault must be attributed to either or both of these processes. The actual state of the exposures does not permit to observe, whether the Bellerophon Zone is thinning off in a direction parallel to the Foiana fault. Neither is it thought probable that the series is present under the – locally abundant – morainic cover, because of the endurance of this hard rock against erosive forces.

Along the Judicaria fault another line of outcrops of the Bellerophon Zone is found. The thickness here is notably less, ranging from 5 to 10 m. So, near Proves, crossing the Campo river, the formation is built up of a 8,20 m thick complex of resistent dolomites and dolomitic limestone beds, their thickness varying from 40-400 cm.

Near Rumo, Lauregno, and between Caldaro and Termeno the Bellerophon rocks have been worked for galena, sphalerite and pyrite. A syngenetic genesis of these bedded ore deposits is advocated by Maucher (1956 and 1959). The mineralizations will be treated in another chapter (VII c).

6. Age determination of the Permian Rocks

Of the rocks described so far, only the upper limit is well defined as late permian or early triassic. Fossils in the underlying strata are very scarce and the rare fossilizations that do occur are confined to plant remains, which are either badly preserved or do not permit an accurate determination of age.

Figure 4 shows the age of the pre-triassic rocks, according to the various authors, who worked in the western Dolomites.

An accurate determination of the age is highly desirable, specially because of the paleomagnetic survey

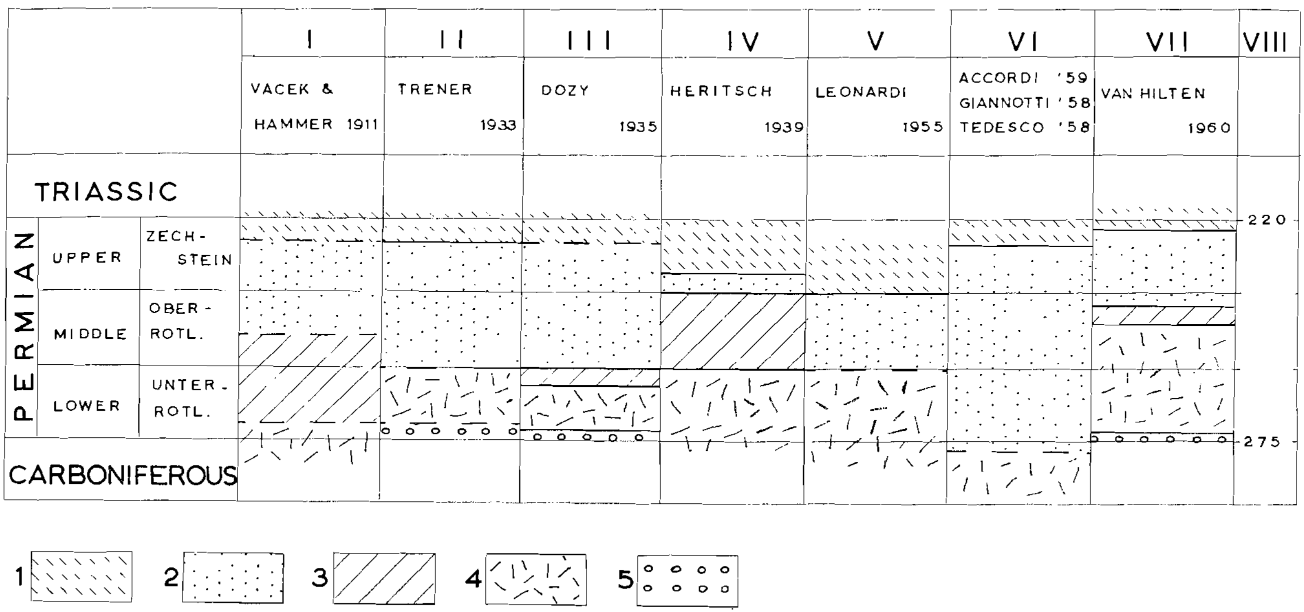


Fig. 4. Age of the formations 1–5, in the Val-di-Non area, according to various authors.
1. Bellerophon Stage. 2. Gardena sandstones. 3. Tregiovo Series. 4. Effusive Series. 5. Basal Series.
In column VIII, the absolute age in millions of years, according to Kulp (1959).

(chapter V) of the effusive system. Before correlating the results with the many permian poles, measured till now in Europe, the permian age of the investigated rocks needs to be ascertained. In particular the dating of Accordi, Giannotti and Tedesco (Fig. 4, column VI) needs our attention, as they assume the effusive system to be of *pre-permian* age.
It is generally agreed (Dozy 1935 a; de Sitter 1949; Giannotti 1958; Accordi 1959) that the Collio series of the Bergamasc Alps was deposited contemporaneously with the effusion of the rhyolitic ignimorites in our area. Tuffs and volcanic sandstones, intercalated in the Collio Series of the eastern Bergamasc Alps are considered to form offshoots of the volcanic activity of our region.
The Tregiovo Series, between ignimbrites and Gardena sandstones, forms on its turn the western-most occurrence of the Collio series; and, as they are immediately covered by the Gardena sandstones, they must form the youngest horizon of this Collio series.
The main problem to be solved is therefore the age of the Collio- and Tregiovo series.
Considerable differences, however, are encountered with regard to the dating of this formation. Some italian workers (Accordi, Giannotti and Tedesco) base their time-scale on the flora (see p. 19) of the Val Gardena sandstones near Redagno, in which the occurrence of *Lepidodendron* and *Lebachia* = *Walchia* would be decisive for an upper carboniferous, possibly lower permian age. This leads unevitably to the – at least – upper carboniferous age of the Collio-, Tregiovo- and the contemporaneous effusive series (see fig. 4).
Firstly, the occurrence of *Lepidodendron*, though generally taken as the guide fossil of the carboniferous, does not preclude a permian age of the beds, in which they were found. Potonié (1921; p. 193) and Scott (1920; p. 112), both authorities on fossil botany, report that the genus *Lepidodendron* is still living during permian times, though not as abundantly as during the carboniferous. The genus is thought to have become extinct during the permian.
Secondly, the determination of the plant remains, as described by Leonardi (1949), offered great difficulties, because of the bad state of preservation. For instance, the remains assumed to belong to *Lepidodendron* cf. *sternbergi* LINDL. and HUTT. or *Schizolepis permensis* HEER, are, according to Leonardi (1949; p. 6 and 7), comparable to *yet six other genera*. Reservation should be made also, regarding the determination of *Lepidodendron* cfr. *veltheimianum* ST. (Leonardi, p. 9).
Furthermore the number of remains is so limited that according to Leonardi (1949, p. 4) 'it is not wise, to base general conclusions on them'.
The other plant remains found near Redagno and other localities in the Val-Gardena sandstones, are all well known from the german and hungarian permian flora and indicate strongly that these sandstones were deposited during permian time. Leonardi himself, in his synthesis of the geology of the Dolomites of 1955, attributes a middle permian age to the Val Gardena sandstones, indicating thus what value should be attached to his own find and determination of the flora of Redagno.
Similar views are favoured by Trener (1933), Dozy (1935 a) and Von Klebelsberg (1935), who all consider these sandstones to be of middle permian age. Accordingly, the underlying effusive series is dated as lower permian by these authors. The Collio Series of the Bergamasc Alps, being mainly contemporaneous with the effusive series of the dolomitic region should therefore have been deposited during lower permian time.
De Sitter (1949) also suggests this age of the Collio series, arguing, that the determinations based on plant remains, like *Walchia*, are not conclusive to provide a final decision. He assumes the Collio Series of the Bergamasc Alps to be of lower permian age, such in analogy to the similar facies of the german 'Unterrotliegendes'.

Heritsch (1939 b), finally, reviewing the carboniferous and permian rocks of all SE-ern Europe, takes into account the fossil finds in the Tregiovo series (see p. 17). He finds that the flora corresponds with the german 'Oberrotliegendes' i.e. middle permian formations. This is in good agreement with the idea that the Tregiovo Series forms the upper part of the Collio Series. According to Heritsch, the flora of the Val Gardena sandstones near Egna (see p. 19) is quite comparable with the one of the german 'Kupferschiefer', i.e. the lower part of the upper permian.

Additional evidence is furnished by an investigation of Mittempergher (personal communication) on the uranium mineralization in the Val Gardena sandstones. He determined the age of this mineralization, making use of the U/Pb radioactivity method, and found an age of 220. 10^6 years. This corresponds, according to the new time-stratigraphic table of Kulp (1959), with the turn from permian to triassic time (see column VIII of fig. 4). It is in good agreement with the ideas about the syngenetic formation of these mineral deposits, to see this mineralization take place in the last depositional stage of the Gardena sandstones.
From the paleomagnetic investigations (chapter V) something may be learned about the period of the volcanic activity of the effusive series. The paleomagnetic diagrams show, that the dispersion is not great and that there is *no trend* discernible. In other words, the dispersion is due to secular variations, and to errors in the measurements, and not to another direction of magnetization of older rocks compared to the direction of magnetization of the younger ones

(trend). This may point to the fact that the whole effusive series was laid down during a relative short lap of time, for instance the lower half of the permian. By these considerations it is made probable, that the Basal Series, underlying the effusives, are still of lower permian age.
Summarizing it may be remarked that the pre-triassic strata of the Val-di-Non area, overlying the quartz-phyllitic Series, are of permian age. A time-stratigraphic classification as shown in figure 4, column VII, is suggested.

e. TRIASSIC

1. Skythian
(Lower triassic; Werfenian)

Throughout the dolomitic region the skythian formation shows the same characteristics, proper to a shallow water sedimentation, with a supply of mostly fine, clastic material. In several layers, fossilization may locally reach great abundance. Lithologically, the skythian is a variable formation; it is composed of sandstones, shales and some oölitic limestones, and the mixtures and alternations of these. Its thickness varies from 300-420 m. Micaceous material is often observed on the beddingplanes, specially in the Strata of Campil.

A division of the skythian, based on outcrops in the western Dolomites, but east of Bolzano, may broadly be applied to our region.

Top:	ANISIAN	Conglomerate of Richthoven
	SKYTHIAN	Cellular dolomite, 'Rauhwacke' Strata of Campil, 'Campiler Schichten' Oölitic limestone ('Gastropoden-oölit') with small Gastropods and the conglomerate of Koken. Strata of Siusi, 'Seiser Schichten'
Bottom:	PERMIAN	Bellerophon Stage.

The lower limit of the skythian is not a sharp one, except at the few places where fossils clearly mark the lower triassic age of the beds. Lithologically, the series starts by a gradual passage from the calcareous rocks of the Bellerophon Stage, by alternations of more marly and finely clastic beds. These Strata of Siusi ('Seiser Schichten' of the austrian geologists) overlie directly the Gardena sandstones, at those localities where the Bellerophon Stage has not been deposited (see p. 21). In these cases, too, no sharp lower limit of the skythian is observed, the upper parts of the Gardena sandstones being also mainly shaly and marly.
Towards higher levels in the Strata of Siusi oölitic limestones are intercalated. They do not form such a conspicuous horizon, as reported by Leonardi (1955) for areas situated more to the east, but – nevertheless – they may be observed at several localities, e.g. at the cuesta of the Passo della Mendola and in the Rio Campo (near Proves). Some beds of these limestones are crowded with small Gastropods, specially *Holopella gracilior*. This calcareous horizon is named 'Gastropodenoölit' by the austrian geologists and separates the Strata of Siusi from the overlying Strata of Campil (austrian: 'Campiler Schichten'). The bedding planes of these calcareous rocks are often covered by numerous round shells of a little oyster, *Ostrea ostracina* SCHL.

The 'Gastropodenoolit' is sometimes accompanied by conglomeratic layers. They are mentioned by Leonardi (1955) in the Dolomites, where they are named 'Conglomerate of Koken'. In our region, too, this conglomerate is met with. The diameter of the calcareous and marly, well rounded pebbles, does not exceed a 2 cm. They reflect a short erosion interval during the skythian, which may be expected in this period of sedimentation in shallow water.
In our region the conglomerate of Koken is found at the cuesta of the Passo della Mendola, E of Rumo and in the Rio Campo near Proves.
The overlying Strata of Campil ('Campiler Schichten') are hardly distinguishable from the Strata of Siusi. Both contain multi-coloured – red, green, yellow, and grey – complexes and intercalations of shales; the arenaceous and calcareous beds are faintly coloured – yellow-brown, light-red, light-green or simply grey. Many authors (Vacek & Hammer 1911; Trener 1933; von Klebelsberg 1935; Leonardi 1955) tried to tell them apart by different characteristics. The Strata of Campil contain slightly coarser and more micaceous sandstones, its marls are often dolomitic and of yellow-brown colour; finally the Strata of Campil are less fossiliferous than the Strata of Siusi. Opinions are contradictory on the point of the prevalence of the red colour for one of the Strata.

The top of the skythian formation is formed by a lithologically notable layer, consisting of a cellular dolomite: by selective weathering of these dolomites a network of resistent material around cavities, out of which softer material has been removed, gives rise to a rough surface. This layer may reach a thickness of 10-15 m, and is found on the Mendola cuesta, W of Prisciano and N of Proves in the Rio Campo. At the latter locality the cellular dolomite is accompanied by occurrences of light-coloured gypsum. Similar intercalations of gypsum in the Strata of Campil are reported by Vacek & Hammer (1911) S of Trento.
At several localities, however, this dolomitic horizon is not found. The anisian starts, in the Western Dolomites, with a conglomerate, in which pebbles of the cellular dolomite occur. Therefore the local absence

of the cellular dolomite needs not be due to the fact, that it was not deposited, but it is thought more probable that, during the erosion interval at the end of the skythian, these dolomitic beds were eroded.

The skythian forms one of the most fossiliferous formations of the triassic deposits in the Dolomites. Apart from those, which occur mainly in the 'Gastropodenoölit' (*Holopella gracilior* SCH. and *Ostrea ostracina* SCHL.) the following fossils may be found: In particular near the base of the Strata of Siusi, many *Myacites*, *Myophoria* and a very small *Bellerophon* sp. are encountered. This *Bellerophon* is not the same one, after which the Bellerophon Stage is named. Frequent is *Pseudomonotis clarai* EMM.
All through the skythian *Avicula clarai* EMM is found. Mostly confined to the higher levels of the skythian are *Naticella costata* and *Turbo rectecostatus*.

From a tectonic point of view, the skythian is an important horizon in all the southern Alps. Being situated between the competent masses of the permian rhyolites and the overlying rigid dolomites of the middle and upper triassic, the skythian forms an incompetent, thinly bedded, complex of strata, in which numerous tectonic features can be studied. In many cases this formation has been used as a sliding plane for large horizontal displacements of the sedimentary cover (Fallot 1946, 1950, and 1955; Signorini 1951 and 1955; de Sitter 1949; etc.).

2. Anisian

The middle triassic of the Dolomites, and of the northern Limestone Alps too, is characterized by a great many facies changes in vertical and horizontal directions. During the anisian they occur in a comparatively moderate measure, reaching their maximum intensity during the ladinian. Innumerable studies have been dedicated to the stratigraphy of the middle and upper triassic of the Dolomites, the name of which is so closely connected with the most prominent of the triassic rocks, the dolomite.
The scenery of the Dolomites is largely built up by high scarps of this almost white rock, which forms exposures of over 1000 m uninterrupted height. Along the Adige river too, the western bank of this stream is formed by a steep cuesta of middle and upper triassic dolomites. The M. Roén (NW of Termeno), for instance, rises almost 2000 m above the Adige valley.
It is beyond the scope of this local tectonic study to unravel the facies changes that took place in the central Dolomites, though the stratigraphy of our area can only be understood by comparing it with that of the more eastern deposits.
The cellular dolomite and the intercalations of gypsum that are found in the upper parts of the skythian formation, announced in our area a regression of the sea. The anisian starts with a conglomerate, the pebbles of which are derived from the underlying skythian sandstones, marls and cellular dolomite. It is called the 'Conglomerate of Richthoven'*), and is thought to accompany the anisian transgression. The well rounded – maximum diameter 5 cm – constituents lay dispersed in the groundmass, mostly a red sandstone. North of Senale, this conglomerate consists of six layers, reaching a total thickness of 5 metres. At the Mendola cuesta the thickness ranges from 3 to 12 m. In our area the conglomerates are always present at the base of the anisian. East of Bolzano this conglomerate is still found, but near Predazzo, and in the central Dolomites the sedimentation has not been interrupted by a regression, and consequently the 'Conglomerate of Richthoven' is absent.
On top of the conglomerate, by gradual passage, a complex of red sandstones and shales of a 30 m thickness has been deposited. In its higher levels, intercalations of calcareous and dolomitic marls of yellow-brown and grey colours are frequent. In this complex plant remains of *Voltzia recubariensis* are abundantly found. A steady decrease may be noticed of the supplied clastic material in the upper parts of the anisian, which are mainly composed of mostly compact limestone beds, in which *Rhizocorallia* and stems of Crinoides may be found.
On the M. Osol (N of Revo), this horizon is rich in *Diplopora annulatissima* (Pia 1925). In the central Dolomites this alga is known to represent the uppermost anisian (Hummel 1932; Rosenberg 1959). This calcareous upper part of the anisian is a 15 m thick in the eastern half of the Val-di-Non area (Adige valley and near Senale). The outcrops near the Judicaria fault are for the greater part covered by scree material from the overlying dolomites, but it is thought, basing this opinion on observations by Lepsius (1878), that the calcareous upper part of the anisian here reaches a thickness of a 70 m.
The transition from the anisian limestones, which are slightly dolomitic, to the thick ladinian dolomites, is very gradual. The shaly intercalations between the limestone beds disappear in the higher levels, while the dolomitic character increases.
In our area the supply of detrital material stopped entirely at the end of the anisian and it revived during the carnian.

3. Ladinian

('Nonsbergdolomit' and basaltic volcanism, see table II)

On top of the anisian formation, a 500-800 m thick complex of dolomites has been laid down. It is a

*) After the geologist Richthoven, who worked the Dolomites a century ago.

monotonous, light-coloured deposit, mostly well bedded, in its lower parts sometimes massive. The thickness of the individual beds ranges from 20 to 50 cm. In weathered state, these often saccharoidal dolomites have a yellow-white colour; on fractures, and near faults, reddish colours are often seen.

At many places in these dolomites *Diplopora annulata* may be found. Pia (1925), studying other parts of the Dolomites, where stratigraphic boundaries are better known, found this *Diplopora annulata* to be characteristic for the ladinian of the southern Alps and the northern Limestone Alps. This alga is entering in the dolomites near the base of the complex. Near the M. Osol (W of Cloz) they are reported (Pia 1925) to be still present near the top of the dolomites, where these are overlain by the carnian series.

It is generally accepted now, that these dolomites are almost entirely of lower ladinian (i.e. fassan) age (Rosenberg 1959). They are therefore contemporaneous with the 'Buchensteiner Schichten', the 'Marmolatakalk' and partly with the 'Schlerndolomit', which are all found in the more central Dolomites.

The lower ladinian (= fassan) age of this dolomitic complex is emphasized by the find of a thin bed of dark-grey 'Bänderkalke' on top of these dolomites, near the Passo della Mendola (Vacek 1903; Vacek & Hammer 1911). 1 Km SW of the Passo della Mendola, a similar horizon is present, in which concretions of black chert occur. These finds are best parallelized with the 'Bänderkalke' and 'Kieselkalke' on top of the 'Buchensteiner Schichten' (Hummel 1932; Rosenberg 1959), that were deposited towards the end of the fassan (lower ladinian).

These ladinian dolomites are beautifully exposed on the steep cuesta of the Passo della Mendola. This induced Richthoven, in 1859, to name this rock 'Mendola dolomite' ('Mendeldolomit'), attributing at the same time an anisian age to these dolomites, this in analogy with dolomites of true anisian age farther to the east (e.g. Fassa valley), where the dolomitic facies developed earlier than in our region. The anisian dolomites there are still called 'Mendeldolomit'. The lower ladinian dolomites, exposed on the Passo della Mendola, however, had rather be referred to as 'Nonsbergdolomit', i.e. dolomite of the Val-di-Non, to avoid the confusing term of 'Mendeldolomit' (Hummel 1932; Rosenberg 1959).

It must be kept in mind, however, that in the lower part of the 'Nonsbergdolomit' the *Diplopora annulata* is not yet present. This lower part still might belong to the anisian, and form a thin formation which may be correlated with the much thicker 'Mendeldolomit' of the central Dolomites, near Fassa etc.

This example may illustrate the very complicated stratigraphy (and nomenclature!) of the Dolomitic region.

The reaction of the dolomites (both ladinian and norian) to tectonic deformation is completely different from that displayed by the skythian rocks and the shales of the anisian. Foldings are hardly observed, fractures and fracture zones are normal occurrences. At those places, where the dolomites are forced to bend or yield, e.g. near the Foiana fault, they are completely brecciated and splintered. Consequently the bedding is obscured and the fossilizations are destroyed, so it is often impossible to tell, which of the dolomitic formations – ladinian or norian – is exposed. The deposition of ladinian formations, younger than the 'Bänderkalke' of the upper fassan, cannot be proved directly. This would point to a stratigraphic break during the middle and upper ladinian in the Val-di-Non area.

In the more central parts of the Dolomites, the middle and upper ladinian are well known by their facies changes: the volcanic facies ('Wengener- and Cassianer Schichten') beside the dolomitic and calcareous facies ('Schlerndolomit' and 'Marmolata- and Latemarkalk'). The volcanic facies – in particular the middle ladinian 'Wengener Schichten' – is characterized by the effusion of basalts and augiteporphyrites. Famous outcrops of this widespread volcanic activity are found near Siusi and in the Fassa valley (See Table II). In our area, too, basaltic effusions, their tuffs and agglomerates are known. Near the Passo della Mendola and Ruffré (and further to the north) they immediately overlie the 'Bänderkalke' of late fassan age, near Cagno a 5 km long exposure of the volcanics is locally well observable; here they are covering the lower ladinian dolomites, like in an isolated outcrop WNW of the M. Macaion. The latter outcrop may be linked with that of the Passo della Mendola, for the interjacent area is hardly exposed; this is largely due to scree material of the overlying norian dolomites.

The basalts (called melaphyrs by most authors, who worked this region) and their tuffs are very dark coloured; weathering calls forth reddish or greenish tints. Throughout our area they are confined to the same stratigraphic horizon, being covered always by strata of carnian age. The lower and upper contacts with the enclosing beds are not exposed in our area, which hinders an accurate estimate of the thickness of the series. Along the road from the Mendola pass to Fondo, an outcrop of this volcanic series is seen of at least 40 m thickness. Towards the south this series is repeatedly found, thinning out to 6 m, north of M. Roén. In the scarp of this mountain, it has wedged out completely. Near Cagno the thickness exceeds 30 m; it wedges out to a 20 m N. of Cagno.

Microscopically a holocrystalline rock is seen to consist mainly of plagioclase (labradorite) in idiomorphic laths. Less abundant are augite, olivine and magnetite. The plagioclase often shows zoning; its boundaries are fresher than the more central parts of the crystals,

which may be slightly affected be sericitization and chloritization and contain some small inclusions. The augite – light-green to colourless – is present in euhedral crystals or beautifully developed four- and eightsided cross sections, the latter frequently showing (100) – twinning. Some crystals suffered alteration to a submicroscopic chloritic mass.
Olivine is not always present. According to Lepsius (1878) it is lacking in the basalts north of Cagno, where the basalts are also more porphyritic. In other occurrences it may form a constituent up to 8-10% of the total mass. Magnetite occurs dispersed throughout the rock, and may be concentrated near altered augite.
A chemical analysis of the rock was published by Lepsius (1878, p. 166).
This basic volcanism of the Val-di-Non area is thought by most authors (Lepsius 1878; Vacek & Hammer 1911; Trener 1933; Von Klebelsberg 1935) to be of carnian age, the only evidence for this assumption being the fact that they are directly overlain by carnian strata. Since we know, however, that the underlying formation is of fassan (lower ladinian) age, a middle and upper ladinian age should not a priori be precluded. In fact, it is more reasonable to correlate these basic volcanic rocks with the widespread basaltic and augite-porphyritic effusions of the 'Wengener Schichten' as found near Siusi, instead of assuming a more or less isolated – in time and space – volcanic activity.
Geological and petrographical descriptions of the 'Wengener'-volcanism by Hummel, von Klebelsberg and Heritsch-Kühn (1939) bear great resemblance to our findings in the Val-di-Non area. Also their chemical analyses adduce additional evidence (Von Klebelsberg 1935, p. 348 and 349).
A direct check on the connection between volcanic activity in the Val-di-Non area and around Siusi is hindered by the absence, due to erosion, of triassic strata between these two localities. The observation of a greater thickness of the basaltic formation near the Passo della Mendola, in comparison with the one near Cagno, might indicate that the volcanic material was supplied from an eastern direction.

4. Carnian

('Raibler Schichten', 'Zwischenbildung')

In the southern Alps and the northern Limestone-Alps, the carnian reflects an epoch of increased detrital – mainly fine clastic – sedimentation.
In our area the carnian is not fossiliferous, but its stratigraphic position is based on lithological grounds, by comparing it with the fossiliferous carnian strata in the central Dolomites. Many-coloured shales being a main constituent of the carnian series, it forms a conspicuous horizon of changing thickness (max. ± 40 m), as it is comprised between the two massive complexes of light-coloured dolomite of the lower ladinian and the norian. At other localities it is overlying the middle ladinian volcanic series.
The formation does not form an uninterrupted sedimentary layer, but is, in fact, of irregular thickness and may locally be absent. Judging by the stratigraphic sections given below, the carnian is also rapidly changing its appearance in lateral directions. All these properties make a sedimentation in undeep water probable.
At the Passo della Mendola (Ruffré) the carnian consists of:

Top: Norian dolomite.
15 m Gradual passage to yellow and white dolomitic strata, intercalations of light-coloured shales.

TABLE II

	CENTRAL DOLOMITES		VAL-DI-NON AREA
	Volcanic facies	*Calcareous facies*	
CARNIAN	'Raibler Schichten'	'Raibler Schichten'	'Raibler Schichten'
LADINIAN Upper	'Cassianer Schichten'	'Schlern-Dolomit' + 'Latemar- Marmolata Kalk'	—
Middle	'Wengener Schichten' + basaltic volcanism		Basaltic volcanism
Lower = (Fassan)	'Bänderkalke' 'Buchensteiner Schichten'		'Bänderkalke' 'Nonsbergdolomit' with *Diplopora annulata*
ANISIAN	'Mendeldolomit'	'Mendeldolomit'	'Mendeldolomit'? dolomitic limestone with *Diplopora annulatissima* Shales (Conglomerate)

Table II. Simplified facies distribution in the central Dolomites and in the Val-di-Non area, during the anisian, ladinian, and carnian.

10 m	Dolomites (often red), with intercalations of red and green shales.
3 m	Conglomeratic beds, with rounded pebbles (of quartz and quartzporphyry?) max. diameter 8 cm; red colours in the shaly groundmass.
Bottom:	Tuffs and agglomerates of the middle ladinian volcanism.

Towards the south this formation is thinning out to vanish near the M. Roén.

South of Cagno, in a natural quarry the following sequence is found:

Top:	Norian dolomite.
40 m	Dolomitic beds, alternating with red, green and yellow shales and marls; the latter showing many lateral changes in thickness. Dolomites with reddish colours.
30 m	Not exposed.
Bottom:	Volcanic series of the middle ladinian.

On the western bank of the Novella gorge, opposite Tret, the carnian is formed by:

Top:	Norian dolomite.
2-4 m	Yellow, soft dolomitic beds.
20 m	Grey, harder dolomites, alternating with shales of grey and green colours.
3 m	Red, soft shales and marls.
Bottom:	Lower ladinian 'Nonsbergdolomit'.

Some interresting sub-recent sliding phenomena are closely connected with the carnian shales (see chapter III).

5. Norian
('Hauptdolomit')

The next-higher formation is formed by the very thick, 600-750 m, dolomites of the norian. A calcareous or dolomitic facies is found all through the eastern Alps in this time. The unstable conditions during the ladinian reflected by its many facies changes, came to a close during the carnian. The supply of fine clastic material is confined to the carnian and died out during the early norian.
On the plateau of the central Dolomites this norian dolomite – mostly called 'Hauptdolomit' – reaches considerable thickness, but towards its borders it has recently been attacked by erosion. The Val-di-Non area, however, is in a favourable posititon, because of its regional dip of $\pm$ 15° to the WSW, so here the 'Hauptdolomit' is present again in its full thickness. It is a well bedded – beds of 30 to 100 cm thick – formation of a grey or dark-grey weathering dolomite, mostly less saccharoidal than the lower ladinian 'Nonsbergdolomit'. Locally it contains *Turbo solitarius*. The norian is underlain by the carnian many-coloured shales or, if the the latter are absent, by the 'Nonsbergdolomit'.
Both the 'Nonsberg- and the Hauptdolomit' cover large areas in our region, forming a slightly WSW-dipping dip-slope, which is cut off by the Adige river, where a steep cuesta originated (see sections I to VI). The dip-slopes of the dolomitic material are dry and are covered by extensive woods. Agriculture is only practised near the carnian horizon, as its shales are better capable of retaining water (Surroundings of Tret and farther to the N and NW; around, and N of Ruffré).
It is observed that some faults, cutting the dolomites, cause locally marsh-like, wet strips of ground amidst the dry woods. A similar phenomenon is described by Wiebols (1938) in the dolomites of the Brenta area.
The upper portions of the 'Hauptdolomit' may locally be of rhaetian age, though a check on this assumption is difficult, owing to lack of fossils in our area. Near Mezzocorona a distinction between dolomites of norian and rhaetian age is still possible (Trener 1933), but farther to the north, in our region, the – mainly lithological – differences become blurred.

It is interesting to enumerate the different formations, which are directly overlying the 'Hauptdolomit' in this area. They inform us about the paleogeography during the jurassic and cretaceous.
Five basicly different sequences are seen, which are schematically represented in Table III.
Lower and middle jurassic are found on top of the 'Hauptdolomit' near Vigo and in the AGIP drilling well of Mollaro, (Column I of Table III). Farther to the north they are not present.
The two next-higher formations – upper jurassic and Cenomanian – are deposits of little thickness and are confined to areas which partly coincide. All four combinations, that are theoretically possible, are found: both, either of the two or none (resp. columns II, III - IV and V). In this last case the senonian rocks directly overlie the upper triassic 'Hauptdolomit'.

6. Rhaetian

Apart from the questionable upper part of the 'Hauptdolomit', the rhaetian is thought to be present only at one isolated location near the Judicaria fault, NW of S. Giacomo. The bad exposure of these rocks allows only to describe them as a well bedded, dark- or light-grey limestone. Weathering may give it a brown or violet tint. It forms the northern-most part of a great complex of rhaetian strata, that are found west of Cles, in the Brenta area and farther southward. They are

TABLE III

Formation \ Locality	I Vigo	II e.g. Vervo	III e.g. Castelfondo	IV e.g. Mollaro	V e.g. Sanzeno
Senonian	×	×	×	×	×
Cenomanian	×	×	—	×	—
Upper jurassic	×	×	×	—	—
Lower & middle jurassic	×	—	—	—	—
'Hauptdolomit'	×	×	×	×	×

TABLE III. The five different combinations of formations overlying the 'Hauptdolomit'.
× = Formation present.
— = Stratigraphic break.

described by Wiebols (1938), Trevisan (1939 a) and Vecchia (1957), who studied there the two different facies, which started their development during the rhaetian: the well-known venetian (E) and lombardian (W) facies. Their views on the limits between these two facies may be briefly summarized here.

Trevisan thinks the facies limits in the Brenta area to coincide with the major faultlines, which run about parallel to the Judicaria fault, i.e. NNE-SSW. (see geological sketch map of the Judicaria region, enclosure 1 and figure 40). The faults forming the facies limit between the venetian and lombardian facies of the rhaetian deposits, are named the Molveno fault and the northern part of the Clamer-Rossati fault. Closely connected with this opinion are his views that *large horizontal movements* along these faults, should have caused the present-day facies differences at either side of the faults.

Vecchia, on the other hand, basing his findings on studies of a more extensive area, attacks the stratigraphic concepts of Trevisan and points with emphasis to the *gradual* passage of one facies into the other, which takes place in the blocks comprised between the faults of the Brenta area. On other grounds, too, he denies the existence of the strike-slip faulting over so large distances – 30 km –, as advocated by Trevisan.

f. JURASSIC

1. Lower and Middle Jurassic

The lower and middle jurassic formations are confined to the southern-most parts of the Val-di-Non area. In the middle and northern parts they have not been deposited (see Table III). Farther southward, around Trento and in the Brenta area, they are well developed. In the central Dolomites they occur only in isolated outcrops, the bulk of them being removed by erosion. In the AGIP drilling of Mollaro lias and dogger formations are reported (personal communication) of 87 m and 55 m thickness respectively. Near Vigo the same formations are met with, both possibly reaching a greater thickness there. The liassic strata are formed by well bedded, grey (sometimes reddish) limestones. The dogger consists of oölitic limestones at its base, towards higher levels gaining a more dolomitic composition.

Of great importance is the absence of the lower and middle jurassic strata in the Taio overthrust block. It is seen there, that the 'Hauptdolomit' is directly overlain by upper jurassic or even cenomanian deposits, while in the drilling well of Mollaro – at a distance of about 1 km – a 142 m thick complex of lower and middle jurassic strata is intercalated. Apart from the tectonic evidence, this stratigraphic feature, too, demonstrates the importance of the overthrust faulting, by which the Taio block was transported over a distance of about 3-4 km, from the NNW to the SSE. This overthrust block forms a small-scale 'Nappe', showing a stratigraphy of more northern development (absence of lias and dogger) amidst a more southern stratigraphic sequence in which lias and dogger start their development.

The stratigraphic break in the northern half of our area, was accompanied by a temporary affect by sea water, or possibly a subaerial erosion, of the underlying 'Hauptdolomit'. This is reflected by the weathered status of its upper beds, immediately underlying the upper jurassic strata.

In the Brenta area the development of a venetian (E) and a lombardian (W) facies beside one another continues during the jurassic. And again the opinions of Trevisan (1939) and Vecchia (1957) differ on the facies limits. The facies limit, according to Trevisan, has leaped over from the Molveno and Clamer-Rossati faults (during the rhaetian) to the more western 'Vedretta dei Camosci' fault. Vecchia however, maintains that the facies change is not connected with faults or other tectonic features.

2. Upper Jurassic
('Ammonitico rosso')

Overlying the 'Hauptdolomit' – or the middle jurassic strata when present – the upper jurassic formation is represented by a well bedded complex of limestones. Its thickness ranges from 3 to 5 m only, it may reach 10 m in the southern half of our area. Locally the series is lacking, which is partly due to later erosion during the cenomanian and senonian transgressions. On the other hand it must be emphasized, that sedimentary conditions during the jurassic were unstable. Teichmüller (1929) points to the transgressive character of the tithonian, in which breccias of underlying formations occur; even rounded pebbles of the permian effusive system are reported (for instance near Trento). He concludes that the jurassic strata were deposited in basins of a complicated and changing pattern, separated by ridges.

In fresh outcrops the compact limestones are white, with faint reddish or green tints; weathering rapidly evokes a typical red colour ('Ammonitico rosso') and renders a brecciated character to the rocks. As they constitute a layer of greater endurance against weathering than the enclosing formations, many dip-slopes on the overthrust block of Taio are formed by this rock. In many quarries, this limestone is worked for building stone, because of these properties. Dispersed cubes of pyrite are found at many instances. Fossilizations are rare and mostly badly preserved. A distinction in a lower part with *Aspidoceras acanthicum* and a higher one with *Terebratula diphya* seems justified (Trener 1933). They represent the kimmeridgian and tithonian respectively.

In the Val-di-Non area deposits of the oxfordian and lusitanian are not present.

g. CRETACEOUS

1. Cenomanian
('Scisti neri' and 'Biancone')

After a stratigraphic break during the lower cretaceous, the upper cretaceous is announced by the cenomanian transgression. Many interesting details on the cenomanian and senonian deposits are reported by Teichmüller (1929) and by Patriciu and Teichmüller (1930), who studied the complicated stratigraphic relations in the southern Val-di-Non and northern Brenta area. East of Mollaro an occurrence is found of black bituminous shales ('scisti neri'), 0,5-2,00 m thick. At its base there is often a conglomeratic layer separating them from the underlying 'Hauptdolomit' (see column IV of Table III). Patriciu and Teichmüller stated that this bituminous formation of Mollaro – and also the identical one in the northern Brenta area – was deposited in an isolated, shallow, hardly aeriated basin. The conglomerate derived its constituents from nearby triassic formations. The very thin bedded black shales contain much ($> 20\%$) organic matter, ore grains (pyrite and marcasite) and foraminifera; the latter permit no determination, because of recrystallization. The cenomanian age of these 'scisti neri' is mainly based on the find of *Belemnites ultimus D'ORB* by Fabiani (1923).

The high content of organic, bituminous matter permits the extraction, by means of distillation of the 'scisti neri', of the pharmaceutical product ichthyol. Detailed data on the chemical properties of these shales and its destillation product are provided by Castelli (1924).

On top of this shale complex, an alternation of grey and dark-grey limestones and thin intercalations of black shales sets in, reaching a thickness of a 20 m. The limestone beds are rich in foraminifera shells. Patriciu and Teichmüller (1930; p. 246) mention the following species:

Lagena apiculata REUSS
Discorbina canaliculata REUSS
D. biconcava PARKER JONES
Anomalina ammonoides REUSS
Globigerina cretacea D'ORB.

Fragments of bivalves and echinodermata complete the fauna of these limestones.

In our area the extension of the bituminous shales is limited, as they are only found E of Mollaro. The alternation of limestones and thin shales is less rare. Specially as black cherts are often present in the limestone layers, their similarity with the wellknown 'Biancone' is striking. The 'Biancone' is the venetian facies of the cenomanian formations, and it covers large areas farther to the south.

The rapid alternation of limestones and shales favoured the intense folding of this formation north of Prio (see chapter III,-6).

2. Senonian
(It.: 'Scaglia'; Fr.: 'Couches rouges')

In continuous extension in many parts of the Alps the red limestones and marls of the senonian are deposited. In our area they form an about 150 m thick complex in which red (brick-red) colours prevail over grey ones. Looked at from a distance, their bedding seems well developed, but from close by it is less distinct, due to the typical weathering of this rock, by which it falls apart in splinters (It.: Scaglia). Finely dispersed throughout the marls, small quartz grains occur in changing amount. The senonian age is confirmed by the abundant find of *Globotruncana*. More

fossils are reported by Lepsius, Teichmüller (1929) and Vialli (1938). In particular *Stenonia tuberculata* is locally frequent.
Near its base, chert concretions of dark-red and yellow to brown colour are often met (Novella gorge, opposite Romallo; north-west of Vervo). In these instances, thus, a gradual lithological passage from the cenomanian into the senonian is seen. Specially near Trento (Trener 1933) this hinders drawing a sharp limit between the two formations. Also in higher levels chert may occur (Noce valley, west of Mollaro). As mentioned above (Table III) the senonian is not always underlain by the cenomanian. Because of stratigraphic breaks and erosion features preceding the cenomanian and senonian deposition, the 'Scaglia' is sometimes directly overlying the upper jurassic or the upper triassic.
Erosion phenomena near the base of the senonian are described in great detail by Teichmüller (1929). The area studied by him is found west of the region covered by our geological map, i.e. west and south of Cles. He found there a folding of the pre-senonian strata, which are transgressively overlain by the 'Scaglia'. The base of the 'Scaglia' is formed by a breccia of sometimes enormous (up to 100 m^3) blocks of 'Hauptdolomit' and jurassic rocks, cemented by the red calcareous material of senonian age. This breccia seems to be restricted to a zone, running roughly N 20° E (i.e. parallel with the Judicaria fault), from Stenico in the south up to west of Cles, where the breccia is found over many kilometres, forming the northern end of this zone.

This highly interesting area originally formed part of our study. The pre-senonian folding phase, however, blurs the later deformations to such a degree, that this badly exposed area does not provide trustworthy evidence for this tectonic study. Besides, in this area a stratigraphy developed since the late triassic, which is closely connected with the Brenta area; a study of this area, therefore, should rather be started from the south.

Along the Judicaria fault, from Rumo to the south the senonian is present in the wedge of young sediments that accompanies this fault. The appearance of the 'Scaglia', however, has changed considerably. This may be best illustrated by the fact that Vacek and Hammer (1911; p. 90) mistook this 'Scaglia' for a lower jurassic formation, in other words, the rock looks 'older' than the 'Scaglia' we know from other places. The brick-red colours have changed to dark-red and dark-grey, green tints are often seen. The weathering into the typical splinters gives way to a more compact rock, often thin bedded or fissile. The occurrence of *Globotruncana*, however, proves their senonian age.
It is obvious that the 'Scaglia' here is slightly metamorphosed. This is, in fact, the case with most rocks that form part of the wedges along the Judicaria fault. The changes are certainly not caused by dynamo-metamorphism, as these wedges have not been subjected to strong deformational forces.
The most probable source of the metamorphism is found in the tonalitic intrusions, which occur all along the peri-adriatic fault zone. Indeed, south of Rumo several of these intrusions are found. They suggest a larger tonalitic mass – possibly connecting the tonalites of the Adamello massif with those of the M. Croce*) – to be present at small depth (see section V). The heat flow from this tonalitic mass must be the direct cause of the metamorphism in the surrounding sediments.

The senonian rocks are often showing considerable deformations; both folds and faults are well developed, for instance along the southern part of the Foiana fault; north of Castelfondo; along the strike-slip fault of Taio; around the Castel of Thun; etc.

h. TERTIARY

1. Eocene

The lower eocene shows two different developments in the Val-di-Non area. The greatest extension is reached by a marly complex; along the Judicaria fault, however, a conglomeratic and sandy development is found.
East of the Foiana fault the lower eocene forms an at least 150 m thick monotonous complex of bluish-grey and greenish-grey marls and shales. Red colours may prevail in some layers. Often some more resistent, sandy strata are intercalated; weathering may colour them brown and yellow. Mica flakes (biotite) occur dispersed through the formation. The lower eocene is deposited concordantly on top of the senonian 'Scaglia' and in many cases a distinction between the two formations is hindered by their many lithological similarities.
The base of the lower eocene along the Judicaria fault consists of a polymict conglomerate of changing thickness. In its northern-most occurrence, halfway Rumo and Bévia, the thickness reaches its maximum of a 50 m; near Bévia and still farther to the south it decreases to about 4 m. The diameter of the well rounded pebbles shows a similar tendency: in the northern exposures diametres of 20 cm are found near the base of the conglomerate; in higher levels, they decrease notably. In the southern exposures the diameter diminishes to 4 cm.
A great number of the rocks, described in the foregoing pages, supplied constituents for this tertiary conglomerate, ranging from fragments of the crystalline

*) The M. Croce (NE of S. Pancrazio) forms the summit of the tonalitic massif in the northern-most part of the Val-di-Non area.

schists to the chert concretions of the cenomanian 'Biancone'.
On top of the conglomerate – and sometimes intercalated in the conglomerate – a formation, at least 40 m thick, of variable character is found. It is composed mainly of coarse sandstones, which are sometimes calcareous; mica flakes are frequently seen, dispersed through the rock. Some shaly layers are intercalated. In particular the conglomerates are very firmly cemented, which is not expected from so young a formation. Vacek and Hammer again (1911), attributed an early jurassic age to them, misled by the 'old' appearance of the rock. In this case too, a slight metamorphism, caused by the nearby hot tonalitic intrusions, effected recrystallizations, which rendered these eocene rocks their massiveness.

In the Brenta area an identical distribution of facies is reported (Wiebols 1938; Trevisan 1939 a) as found in our area. Along the Judicaria fault a conglomeratic and sandy one; more to the east a marly and shaly development. The conglomerates are of small thickness, the maximal diameter of the pebbles is about 2 cm; they are very well rounded and contain only hard constituents, the fragments of schists are missing, for instance. They therefore seem to be more mature than the conglomerates found in our area.
Two interesting features are to be learned from these lower eocene deposits:

1. From their properties in the Val-di-Non area alone, and in combination with the exposures in the Brenta area, a supply of coarse material from northern directions may be concluded. Towards southern directions the thickness and the diameter of the pebbles decrease steadily; only hard rock fragments outlive the longer transport.
2. The conglomeratic facies of the lower eocene deposits is confined to a zone – at least 30 km long – *parallel* to the Judicaria fault.

North of Romallo, Lepsius (1878) and Fabiani (1919) report the occurrence of middle and upper eocene formations. Fabiani documents this find by a comprehensive list of fossils.
Nowadays, in the area between Cles and Castelfondo, the exposures are covered by extensive orchards. Some dispersed limestone blocks bear witness of the outcrops of some decades ago. We, therefore, have to rely on the descriptions of Fabiani. The age of the two formations (lutetian and priabonian) is sufficiently established by fossils (*Nummulites perforatus* and *Nummulites fabianii* with *Pecten biaritzensis*). The interrelation of the formations, however, is complicated by – according to Fabiani – a transgression of the priabonian: limestone blocks of lutetian age 'swim' in marls and shales of the priabonian.
The nearness of the Foiana fault, however, suggests that a tectonic interpretation of these observations of Fabiani should not be precluded. Intense deformations along this fault are seen at many places (see sections of figure 15).

2. Mid-tertiary tonalitic intrusions

At many localities on and near the peri-adriatic line, tonalitic intrusions have penetrated the surrounding rocks.
Over a distance of almost 600 km their characteristics exhibit a remarkable stability: apart from their tonalitic chemism and petrography, they show an apparent relation with the peri-adriatic line. An oblong form, parallel to this line is often seen. The massifs may occur too, at some distance from the peri-adriatic line.
Well-known massifs, belonging to this system of intrusions, are – from west to east – the Biella and Traversella syenites, the Bergello, Disgrazia and Adamello tonalites, which all accompany the Insubric fault. The N. Judicaria fault is well provided with intrusions of different sizes: the large Adamello tonalite, at the junction of the Insubric and Judicaria faults, a series of smaller ones between Dimaro and Rumo, and the larger massifs of the M. Croce, Ivigna and Bressanone. This last one is situated on the transition from the Judicaria fault into the Pusteria fault. East of Eisenkappel, in Austria, again a large tonalitic massif is met with.
Descriptions of the M. Croce tonalite are provided by Andreatta (1937), G. B. Dal Piaz (1942), Karl (1959) and Dietzel (1960). The outcrops in our area do not permit a close study of this rock.
The constituting minerals of this tonalite are, in order of quantitative importance: plagioclase, quartz, amphibole and biotite; the quantities of amphibole, potassium-feldspar and quartz are liable to variations, by which the tonalite, locally, may grade into K-feldspar-rich tonalite, quartz-diorite or granite.
Karl (1959) – in an interesting petrographic study on the peri-adriatic tonalite massifs, and their relation with the granites of the Tauern Window (Austria) – advocates a *syntectonic* intrusion and principal crystallization of the tonalite massifs. This crystallization is characterized by protoclastic structures and took place in a sub-volcanic or 'hochplutonisch' environment. It is not impossible that the intruding magma already contained crystallized minerals, which is specially probable for the very basic (An_{85-60}) cores of zoned plagioclase crystals.
A second and last phase of crystallization of the rest magma is accompanied by many autometamorphic phenomena, under conditions of little depth. These findings of Karl are in good agreement with the older petrotectonic study of Andreatta (1937).

Apart from this detailed information on the intrusions along the Judicaria fault, Karl concludes, on petrographic, chemical and field-geological evidence, to the 'Zusammenfassung der Tauern-Tonalitgranite und Periadriatica zu einem 'Tonalit-Granit-Stamm' ', because of the great resemblance in many details of the petrogenesis in the two adjoining petrographical provinces (Karl 1959, p. 187).

In the Tauern Window, too, two crystallizations took place, but they are separated by a tectonic phase. And the last crystallization has the character of regional metamorphism, and happened, thus, at a greater depth than the corresponding crystallization in the peri-adriatic tonalites. This causes the different mineral parageneses in the two provinces.

Throughout the tonalite, inclusions of different sizes are frequently met with. In spite of the metamorphism they have undergone, they seem to be blocks of sericite-chlorite schists, gneisses and quartzites, carried along by the tonalitic magma during its intrusion.
Numerous dykes are cutting the M. Croce tonalite itself and – in our area – the surrounding quartz-phyllite series. According to Andreatta (1937) and G. B. Dal Piaz (1942) they may be classified as aplites, basic dykes and granitic porphyries. For their petrographic descriptions we may refer to these authors. On their contacts with the quartz-phyllites, the tonalite and its apophyses caused contactmetamorphism, as described on page 14.
At its eastern side, the tonalite massif of the M. Croce is cut off by the Foiana fault. Apophyses and contactmetamorphism in the adjoining lower triassic and permian rocks are *not* observed (Andreatta 1937; Dietzel 1960). The contact here, seems to be a purely tectonic one.
The tertiary age of the dykes in the quartz-phyllite series, and their relation with the tonalite, which they are assumed to be derived from, is not certain in all cases. In particular the dykes of granitic porphyries might as well be of permian age.

South of Rumo, on the Judicaria fault, a series of eight tonalitic intrusions was reported by G. Dal Piaz in 1926. Later investigations by Schmidegg (1936) and Andreatta (1953) demonstrated that at least some of the eight intrusions formed one, continuous plate, of tonalitic to quartz-dioritic composition, coinciding with the Judicaria fault. They suffered strong mylonitization. Andreatta (1953, p. 102) mentions the presence of contactmetamorphic phenomena in the katazonal crystalline schists, NW of the Judicaria fault, caused by the intrusions. The sediments, SE of the fault, are not contactmetamorphically altered. They only show some light recrystallizations, as mentioned on page 30 and 31, probably caused by a heating up of a larger area by the tonalitic masses at shallow depth.

Near Samoclevo (just outside our map, SW of S. Giacomo), G. Dal Piaz (1926) reports a 20 m thick tonalitic intrusion, coinciding again with the Judicaria fault. The tonalite is in contact with oligocene limestones (*Lepidocyclina*), which make their appearance there. This is not a purely tectonic contact, because of contactmetamorphic minerals (garnets), observed there. Mylonitization of this intrusive tonalite is reported by G. B. Dal Piaz (1942; p. 105, 106).
These observations afford us to make some speculations on the age of the Judicaria fault and the tonalite intrusions.
The intrusions take place towards the end of the principal movements along the Judicaria fault. For some intrusions suffer mylonitization, others do not. One of the intrusions (near Samoclevo) is in contact with oligocene strata.
In the miocene molasse conglomerates near Como, rounded pebbles of the Disgrazia tonalite massif (West of the lake Como) are found (Cornelius and Furlani-Cornelius 1931).
Assuming that the tonalites in this part of the Alps intruded rather simultaneously, we must date their *intrusion as late oligocene or early miocene*.
The principal movements along the Judicaria fault have finished by that time.
In the crystalline schists of the Central Alps, NW of the Judicaria fault, many small-scale intrusions are found. They comprise both syntectonic and post-tectonic, mainly granitic rock series. They have been studied extensively by Andreatta, to whom may be referred here (Andreatta 1948, 1952 and 1953; Andreatta and Pirani 1954).

i. QUATERNARY

During the quaternary glaciations our area was completely covered by glaciers.
In their recessional stage they left locally thick deposits. Some of them are totally unsorted and unstratified, forming typical boulder clays (Rio dei Prati). Others show distinct stratification and contain layers of coarse material, alternating with finer sandy strata. These deposits might be laid down during periglacial conditions (Fondo, Castelfondo).
The next-important quaternary formation is formed by the alluvial deposits of the Adige valley and the Noce valley. They both provide fertile soils, mainly in use for fruitgrowing now.
Two beautiful examples of rockfall and rockslide, both comprising considerable masses of permian quartz-porphyries, may be mentioned here. They are found in and south of Senale, and NE of the Passo della Mendola.
At the foot of all dolomitic scarps large talus cones are

built up by abundant scree material, which is constantly supplied by falling-stones and stone rivers.
Apart from the alluvial plain of the Adige valley no quaternary deposits are marked on our geological map.

h. SUMMARIZING REMARKS ON THE STRATIGRAPHY

Reviewing the sedimentary history of the Val-di-Non area and its surroundings, we see a region in which shallow water sedemintation prevails. Conditions were unstable, periods of regression and transgression succeeded one another, stratigraphic breaks, conglomerates and breccias were met with.
Secondly, our attention is drawn by the role of the Judicaria fault zone, in the periods preceding the main displacement along this fault (late oligocene).
In the foregoing descriptions of the individual formations it is repeatedly seen, that facies changes occur in the immediate neighbourhood of the Judicaria fault. They take place in narrow zones parallel to this fault, causing different facies, east and west of this zone (e.g. the Venetian and Lombardian facies). A brief summary of these facies differences is given in Table IV.
In the Brenta area, Trevisan (1939) even thinks these zones to coincide with the many, large faults (see tectonic sketch map of the Judicaria region, enclosure I) that run parallel to this Judicaria fault. He made the assumption that the facies differences at either side had been caused by large, strike-slip displacements along them, bringing thus synchronous deposits *beside* one another, that were laid down – originally – a great distance from each other. By these strike-slip displacements invariably the E block was thought to have moved relatively towards the north (Trevisan 1939, p. 99, fig. 30). This figure assumes that also along the Judicaria and Foiana faults, such horizontal displacements occurred.
Similar considerations proved very useful in other parts of the Alps. The stratigraphy of the Swiss Helvetides could only be unraveled by assuming large tectonic displacements of enormous sheets of sediments, nappes. By thinking all these nappes replaced in their original position in the sedimentary basin, the observed important differences in facies and thickness, appeared to be reduced to gradual ones, which are simply due to their different position in the sedimentary basin.
In the Brenta area, however, the replacement of the various blocks in their assumed original position, does not create a situation by which the facies differences are eliminated or reduced. It only moves the same problem to an other area.
There are no stratigraphical grounds, therefore, to assume large-scale strike-slip faulting in the Brenta and Val-di-Non area areas, as proposed by Trevisan. His tectonical arguments for such strike-slip faults, which will be reviewed in the next chapter, are hypothetical and not substantiated by field data.
There are, on the contrary, some stratigraphic observations in our area, that plead against strike-slip faulting along the Foiana fault.
Firstly, at both sides of the Foiana fault, in the surroundings of Cles, the middle and lower jurassic formations wedge out towards the north.
Secondly, at both sides of this fault, east and west of Cloz, the extension of the volcanic rocks of the ladinian renders it not plausible that large-scale horizontal movements took place after their deposition. These volcanic rocks were probably supplied from an eastern direction, and they are confined to a roughly triangular region – M. Roén, Preghena and M. Macaion. This regular, triangular form does not seem to be affected by the Foiana fault, by which it is cut.
According to observations of Vecchia (1957), in the Brenta and adjacent areas, the facies changes are not *directly* connected to tectonic lines, as suggested by Trevisan. In general, he finds the facies changes to take place gradually, in NNE-SSW extending zones. NNE-SSW being the strike of the Judicaria fault, and of many of the faults cutting the Brenta area, an *indirect* relation between facies change and fault system is obvious.
The most plausible inference is to consider the zone, in which the many facies changes took place, to be a zone of weakness during at least a part of the the sedimentary history since the permian. Such persistent zones of weakness, often oblique to later structural or orogenic trends, are known to have influenced sedimentation in many an orogene (von Gaertner 1960).
In fact, the direction of the Judicaria fault, NNE-SSW, is a well-known and important direction in Europe, and is named the Rhine-Graben direction in lineament tectonics (Sonder 1956). According to Hupé's classification (Hupé 1958) the Judicaria direction (NNE-SSW) is perpendicular – thus closely related – to one of his 'Pacific' directions (WNW-ESE), which is clearly represented by the Alpine chains from Switserland to the Himalaya (Hupé 1958, p. 5).
Such lineaments may influence the sedimentation in a way as is found along the Judicaria fault, forming a zone of crustal instability, by which facies differences, and changes in thickness originate. Synsedimentary faulting and flexures may form accompanying phenomena.

This way of representing things, offers the opportunity, that the observations of Trevisan (1939 a), Vecchia (1957) and Teichmüller (1929) are not in conflict with one another. This also implies that some of those faults, which Trevisan takes as facies limits, originally are – at least in part – synsedimentary faults or flexures; tertiary reactivation may have changed their character and dimensions (Trümpy 1955 and 1958). The sediments, deposited in this zone along the Judicaria fault, constitute a formation, in which deformations will concentrate, under favourable conditions, because:

1. They are situated in a zone of crustal instability, and
2. Deformations tend to be attracked by that part of a sedimentary complex, where facies changes took place (Trümpy 1955).

TABLE IV

	WESTERN Facies. p.p. Lombardian facies	EASTERN Facies. p.p. Venetian facies
Eocene	Conglomeratic along the Judicaria fault	Marly and shaly
Upper Cretaceous, 'Scaglia'	Zone of breccias from Stenico to Cles	
Cenomanian	'Majolica'	'Biancone'
Upper Jurassic	Radiolarites	Calcareous
M. Jurassic	Variable N: absent	
Lower Jurassic	S: Cherty, 'Selcifero' N: absent	S: grey limestones N: absent
Rhaetian (Brenta area)	Poorly bedded limestones and dolomites Well bedded limestones Absent or dark marls and shales	Absent or dolomitic
Permian		Tregiovo series
	Collio series	Effusive series

TABLE IV. Different facies developments in the Brenta (S) and Val-di-Non (N) areas, separated by faults (Trevisan) or zones (Vecchia) parallel to the Judicaria fault. After Trevisan (1939 a) and Vecchia (1957).

Tectonics

a. TECTONIC POSITION OF THE VAL-DI-NON AREA IN THE ALPINE SYSTEM

(See: Geological sketch map of the Judicaria region, on the geological map, enclosure I, and Tectonic map of the Val-di-Non Area, fig. 5).

A tectonic analysis of the Val-di-Non area as a whole, has not been made till now. Only fragmentary descriptions of some of its tectonic elements could be traced. They mainly deal with its three major faults: the Judicaria and Foiana faults and the faults that border the Taio overthrust block. Previous studies on the area occupied themselves almost entirely with stratigraphic and petrographic surveys.
This is at least remarkable, as this area and the Judicaria fault occupy a key-position in many Alpine orogenic hypotheses.

The peri-adriatic line separates the Central Alps from the Southern Alps. In the part of the alpine orogene under consideration now, 'Central Alps' is used as a collective noun for a complex of crystalline rocks, which are often supposed to belong to the east alpine thrust sheets.
The peri-adriatic line is formed by three faults. From west to east, they are the Insubric, Northern Judicaria and Pusteria faults, extending eastward into the Drau Faultzone. As shown on the tectonic sketch map of the Judicaria region (enclosure I), the Insubric and Pusteria faults extend roughly E-W. The Judicaria fault – striking SSW – links these faults between Dimaro and Mules, by which their regular E-W direction is sharply interrupted over a distance of 75 km.
This change in the direction of the peri-adriatic line gave rise to a great deal of speculations.

Even the peri-adriatic suture itself plays a much disputed part in many theories on alpine orogenesis. It separates two parts of the Alps, each with its own tectonic style.
North of it the intensely folded and thrusted complex of Pennides and east alpine thrust sheets, which are all verging to the north*). South of it the deformations are far less extreme, generally the folds are directed towards the south.
The tectonic function during the alpine orogenesis of the Insubric and Pusteria faults, attributed to them by the various authors, diverges widely.
Kober (1914), for instance, thinks of an orogene built up of three complexes: two outer folded regions, verging outwards, and a central block. The folded regions being present at either side of the peri-adriatic line, he assumes the central block to be squeezed out of this fault by an enormous 'Pilzfalte' – mushroom fold.
Kraus (1951 and 1956) on the other hand, takes the peri-adriatic fault for the scar through which large masses of rock disappeared into depth, sucked down by mighty convection currents.
In many theories (e.g. Argand, Cadisch, Heim and Termier) the zone immediately north of the Insubric fault is formed by the extremely compressed roots of thrust sheets, that are found farther to the north. This compression is thought to be due to the steady northward movement of the Southern Alps.
Staub (1949) maintains that the Insubric fault is only the separation between the roots of the middle and upper east alpine thrust sheets, the true border between Central and Southern Alps being formed by the Orobic thrust, a fault farther southward.
According to van Bemmelen (1957 and 1960 b+c), the peri-adriatic line is a normal fault of great throw, which developed at the southern flank of the rising central alpine geanticline in mid-tertiary time. Secondary, gravitative reactions near this fault may obliterate the original simple structure, for instance in the 'Gailtaler' Alps (van Bemmelen 1957). Recent investigations by Dietzel (1960) on the Judicaria fault in the Merano region, support the validity of this thought for this part of the peri-adriatic line.
This incomplete enumeration of concepts on the tectonic function of the peri-adriatic line, may show the great diversity of thought in this matter.

In order to explain the sudden change of direction of the peri-adriatic line between Dimaro and Mules, some of these authors (Staub 1949 and Kraus 1951) assume that this is due to a sinistral (anti-clock wise) strike-slip faulting along the Judicaria fault. Staub describes this miocene process — the moving of the Dolomitic region farther northward than the Berga-

*) Verging (germ. Vergenz) to the north: folds and overthrusts are directed towards the north, the axial planes of folds are dipping southward.

masc unit — with these words (Staub 1949, p. 380): 'Vollständig gesichert aber ist der tridentinische Vorstoss der Bozener-Front zum Brenner hinauf als der Vormarsch der grossen südalpinen Zentralscholle Tirols gegenüber den westlichen bergamaskischen Elementen. Der ganze Bau des Etschbucht-Gebirges, vom Gardasee und den südlichen Judikarien bis hinauf in die Brenta-Scholle lässt sich ohne einen solchen Sondervorstoss der tridentinischen Einheit zum Dinaridenkopf des Brenners überhaupt nicht verstehen'. Kraus interprets this strike-slip faulting as (Kraus 1951, p. 65-82): 'ein Unterströmen zyklonal im Gegensinn des Uhrzeigers'.

Earlier efforts to explain the Judicaria fault as a strike-slip fault were published by Heritsch (1915). He, too, seems to be guided more by the motive to connect the Insubric fault to the Pusteria fault, rather than by an analysis of the tectonics of the Judicaria fault and its adjacent areas.

Trevisan (1939 a) extrapolates his findings in the Brenta area to the Judicaria and Foiana faults of the Val-di-Non area, assuming thus a sinistral strike-slip faulting along them.

De Sitter, finally, believes also in a rectilinear connection of these faults, previous to a strike-slip faulting along the Judicaria and Foiana faults, a movement by which the Insubric and Pusteria faults were separated (de Sitter 1947, 1956 a and 1956 b).

The first detailed study on the Judicaria fault itself by G. B. Dal Piaz (1942) did not reveal arguments for large-scale strike-slip faulting (G. B. Dal Piaz 1942, p. 119). This also applies to the tectonic study of Dietzel (1960), on the Judicaria fault in the Merano area.

As opposed to the surrounding regions, the Val-di-Non area has recently not been surveyed on structural features. This may be caused by its geologically isolated position. The petrographic and petrotectonic studies of the crystalline schists of the Central Alps (Andreatta 1948, 1952, 1953, and Andreatta and Pirani 1954; Schmidegg 1946) did not cross the Judicaria fault. The surveys of Wiebols (1938) and Trevisan (1939 a and b) on the Brenta area confined themselves to this better exposed region. The recent papers of Leonardi (1955) and Signorini (1951 and 1955) on the geology of the more central Dolomites did not cross the extensive and monotonous exposures of permian effusives, east of the Adige valley. The Bergamasc Alps, farther west, were studied by Dozy (1935 a and b) and De Sitter and De Sitter-Koomans (1949).

Opinions on the general tectonic situation in the Val-di-Non area are expressed by Schwinner (1913) and Trener (1933). The former thinks that in this area the strike directions turn from ENE-WSW (in the north) to SSW-NNE (in the south).

Trener distinguishes three systems of deformations:

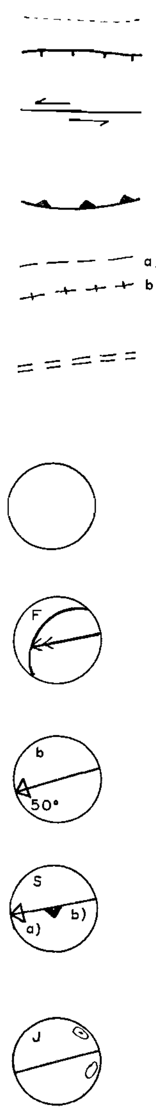
1. Judicaria system, causing deformations with folding axes parallel to this fault.
2. Valsugana system, responsible for deformations that strike WSW-ENE.
3. Interferences between the systems 1 and 2.

The opinions of the various authors on the individual tectonic elements will be mentioned in the following paragraphs, dedicated to these elements.

b. DESCRIPTION AND SIGNIFICANCE OF THE TECTONIC ELEMENTS

In order to describe the structure of the Val-di-Non area, a division into six tectonic units is introduced. These units are, in order of their treatment in this study (see fig. 5):

Fig. 5. Tectonic map of the Val-di-Non area.



Formation boundary

Fault, barbs on downthrown side

Strike-slip fault

Overthrust

a) Folding trend in general, and synclinal axis

b) Anticlinal axis

Axis of the Foiana depression

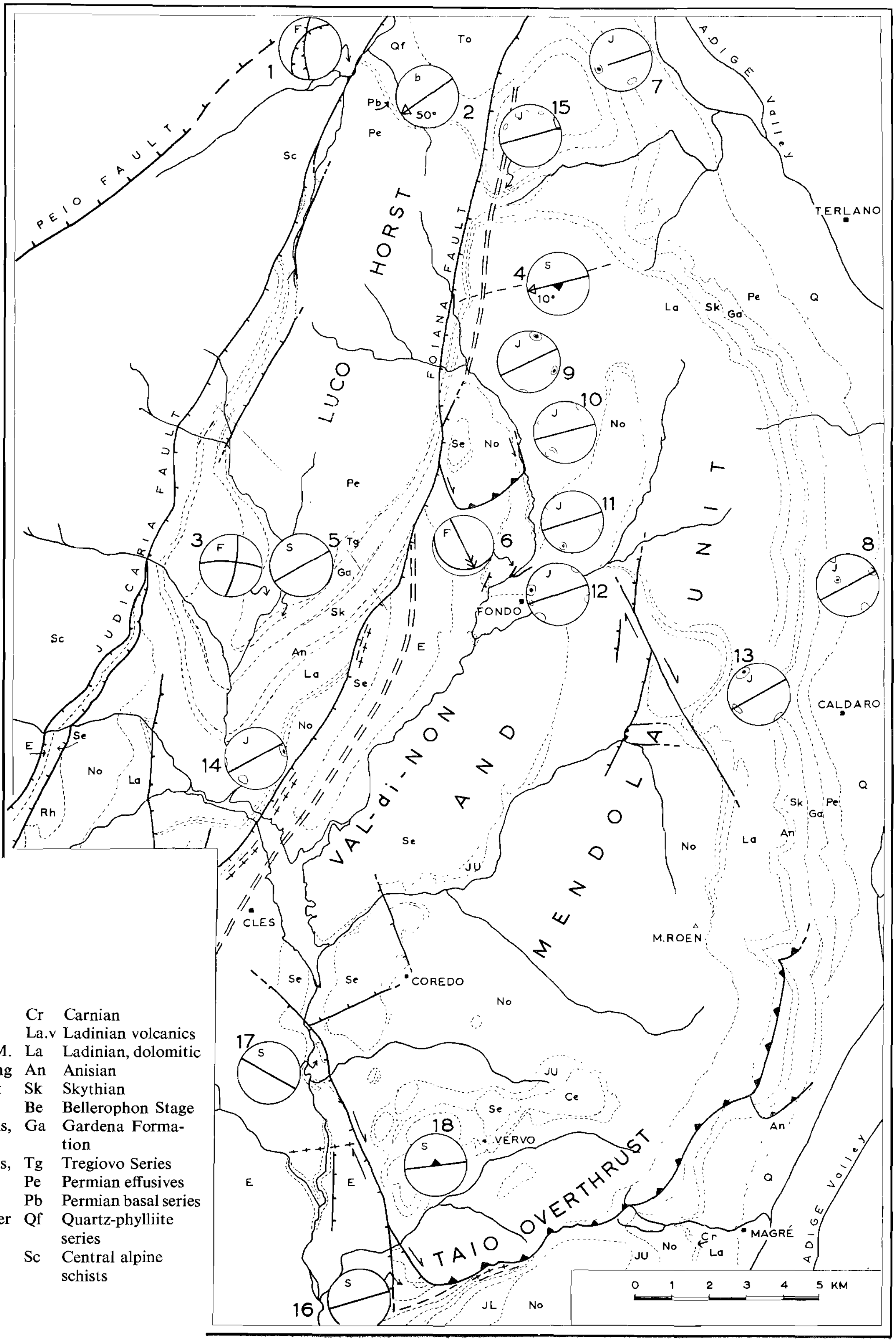
Position of tectonic diagram (or diagram series)

Diagram dealing with faults and striae on fault plane (arrow indicating relative displacement of upper block)

Diagram dealing with *b*-axes in quartz-phyllites, with indication of their mean inclination

Diagram dealing with bedding planes, from which is constructed a) azimuth and dip of fold axis
b) direction of folding (Vergenz).

Diagram dealing with joints, with principal concentrations and obtained b-axis of symmetry



	Quaternary	Cr	Carnian
	Tertiary tonalitic intrusions of the M. Croce and along the Judicaria fault	La.v	Ladinian volcanics
		La	Ladinian, dolomitic
		An	Anisian
		Sk	Skythian
	Eocene	Be	Bellerophon Stage
	Upper Cretaceous, Scaglia	Ga	Gardena Formation
	Upper Cretaceous, Biancone	Tg	Tregiovo Series
		Pe	Permian effusives
J	Upper Jurassic	Pb	Permian basal series
	Middle and lower Jurassic	Qf	Quartz-phylliite series
h	Rhaetian	Sc	Central alpine schists
o	Norian		

1. the crystalline basement, west of the Judicaria fault,
2. the Judicaria fault, between San Pancrazio and Dimaro,
3. the Foiana Fault,
4. the M. Luco horst, the area between the Judicaria and Foiana faults,
5. the Val-di-Non and Mendola unit, formed by the area east of the Foiana fault, excluding,
6. the Taio overthrust block, and the structures related to this overthrusting.

In general these units will be described from north to south.

1. The crystalline basement west of the Judicaria fault

According to observations of Andreatta (1948, 1952 and 1953) the crystalline rocks of the Central Alps, immediately west of the Judicaria fault, may be classified as katazonal metamorphic schists. Generally, their schistosity is striking NE-SW to ENE-WSW: the schistosity planes are dipping steeply around the vertical. Schmidegg (1936) reports instances of 'Schlingentektonik' – deformations around steeply dipping b-axes.
At their NW-ern side, these schists are bordered by the Peio line, a mylonitic fault zone, mainly discovered by Andreatta (1948). The tectonic sketch map of the Judicaria region (enclosure I) and fig. 2 show this fault zone, as mapped by Andreatta (1953, fig. 1, p. 99). The NE half of this Peio line is greatly covered by the quaternary deposits of the Valsura river. NW and N of S. Pancrazio mylonitic zones are met with again, which may be connected with the Peio line. The fault zone is dipping moderately towards the SE (Andreatta 1948).
NW of this fault zone a complex of mesozonal and epizonal metamorphic schists is found, by which it is made probable that the Peio fault acted – at least in part – as a reverse fault.
This complex of crystalline schists has not been studied closely by the present author, apart from the narrow zone, directly next to the Judicaria fault. For the studies on these rocks by Hammer (1902 b), Schmidegg (1936) and Andreatta clearly demonstrate that already before the alpine tectonic phases, these rocks were deformed and metamorphosed in a complicated way. Furthermore, the alpine tectonic phases attacked them at a much greater depth than the adjacent south alpine sedimentary complex. This caused quite an other style of deformation, probably accompanied by anatectic processes and plastic deformations.
Schmidegg distinguished at least three principal deformation phases. Of the oldest one practically no details could be traced; it is taken for a folding of the already highly metamorphic schists and gneisses. The second phase took place at increasing depth and caused the reported 'Schlingenbau', characterized by steeply dipping b-axes. It is partly synchronous with recrystallizations of biotite, quartz and amphibole. Some large – diameter of the structures 2 km and more – 'Schlingen' are reported by Schmidegg north of the Insubric fault, a 10-20 km west of Dimaro. Further, he mentions such structures around the M. Pin (N of Bévia). The 'Schlingen' along the Insubric fault may be caused by the relative movement of masses in an E-W direction, the northern-most moving towards the west (Schmidegg 1936, p. 135). These supposed movements, occurring in a stage before the formation of the Insubric and Judicaria lines, are thus of little importance to us. The intrusion of the Adamello tonalite is thought to have happened after this second phase.
The last deformation is post-crystalline, kataclastic and, in higher levels, often accompanied by diaphtoresis. Schmidegg thinks this deformation to coincide with the movements along the large – Insubric and Judicaria – faults. No general stressfield could be deduced from this ultimate deformation to inform us on the forces, active in this part of the central alpine territory.

Schmidegg emphasizes the necessity in so complicated a structure, of good and large outcrops, and of some marked, traceable rock series. Instead, however, the crystalline schists are extremely monotonous and extensively covered by vegetation.
It seemed, therefore, more profitable to extend the tectonic investigations not far to the west, but to concentrate them rather on the area east of the Judicaria fault.
In a zone – about 2 km wide – along the Judicaria fault, the strike of the schitosity has turned to NE-SW, or even parallel to this fault. It is generally dipping steeply to the (W)NW, only quite near to the fault its dip may diminish to more moderate values. In many instances, thus, the Judicaria fault cuts the schistosity obliquely (see e.g. detail map A, fig. 6).
Exceptions on this general strike direction are met with SW of Bagni di Mezzo, but the extent of this aberrant strike could not be pursued in the field. It may be explained as one of the 'Schlingen', as described by Schmidegg.
SW of San Pancrazio, the junction of the Valsura and Marano rivers offers a fairly good exposure of the crystalline schists, a 100 m west of the Judicaria fault. The Valsura river, here, cuts the schists perpendicular to their strike. At the foot of the lake barrier, the section of figure 7 can be studied. The detail map A (fig. 6) gives a more elaborate picture of the situation. The schistosity is fairly steady, 203/64 (i.e. striking N 203° E, dip 64° to the WNW). As shown in figure 7, the schists are cut by numerous – both normal and reverse – faults.
All tectonic features, found in this section and in its

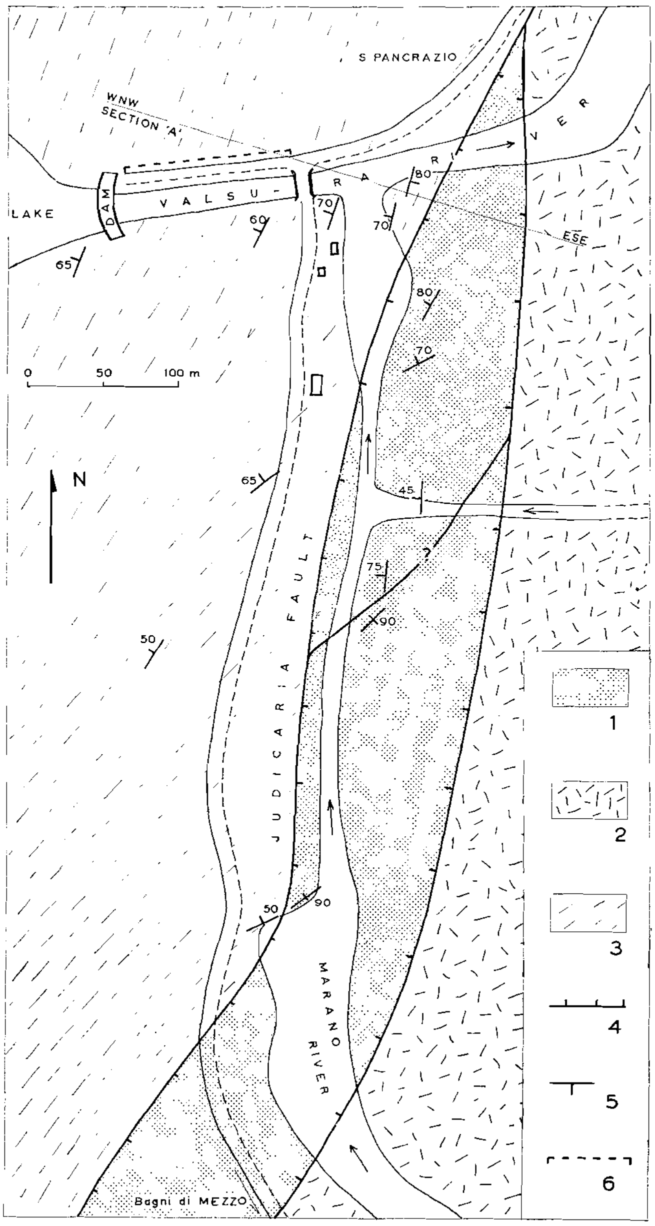


Fig. 6. Detail map A, SW of S. Pancrazio.
1. Triassic sedimentary wedge; 2. Permian effusive series; 3. Crystalline schists of the central Alps; 4. Fault, barbs on downthrown side; 5. Strike and dip symbols of bedding and schistosity planes; 6. Section of fig. 7.

immediate neighbourhood, are collected in diagram 1A of figure 8.*) For each of these features, the mean value was determined. These values are, as represented in diagram 1B of figure 9:

203/64 for the schistosity,
215/56 for the reverse faults, i.e. about parallel with the Judicaria fault,
179/76 for the normal faults, by which the eastern block has risen, relatively to the western one,
214/35 for a set of very closely spaced, small shear planes that only affect the schistosity, see figure 10, III.

For the faults of the section, with unknown displacement, no mean value is constructed. They lie scattered between the other faults and form no separate cluster. They apparently belong partly to the normal and partly to the reverse faults.
As may be read from the section of figure 7, and as is also observed in other neighbouring outcrops, both – normal and reverse – systems of faults seem to have been active synchronously, for no system is clearly younger than the other; i.e. cuts off the fault planes of the older system.
Trying a first theoretical explanation of the obtained data, the following thought may be advanced, which is, of course, to be supported by additional evidence.
The reverse faults being parallel with the Judicaria fault, are taken for its auxiliary faults. This means, that the Judicaria fault itself is a large reverse fault, dipping a 55° WNW.
Looking for a cause, which evoked the other system – 179/76 – of normal faults, our attention is drawn by the intrusive mechanism of the M. Croce tonalite. The close relation of these intrusions with the peri-adriatic line (see p. 31) is in favour for a synchronous activity of these elements. The intrusion is situated about east of the location under consideration, and may have been accompanied by faults with the mentioned relative displacement (eastern block rising relatively to the western one).
The last set (214/35) of small, closely spaced – about

*) Tectonic data of this study are plotted in the lower hemisphere of an equi-areal projection (Schmidt' net).

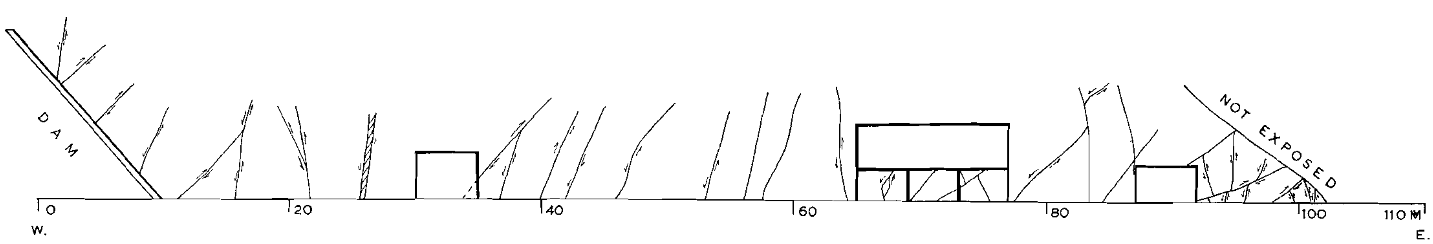


Fig. 7. Sketch of faults, with relative displacement, in the central alpine schists 100–200 m west of the Judicaria fault. Along the Valsura river.

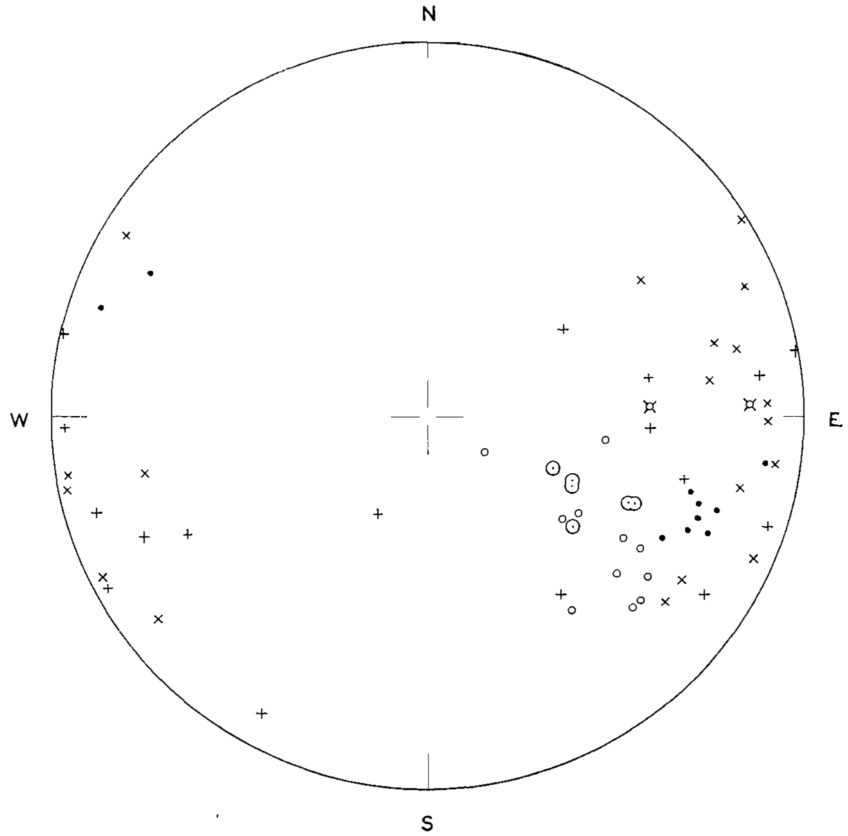


Fig. 8. DIAGRAM 1A Data taken from section of fig. 7, and its immediate surroundings.

. Poles of schistosity (10)
○ „ „ reverse faults (13)
× „ „ faults (E block risen relatively to W block) (21)
⊙ „ „ closely spaced, small shear planes (upper block towards ESE) (6)
+ „ „ faults with unknown relative displacement. (14)

2 cm – shear planes, affecting only the schistosity, strike parallel to the Judicaria fault, which suggests a close relation to it.

The displacement along this set is regular and always shows a relative movement of the upper block towards the ESE, i.e. a horizontal couple of forces around a NNE-SSW striking axis (see fig. 10) is responsible for it.

In connection with the Judicaria fault, this means a bending of the fault plane towards the sunken block, i.e. the reaction to gravitative stresses, acting on the relatively elevated mass of the crystalline schists. It is

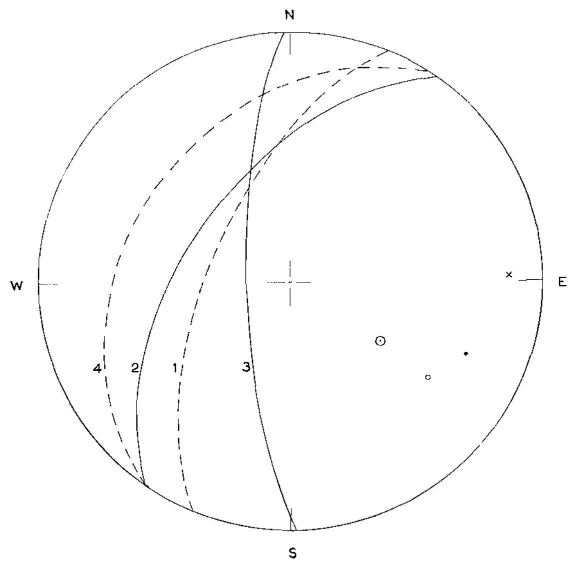


Fig. 9. DIAGRAM 1B Mean values of the elements of diagram 1A. Symbols for poles as in fig. 8

1. Plane of schistosity
2. „ „ reverse faults
3. „ „ faults (E block risen relatively to W block)
4. „ „ closely spaced, small faults (upper block towards ESE)

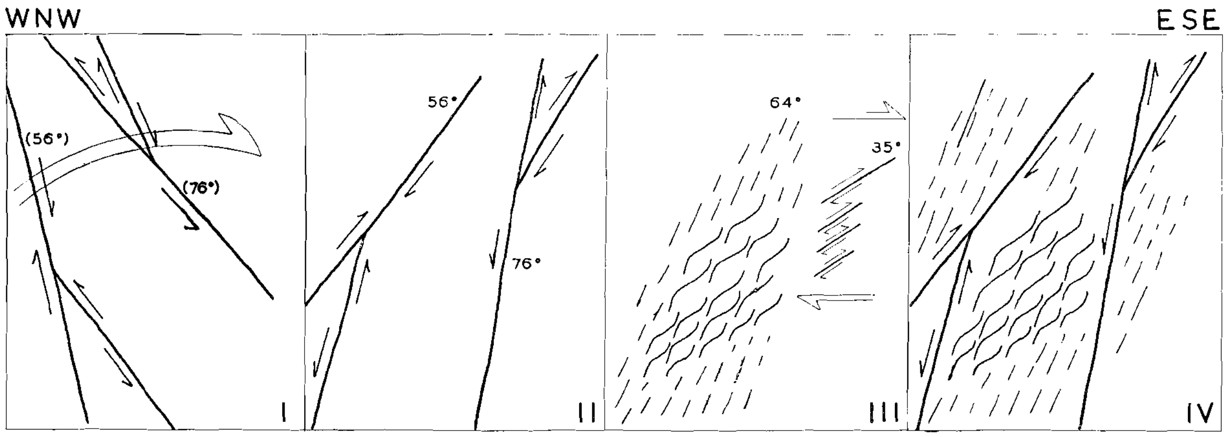


Fig. 10. Reconstruction of the deformations in the crystalline schists, 150 m west of the Judicaria fault, along the Valsura river.
IV. Schematic presentation of the present-day situation, as obtained from data of fig. 7 and diagram 1^B (fig. 9)
III. Detail of schistosity (dipping 64°), cut by shear planes (dipping 35°). They reveal a relative displacement of the upper block towards ESE, which caused the bending of the Judicaria fault.
II. Detail of about synchronous fault systems, reverse faults (dipping 56°), parrallel to the Judicaria fault, and normal faults (dipping 76°)
I. Original position of the faults of II, before the bending of the Judicaria fault, which caused an inversion of character of the faults.

often observed (van Bemmelen 1957, p. 201) on faults of large throw, that their fault planes are bended by such gravitative reactions; normal faults may be altered thus in reverse faults.

Furthermore, experiments of Wunderlich ('57 b) on the accompanying features of graben structures, point to this direction too. It is dependent on the materials used in the moving blocks, whether these features suggest compression (reverse faults), or whether they suggest tension (normal faults), according to the side, which the fault plane is bended to.

Similar results are obtained by Sanford (1959). In his experiments, in which a part of a horizontal 'sedimentary complex' is subjected to a purely vertical displacement of its 'basement', a subvertical dip-slip fault originates in the lower parts of the 'sedimentary complex'. In its higher levels, this fault exhibits a curvature, away from the relatively uplifted block. It reaches the surface thus, as a reverse fault, which is dipping moderately towards the side of the uplifted block (Sanford 1959, p. 44 and fig. 17 of p. 45).
In our case, the last set of small, closely spaced shear planes, indicates a bending of the Judicaria fault plane towards the ESE, by which this fault acquired the appearance of a reverse fault dipping moderately WNW, though originally the fault plane was vertical or dipping ESE (see fig. 10).
Other outcrops of the crystalline schists immediately beside the Judicaria fault are less well exposed and therefore they do not permit a similar elaborate analysis.
West of Proves (section C of fig. 11; Section III of enclosure II) and NW of S. Giacomo (section E of fig. 11) again the system of closely spaced shear planes is found, exactly as described before. In the sections this system is symbolized by an additional hatching of the schists. Here too, the same sense of displacement, resulting in a bending of the Judicaria fault towards the ESE, is observed.
The present-day inclination of the Judicaria fault, therefore, is largely achieved by these secondary movements, which seem to have occurred all along this fault.

2. The Judicaria fault between S. Pancrazio and Dimaro (see sections of figure 11)

In our area, the Judicaria fault is not exposed as a well defined plane, but rather as a mylonitized zone, covered by soil and vegetation. Its tectonic function, therefore, can only be proved by indirect evidence. As may be gathered easily from its line of outcrop, the Judicaria fault is dipping 50°-60° WNW. In the field it does not form a marked zone. A notable feature is its position in the Marano valley, where it is generally not found at the bottom of this valley, as might be expected, but somewhere halfway its steep WNW-ern slope. This position favours an additional bending of its faultplane, by recent creep phenomena, as is observed in the upper course of the Marano river.

The presence of young-sedimentary wedges and fault troughs along the Judicaria fault is a structural phenomenon of great interest. These troughs and wedges are comprised between the Judicaria fault and one or more faults at their ESE-ern side. At least four occurrences are known:

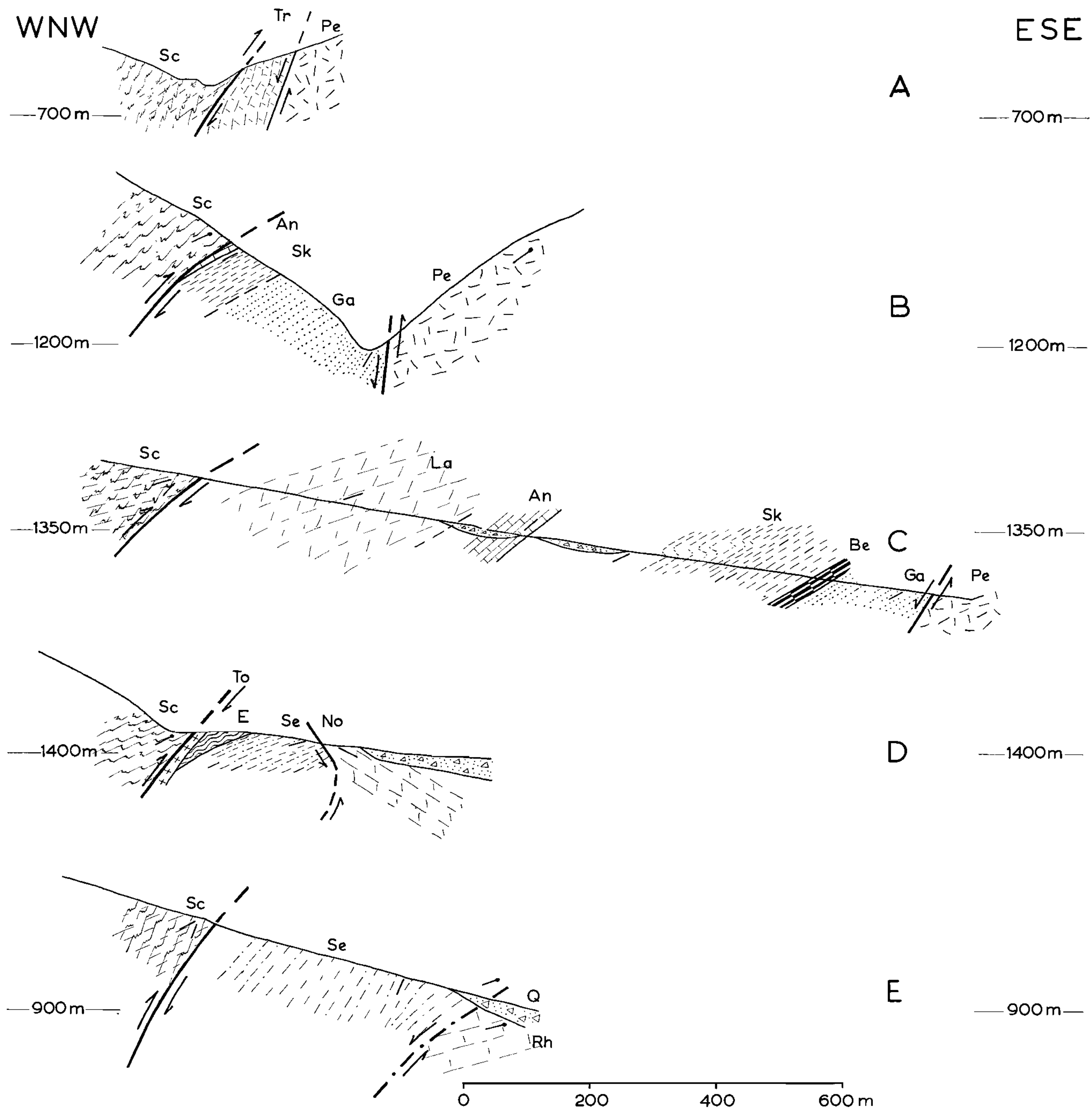


Fig. 11. Serial sections of the Judicaria fault.
Location of sections:

A	Marano mouth	C	Proves	E	NW of S. Giacomo
B	South of Bagni di Mezzo	D	South of Rumo		

Formations:

Q	Quaternary	Sk	Skythian
To	Tonalitic intrusion	Tr	Triassic
E	Eocene	Be	Bellerophon Stage
Se	Senoinan	Ga	Gardena formation
Rh	Rhaetian	Pe	Permian effusives
No	Norian	Sc	katazonal crystalline schists. In sections, A, C and E shear planes developed in them.
La	Ladinian		
An	Anisian		

1. the triassic wedge at the junction of the Marano and Valsura rivers,
2. the fault trough SW of Bagni di Mezzo,
3. the fault trough between the Passo di Castrin and Proves,
4. the cretaceous and tertiary wedge, which extends from Rumo southward.

Moreover, Künzli (1899, p. 427) reports north of S. Pancrazio (North of the area, covered by the present survey) the find of a small outcrop of a calcareous breccia, which he thinks – on lithological grounds – to form a continuation of the wedge near the Valsura – Marano junction. This opinion is shared by G. B. Dal Piaz (1942, p. 49 and 99) too, who found the thickness of this lense to be 1 m.

The wedge near the Marano – Valsura junction was discovered by Blaas (1909) and is extensively described by Von Klebelsberg (1911), G. B. Dal Piaz (1942, p. 42-49), and Vecchia (1957; p. 88 and 89). It is tectonically disturbed, its stratigraphic planes are dipping steeply around the vertical, the directions of strike are variable, but about parallel to the limiting faults of the wedge. The limestones and dolomites, which form part of it, are extremely hard; they partly recrystallized, probably under influence of nearby hot tonalitic masses (see also p. 30 and 31). The wedge is composed of triassic rocks, the thickness of which has been reduced tectonically. As was pointed out also by Von Klebelsberg (1911) and G. B. Dal Piaz, they belong to the south alpine lithological series. This opinion is supported by the position of the series: the limestones and dolomites are probably of ladinian and/or anisian age; they are underlain at their ESE-ern side by red coloured shales of skythian age. This sequence – from young to old – proceeding in ESE-ern direction, can hardly be reconciled with its function as the root of an east alpine thrust sheet. This role was attributed to this wedge – and to some more identical sedimentary lenses along the Insubric fault and near Mules – by Furlani and Henny (1920). In his earlier works, Staub (1924) also took this wedge for a part of the middle east alpine thrust sheet.

The most prominent characteristic of the more southern wedges, is their being tectonically undisturbed. Even a few metres from the Judicaria fault – as close to it, as the outcrops permit – the sediments show in no way, that we are quite near to one of the largest faults of the alpine orogene. This is the more remarkable, as this fault is, according to several geotectonic concepts, a wrench-fault, along which a horizontal displacement of 40 km or more should have taken place.

It can be remarked, that the northern-most wedge, near the Marano and Valsura junction is highly disturbed, but this is only due to the intrusive mechanism of the M. Croce tonalite, and the resulting updoming of the M. Luco horst (see next paragraph).

An almost continuous series of sub-parallel faults is thus accompanying the Judicaria fault at its ESE-ern side. They have in common, that always the WNW-ern block has sunken, relatively to the ESE-ern block.

A comparison with the study of Cornelius and Furlani-Cornelius (1931) on the Insubric fault is useful at this moment.

The Insubric fault appears to exhibit exactly the same characteristics as the Judicaria fault in our area.

This E-W fault shows, apart from one exception, an inclination towards the north. It is mostly situated in the northern slopes of (E-W running) river valleys. Tonalitic intrusions are frequent; they are mostly free from post-intrusive mechanic disturbances. Sedimentary wedges, like along the Judicaria fault are found in many places. Facially and tectonically these wedges belong to the southern Alps. They can not be taken for 'tectonically thinned roots of the east alpine thrust sheets' by this analogy of facies and by the same tectonic reason, as was adduced for the wedges along the Judicaria fault; for here again, the youngest formations are always situated at the northern side of the wedges.

This far-going similarity between the Insubric and the Judicaria fault renders it clear, that *they are both performing an identical tectonic function in the alpine orogenic system.*

It is, anyway, in flat contradiction to the facts, if one considers one of them – the Judicaria fault – as a large strike-slip fault, while attributing another function to the Insubric fault.

The sediments along the Judicaria fault being practically undisturbed, it is not probable that the faulting was accompanied by compression or torsion. No traces of such forces can be found. The 'Schlingen' in the crystalline schists originated in a stage, long before the activity of the large faults announced themselves (Schmidegg 1936). Besides, they are appearing along the Insubric fault as well.

The possibility was advanced, that the Judicaria fault originally had another inclination, and was then a ESE-dipping normal fault (p. 41). This idea fits in very well with the undisturbed status of the sediments next to this fault, as normal faults are mostly accompanied by tension.

This assumption is strongly supported by the regular presence of the young-sedimentary wedges and fault troughs. For they must be considered then as oblong blocks, limited at their ESE-ern side by *antithetic faults*, which are known to accompany *large normal faults* (de Sitter 1956, p. 153). Furthermore, the absence of compressive forces is suggested by the many tonalitic intrusions along the peri-adriatic line.

Cornelius and Furlani-Cornelius (1931), in their excellent study on the Insubric fault, consider all possible tectonic functions, that have been proposed for it by the various authors. They conclude to a steep southward upthrust of the northern block (the central alps) on the southern one, as the most acceptable explanation of the observed facts. Obviously, they were misled by the inclination of the fault (dipping north) and the fact, that at both sides the strike of the schistosity is parallel with it. As for the inclination of the fault plane, many minor structures (e.g. op. cit. fig. 16, p. 268) indicate, that the Insubric fault too, was originally an southward dipping fault, bended later to its present-day position of an apparent upthrust. The parallelism of the schistosity with the fault, induced Cornelius and Furlani-Cornelius to look for a compressive mechanism, directly related to the faulting. The Judicaria fault, which cuts at many places the schistosity of the central alpine schists obliquely, demonstrates however, that there is no such a direct relation between general trend of the schists and the direction of the fault.

The vertical throw of the Judicaria fault can only be guessed.

In section V (Enclosure II), for instance eocene formations, SE of the fault, are found at the same level as the katazonally metamorphosed schists of the central Alps, exposed NW of the fault. Here the throw amounts to:

4,0 *km*, being the thickness of the sedimentary column from the permian to the eocene; plus

>1,5 *km*, being the minimal thickness of the quartz-phyllite Series in this part of the W-ern Dolomites; this number is borrowed from Dietzel (1960, p. 29), as the Merano area is the nearest location, where their thickness may be estimated; plus

±3,0 *km*, being the roughly estimated thickness of the mesozonal, and part of the katazonal central alpine schists.

8,5 *km* in total.

In section I, the throw is notably smaller, for here we see anisian rocks at the same level as the crystalline schists. This decrease of the throw by a 2 km, (that is the thickness of the sediments from anisian up to eocene) makes a throw of about 6,5 km a probable estimate.

In the Merano region, the vertical throw of the Judicaria fault is thought to range between 5 to 9 km (Dietzel 1960, p. 29).

However, the throw of the Judicaria fault is dependent on many accidental factors, as will be seen in the next paragraphs. The antithetic faults, parallel to it, and a tilting of the Val-di-Non area to the WSW, both tend to increase the throw of the Judicaria fault. An opposite result is effected by the rising of the M. Luco horst. It is suggested, therefore, to consider the throw of this fault again later on, when its disturbing factors are known in more detail (see chapter IV).

3. The M. Luco horst

The M. Luco horst is comprised between the two large faults in our area, the Judicaria fault at its WNW-ern side and the Foiana fault at its ESE-ern side. Its most conspicuous rock is the permian effusive series, that is elevated in this horst to an altitude of 2433 m, the M. Luco after which this element is named. The rigid plate of quartz-porphyries, over a 1000 m thick, was pushed upwards by the intruding tonalites.

A first reflection of this process is found in the quartz-phyllite series that covers the M. Croce tonalite between S. Pancrazio and Plazzoles. These phyllites are mechanicly highly disturbed; they are intensely folded, and they are cut by many mylonitic faultzones. In diagram 2 (fig. 12) the poles of the measured schistosity planes in this series are plotted. They clearly show, that at least two crossing folding phases have been active. At several places along the Rio dei Prati, moderately dipping small fold axes are seen in this series. They, too, are plotted in diagram 2. Their uniform inclination of 50° towards the SW, renders it evident that the whole quartzphyllite complex was tilted by the rising tonalite intrusion. A hint in this direction is given also, by the greater concentration of

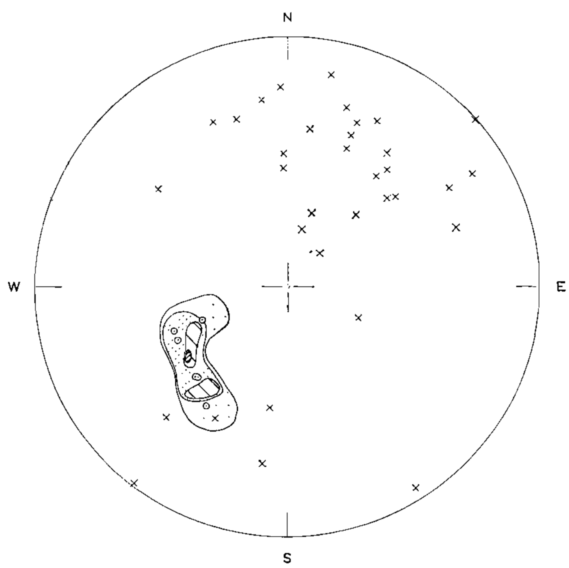


Fig. 12. DIAGRAM 2.
34 Poles of schistosity planes, and
6 b-axes in the quartz-phyllites south and southwest of the M. Croce tonalite.
Mean inclination of the b-axes 50° to the SW, indicating a tilting of the quartz-phyllite series to the SW by the rising tonalitic intrusion.

the schistosity poles in the NE part of diagram 2. It is reported by Dietzel (1960, p. 36 and p. 37) that similar b-axes in the nearby quartz-phyllite complex south of the Ivigna tonalitic intrusion, are generally horizontal or subhorizontal; their greatest concentration is found near the SW-ern margin of the Schmidt'net (op. cit. fig. 23 and fig. 24).
It is obvious, thus, that the six measured b-axes of diagram 2 (fig. 12) were turned from an originally subhorizontal SW-NE direction, to their present-day inclination of 50° to the SW, by a tilt of the entire quartz-phyllite complex as a reaction to the intruding tonalite of the M. Croce.

Secondly, we already reported the faults 179/76*) (see diagram 1^A and 1^B) in the central alpine schists near the Marano – Valsura junction. Along these faults the eastern block rose, relatively to the western one.

Summarizing the tectonic history of that location, we firstly see the Judicaria fault and its antithetic faults originate, giving birth to the triassic wedge. During the last stage of movements along the Judicaria fault, the M. Croce tonalite pushed upwards the M. Luco horst. By these movements the faults 179/76 in the crystalline schists formed, and simultaneously the triassic wedge was crushed by them. The originally antithetic faults are used then as faults, along which the Luco horst is pushed up. Farther southward this influence of the M. Luco horst decreases steadily, so the antithetic faults retain more their tensional character, which is reflected by the undisturbed status of the sediments comprised between the Judicaria fault and its accompanying antithetic faults.

The structure of the M. Luco horst itself is simple. The permian porphyries are overlain by the permian and mesozoic sedimentary cover, as is easily seen on the geological map and section VII. The quartz-porphyry 'nose' of Mione plunges regularly towards the SSW (section VII), the overlying sediments forming and arched roof, dipping towards the limiting faults of the horst (sections IV and V).
The reaction of the very thick and rigid quartz-porphyry plate to deforming stresses, consists mainly of faulting and jointing.
In the Marano valley, for instance, numerous faults are met with, most of them striking about parallel with the Judicaria fault. In some cases the relative displacement can be determined; they invariably showed a rising of the eastern block, relatively to the western one, which confirms the active rising of the M. Luco horst. Their line of outcrop can hardly be pursued over some distance, because of the badly exposed area.

Diagram 3 of figure 13, presents the fault systems in the quartz-porphyries NE of Mione. A large number (92) of faults are cutting the series along the recently constructed road from Rumo to Lauregno. Diagram 3 shows us one system of two sets of faults, that are almost at right angles to one another: the larger concentration with a mean value of 276/80, the smaller one with 13/80. This fault system is often reflected, too, by the drainage pattern of the rivers on the quartz-porphyry plate.

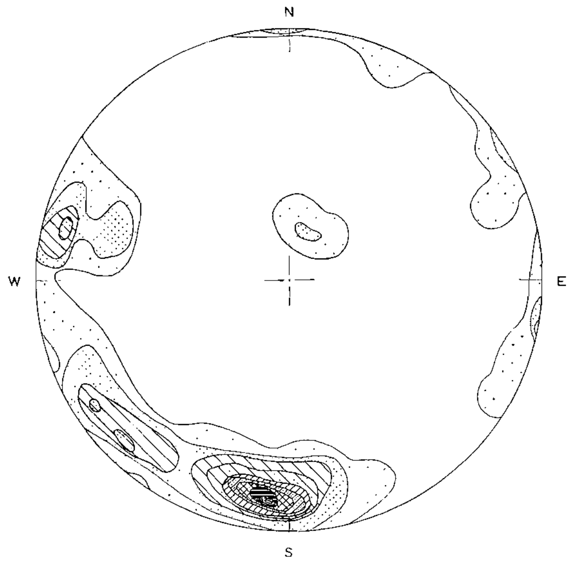


Fig. 13. DIAGRAM 3.
Concentrations of 92 poles of fault planes in the permian quartz-porphyry, NW of Mione.
Contours: 2, 4, 6, 9, 11, 13, 15, 17, 19 and 21%.

A relation with the direction of the Judicaria and Foiana faults is apparent, the fault sets being perpendicular and parallel to them. Striae on both fault sets reveal that more or less horizontal displacements took place along these almost vertical faults; the relative movements of the blocks, however, is variable, so neither of the sets of faults is completely dextral nor sinistral.
The third set of faults of diagram 3 – 314/80 – is less pronounced and shows similar characteristics as both previous sets: about horizontal striae on the fault planes, but here an almost constant relative displacement of the blocks is apparent. The NE-ern block is relatively displaced towards the SE.
No simple general stressfield is thought to be responsible for the observed, asymmetrically arranged fault sets. It proposed therefore, to consider the discussed movements along these faults as a non-systematic reaction of the quartz-porphyry plate to relative small stresses, evoked by:
1. The faulting process along the Judicaria and Foiana faults,

*) In this study the strike and dip of planes are indicated by this notation. It means: Strike N 179° E; inclination N (179 + 90)° E, i.e. west 76°.

2. the updoming of the M. Luco horst by the tonalitic intrusions, and
3. sub-recent collapse phenomena, along the Foiana fault.

The first two processes may have caused the first mentioned system of faults – the sets 276/80 and 13/80.
A connection of the third process with the fault set 314/80 is not impossible, as will be pointed out in the next paragraph.
For the understanding of the function of the Judicaria and Foiana faults, it is important to state that no indications are found of a systematically sinistral strike-slip faulting in these quartz-porphyries.

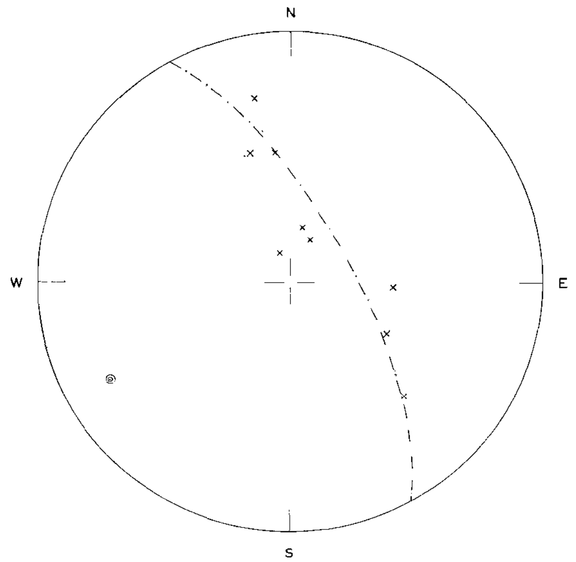


Fig. 14. DIAGRAM 5.
9 Poles of bedding planes and the b-axis 241/20, derived from them. Synclinal fold in the Tregiovo series, 500 m west of Tregiovo.

In the Tregiovo series (500 m west of the village of Tregiovo) along the road from Revo to Lauregno a synclinal fold is exposed. Measuring of bedding planes and plotting of these data in diagram 5 (fig. 14), reveals that this folding took place around a SW-dipping fold axis, 241/20**) As will appear in the next paragraphs, deformations around b-axes with this direction, occupy an important position in the tectonic history of the Val-di-Non area.

Along the Rio Campo, near Proves, in the incompetent skythian beds, an interesting fold needs our attention (see section C of fig. 11, section III of enclosure II and photograph 1). The striking characteristic of this fold is its growing intensity towards higher levels: no discernible deformations occur in the shales and sandstones at its base, in higher levels a distinct asymmetric fold is developing, clearly verging towards the WNW. Its fold axis is parallel with the Judicaria fault, N 30° E.
This style of folding, often observable in the field, is hardly discussed in the literature, which may be due to the impossibility, to explain its style by classic – compressive – theories.
This fold can only be explained by a sliding of the upper beds over the lower beds, towards the WNW. The material – shales – favours this sliding process, but as soon as the movement is obstructed, folding sets in.
As suggested already by the sections and photograph, this sliding mechanism is caused by *gravitative* forces, acting on the moderately dipping strata. The rising of the M. Luco horst (see section C of fig. 11) in this case brought about the required inclination for the skythian beds, to start the observed folding.

West of Preghena, finally, a N-S striking fault is suspected to account for the presence of anisian and skythian formations in the Rio Barnes valley. Bad outcrops however, prevent a closer investigation of its character.

**) In this study lineations are indicated by this notation. It means: the lineation (fold axis, striation, etc.) is dipping 20° towards N 241° E.

4. The Foiana fault
(see sections of figure 15)

Like the Judicaria fault, the Foiana fault is not well exposed in our area. It is an about 45 km long fault, striking parallel with the Judicaria fault. It is named after the village of Foiana, just outside the northern border of our map. Both its (supposed) ends are covered by thick alluvial deposits; in the north, near Lana, it terminates in the alluvial plain of the Adige valley, in the south (SW of Cles) it ends in the alluvial deposits, which are abundantly present there.
Only a few investigations of this fault are known. Schwinner (1915 a) thinks it to be an upthrust fault, by which the M. Luco complex is pushed on the Mendola Unit. Spitz (1919 b) favours the idea that the Foiana fault originated from a folding system, parallel with the Judicaria line; this fold ultimately reached the stage of a fault. Dietzel (1960) working the northernmost end of the Foiana fault, takes it for an upthrust fault, such on the analogy of the Nova fault, that forms the possible northern continuation of it.

In an earlier paper, Spitz (1919 a) proposed tentatively the assumption, that the Foiana fault might be a strike-slip fault. He did so after taking a good look on the geological map of the Alps. His later field examinations convinced him, that this assumption had to be abandoned (Spitz 1919 b). Both papers were published after his death.

ESE  WNW

Photograph 1. Gravitative folding of skythian strata near Proves, as reaction to the rising of the M. Luco horst.

Trevisan (1939 a), as noted before, extrapolated the supposed strike-slip mechanism in the Brenta area northward to our region, taking the Foiana fault for a sinistral wrench fault. According to him, the Foiana fault should be linked to the Clamer-Rosati fault of the Brenta area.

De Sitter, though not mentioning the Foiana fault in the accompanying text, presents the Foiana fault and the Judicaria fault as sinistral strike-slip faults in his figures (de Sitter 1956 a, fig. 114, p. 167; 1956 b, fig. 2, p. 72). It may be remarked, that only those authors, who did not investigate our area in the field, tend to consider the Foiana fault as a sinistral strike-slip fault.

Some remarkable characteristics of the Foiana fault are easily read from the geological map:

1. The Foiana fault is, in general, parallel with the Judicaria fault, and shows the same sense of relative displacement, a sinking of the eastern block.
2. The throw of the Foiana fault diminishes from north to south.
3. A considerable drag of the easterly adjacent strata is seen along the Foiana fault.
4. The inclination of the Foiana fault is variable, from vertical to a 60° WNW.

North of our area, Dietzel (1960, p. 30 and photograph 2) found the Foiana fault separating the M. Croce tonalite (WNW) and the permian quartz-porphyries (ESE); there the position of the fault is 195/55. Farther to the south, as soon as – in the WNW-ern block – the tonalites make room for the quartz-phyllite series and for the quartz-porphyries, the Foiana fault becomes a vertical fault, as is clearly seen by its straight line of outcrop. Some beautiful examples of drag can be studied here on the formations of the eastern block (see sections A, B, and C of figure 15).

In the formations of section A (west of Bagni di Caprile) a fault system developed due to this drag, as schematically drawn above this section. It is composed of a group of normal faults 19/48 and a group of reverse faults 167/54.

The purity of this drag mechanism is convincingly proved by an outcrop NE of Senale, along the road from Fondo to the Passo del Palade (see photograph 2). For here, by lucky coincidence, a fold system, previous to the activity along the Foiana fault, is dragged up by the Foiana fault. All movements have been registered precisely by the – tectonically sensitive – formations of the skythian and anisian.

From the measured bedding planes in this outcrop, the b-axis (62/41) of this fold is readily obtained, as shown in diagram 4^A of figure 16.

The construction of the b-axes from measured bedding planes, is carried out in this study in the following way: The bedding planes are plotted in a Schmidt' net. The concentration of their points of intersection is worked out. In the area with the highest concentration, the desired b-axis is situated.

The NE-dip of this b-axis was caused by a drag of the Foiana fault, i.e. a folding around a b_F- axis, parallel to this fault.

By rotating the obtained b-axis (62/41) backwards around this b_F-axis (N 12° E, in this part of the Val-di-Non area), it should reach its original position. This original position, now, is known from a series exposures 1-2 km more to the east, where the influence of the Foiana fault is not felt any more. Diagram 4^B of figure 17 shows the constructed b-axis there, 256/10. Indeed, this position is reached by the 62/41 b-axis after a rotation of 61° around the b_F-axis (N 12° E) (see diagram 4^A). This fact proves that the displacement – and the accompanying drag – along the Foiana fault is a *purely vertical* one and it contains no,

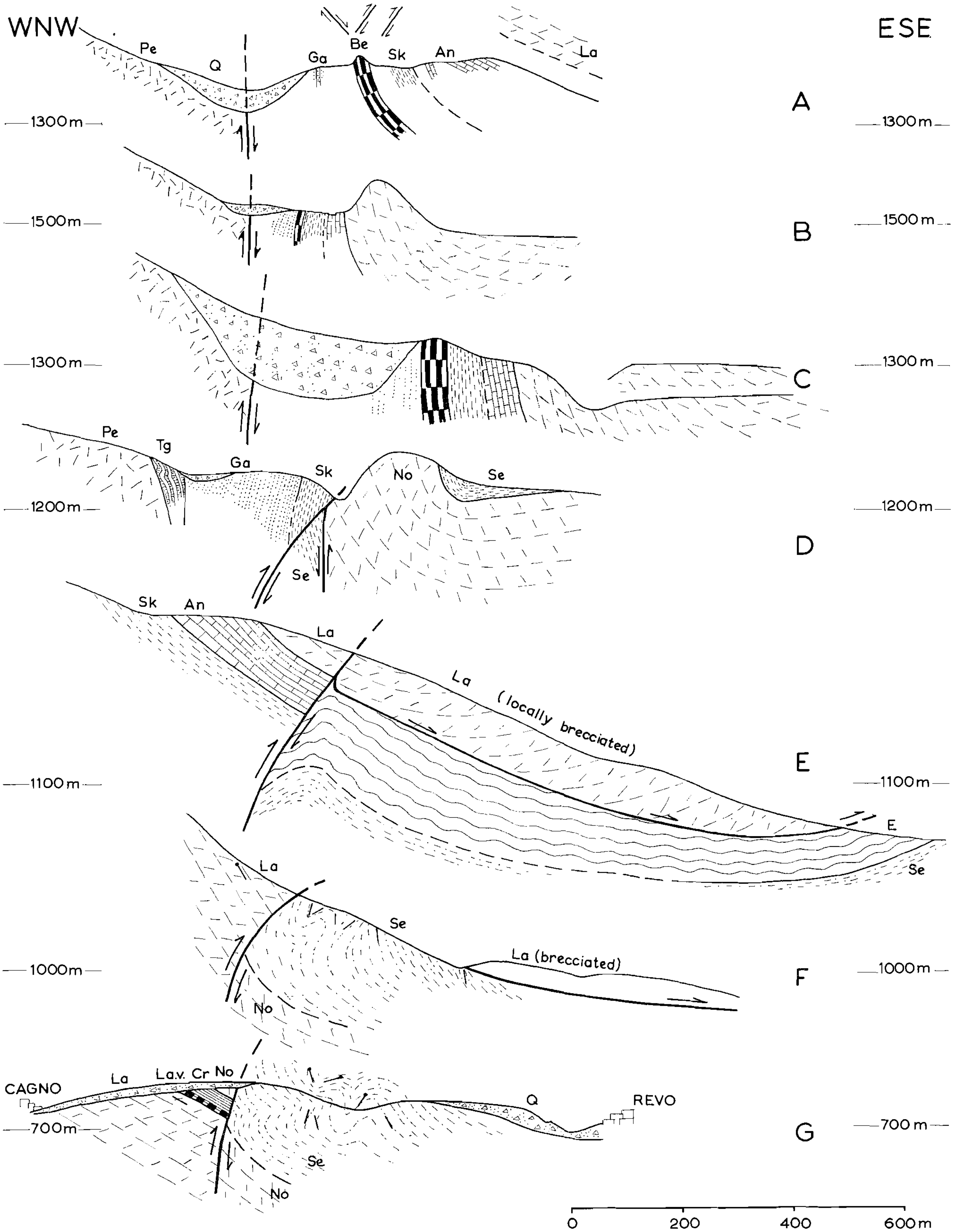


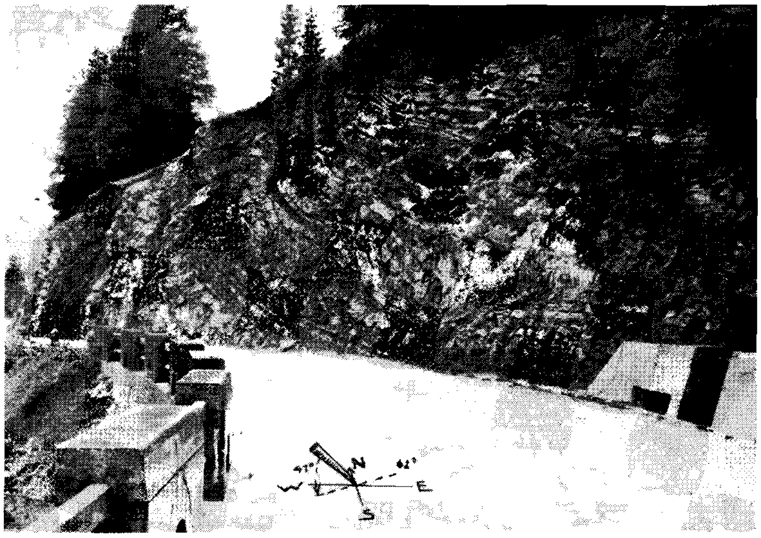
Fig. 15. Serial sections of the Foiana fault.
Location of the sections:

A	W of Bagni di Caprile	C	Upper course of Rio Novella	D	Upper course of Rio Rabiola
B	Passo delle Palade	G	Between Cagno and Revo	E	ESE of Lauregno
				F	NW of Cloz

Formations:

Q	Quaternary	Cr	Carnian	An	Anisian	Ga	Gardena formation
E	Eocene	La.v.	Ladinian volcanics	Sk	Skythian	Tg	Tregiovo Series
Se	Senonian	La	Ladinian dolomites	Be	Bellerophon Stage	Pe	Permian effusives
No	Norian						

Photograph 2. Folded anisian shales and limestones NE of Senale, along the road from Fondo to the Passo delle Palade.
Their fold axis plunges 41° to N 62° E, due to upward drag by the Foiana fault.



or only a very small, horizontal component. A large-scale horizontal movement – Trevisan proposes a displacement of ± 40 km – should doubtlessly leave traces in the tectonically sensitive alternation of strata of this outcrop; additional bending of the fold axis (256/10) around a vertical axis instead of around the horizontal (N 12° E) axis should at least have resulted. De Sitter (1956 b) assumes a SSE-NNW directed compressive force, which pushed the entire Dolomitic region much farther northwards, than the Bergamasc Alps. The Judicaria and Foiana faults, along which the Dolomites were displaced, make a notable angle with this hypothetical SSE-NNW directed stress. We might expect, therefore, a clearly developed deformation of the complexes along these faults, because the *shearing along them should be accompanied by a considerable compressive component.*
It will be shown in the next paragraphs, that strike-slip faults are present in our area, and that they can very well be recognised in the field. The fact, that they were nowhere observed along the Judicaria and Foiana faults, definitely indicates, that the movements along these faults, did not have a strike-slip character.
The outcrop NE of Senale discussed above, gives also

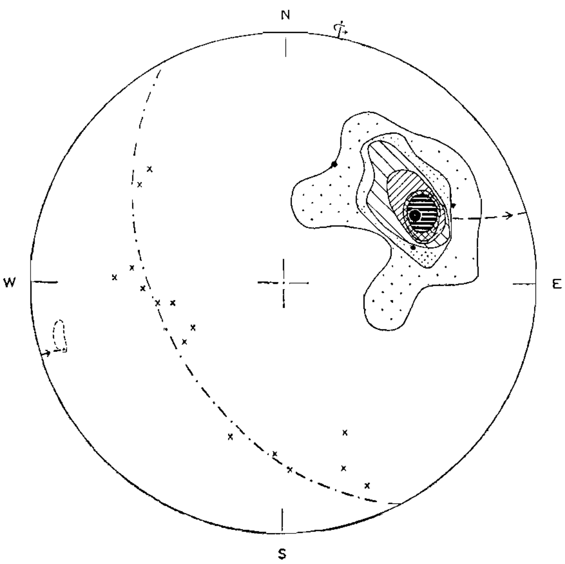


Fig. 16. DIAGRAM 4A.
15 Poles of bedding planes, and the b-axis 62/41 derived from them. Anisian shales and limestones, NE of Senale. After rotation around the axis N 12° E (strike direction of the Foiana fault) over 61°, this b-axis returns to its original position 256/10.

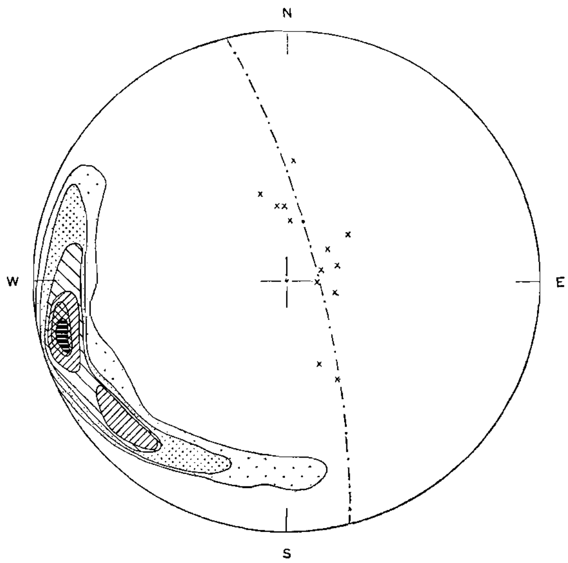


Fig. 17. DIAGRAM 4B.
13 Poles of bedding planes, and the b-axis 256/10 derived from them. Ladinian dolomites SE of the Passo del Palade.

information on the sequence of deformations. For it is seen, that the Foiana fault drags upward the fold with the b-axis 256/10. The Foiana fault, thus, is younger than this folding phase, which occupies an important position in the deformational history of the Val-di-Non area, as will be pointed out later.

The Foiana fault, meanwhile, keeps its vertical inclination farther southward, up to the point is reached, where, on the M. Luco horst, the competent plate of quartz-porphyries is overlain by its sedimentary cover. Here suddenly, the fault exhibits an eastward deviation from its originally straight line of outcrop. From this point (the Rio di Rabiola) to the Lago di Cles, its line of outcrop is less straight, its strike ranging between N 5° W and N 55° E.

At many localities between the Rio di Rabiola and the Lago di Cles, the position of the fault on the geological map (enclosure I), differs from the position it takes on older maps and sections (Carta Geologica delle Tre Venezie, foglio Bolzano; sections by Spitz 1919 b). This is mostly due to the recognition of the factors, that are responsible for the observed changes of strike of the Foiana fault.

Briefly, some facts are enumerated, that are indispensable for the understanding of the behaviour of this part of the fault (see too sections D-G of figure 15):

1. The deviation from its original more or less vertical inclination is always caused by a bending of the fault plane towards the ESE.
2. This bending begins where sediments start to occur on the quartz-porphyries of the M. Luco horst.
3. The inclination of these sediments on the M. Luco horst is directed towards this fault, dipping thus ESE to SE.
4. Topographically too, the M. Luco horst is more elevated than the area ESE of the Foiana fault.

Combination of these data suggests strongly that the Foiana fault plane has been deformed by gravitative processes in the sedimentary epiderm. Though outcrops are generally bad, many observations are collected that support this opinion. Section F and G of figure 15, for instance, reveal a folding mechanism in the senonian marls and limestones, that indicates a superficial movement from WNW to ESE (high to low), of formerly present ladinian and norian dolomites, that slid down along their bedding planes, bending thus the upper part of the Foiana fault to the ESE, by which, on its turn, the senonian marls were compressed and folded, along a folding axis parallel with the Foiana fault.

This sliding down of rocks of the M. Luco horst, using mainly their bedding planes as sliding surface, is observable in many places farther to the north, e.g. in section E of figure 15. Here, large masses of ladinian dolomites are found on top of eocene marls. The dolomites retained largely their coherence, but they present more faults and fault zones than are normally found in these rocks. Often too, the inclination and strike of the strata are highly irregular. They slid down from the WNW to the ESE, covering a distance of at least 1–1,5 km. They are, at their 'tail' still connected with the ladinian dolomites at the other (WNW-ern) side of the Foiana fault; consequently, this fault is completely blurred by them, and its position can only be guessed by the different degree of tectonical disturbedness of the ladinian dolomites at either side. These sub-recent collapse structures will be discussed in more detail in paragraph III b 8.

Looking at these secondary deformations of sections F and G of figure 15, it is easily understood, that Spitz (1919 b) considered the Foiana fault to be a fold system (parallel to the Judicaria fault), which locally developed into a fault with upthrust character. This idea persisted also in later literature, in which a folding of this area, parallel to the Judicaria fault, is suggested (Trener 1933 and Vecchia 1957). This folding appears to be simply the effect of local gliding tectonics in the sedimentary cover.

It was supposed, that the fault set 314/80 of diagram 3 (fig. 13) might be connected with this deformation of the Foiana fault plane.

The considerable transport of sedimentary masses from the M. Luco horst towards the ESE, may, indeed, have influenced the underlying quartz-porphyry plate. Furthermore, it must not be precluded, that the stress gradient itself, which caused this tectonic denudation, affected also the quartz porphyries and led to the formation of this dextral fault set.

Section D of figure 15 has not yet been discussed till now. Here a great number of complications accumulated, in an area that is only locally exposed.

North of Castelfondo we see the front of a SSE directed overthrust block. The western limiting fault of this block, a dextral strike-slip fault, is cut off by the Foiana fault. This overthrusting belongs to the same tectonic system as the fold NE of Senale, and is thus older than the Foiana fault. The later gravitative deformation of the Foiana fault plane, affected of course also this dextral strikeslip fault, by which the complicated structure of section D originated.

North of section D a fault developed, separating the compact ladinian and norian dolomites; these could not adjust themselves to the folding by the upward drag of the Foiana fault, and consequently reacted by a steep fault, with the same direction and sense of displacement as the Foiana fault.

In the stratigraphic part of this study, it was reported, that along the northern part of the Foiana fault tectonic thinning of the formations is often observed. Being informed now on the mechanism of this fault, it is reasonable to suggest that secondary faults occur too in the deeper, unexposed parts beside the Foiana fault, as schematically indicated in the sections I and II.

The throw of the Foiana fault decreases steadily from north to south. Near Plazzoles this throw reaches a value of about 1800 m, being the total thickness of the formations between the tonalite and the ladinian. South of Revo, the throw amounts to about 750 m only.

This decrease of throw towards the south demonstrates again the updoming of the M. Luco horst at its northern side by the M. Croce tonalite.

Briefly summarizing the mechanism of the Foiana fault, we see it initiate as a secondary, accompanying fault of the Judicaria line, with an about vertical inclination. The rising of the M. Croce tonalite used this fault plane too, to push upwards the M. Luco horst. This caused an increasing throw of the Foiana fault towards the north.

The southern half of the Foiana fault is deformed by gravitative processes in the sedimentary cover, that are favoured by a ESE-inclination of the strata on the M. Luco horst. They evoked the compression phenomena in the incompetent sedimentary strata ESE of the Foiana fault.

In its northern half, where the tonalitic magma reached higher levels, the Foiana fault was deformed by gravitative processes in the tonalitic intrusion (Dietzel 1960, fig. 5 on p. 28 and fig. 28, subphase c on p. 41).

5. The Val-di-Non – Mendola unit

East of the Foiana fault, a tectonically hardly disturbed area is met, the Val-di-Non and Mendola Unit (see fig. 5). South of the line 'Lago di Cles – Lago di Caldaro', the tectonic activity increases again, by the mechanism of the Taio overthrust block. This line is considered the southern limit of the Unit under consideration in this paragraph.

The entire complex is dipping 10°-15° to the WSW, forming an extensive dip slope between the steep cuesta of the Adige valley and the Foiana depression (see figure 5). In particular south of Castelfondo, this Foiana depression is a syncline-like depression, with its axis parallel to the Foiana fault, plunging slightly to the SSW. Its eastern limb is formed by the mentioned dip slope of the Val-di-Non and Mendola Unit, the other, steeper dipping limb, by the cretaceous and tertiary strata, that are dragged up by the Foiana fault. This implies, that the depression is only a secondary effect of the Foiana fault, and does not form a synclinal folding, related to an orogenic phase, as advocated by Schwinner (1915 b), Spitz (1919 b), Trener (1933), and Vecchia (1957).

In the foregoing paragraph, the presence was reported of a fold NE of Senale. Its fold axis extends WSW-ENE, 256/10. Near the Foiana fault it is dragged upwards. Besides this direction of the fold axis, another property of it deserves our attention: its style of folding. Like the discussed fold near Proves (photograph 1) this fold NE of Senale shows an increasing intensity of deformation in the younger, higher formations. Figure 18 shows a sketch of this feature. The oldest formation, the limestones of the Bellerophon Stage, is undisturbed; in the overlying skythian shales and sandstones folding sets in, the asymmetrical folds verging towards the SSE. The conglomerate at the base of the anisian (the Conglomerate of Richthoven)

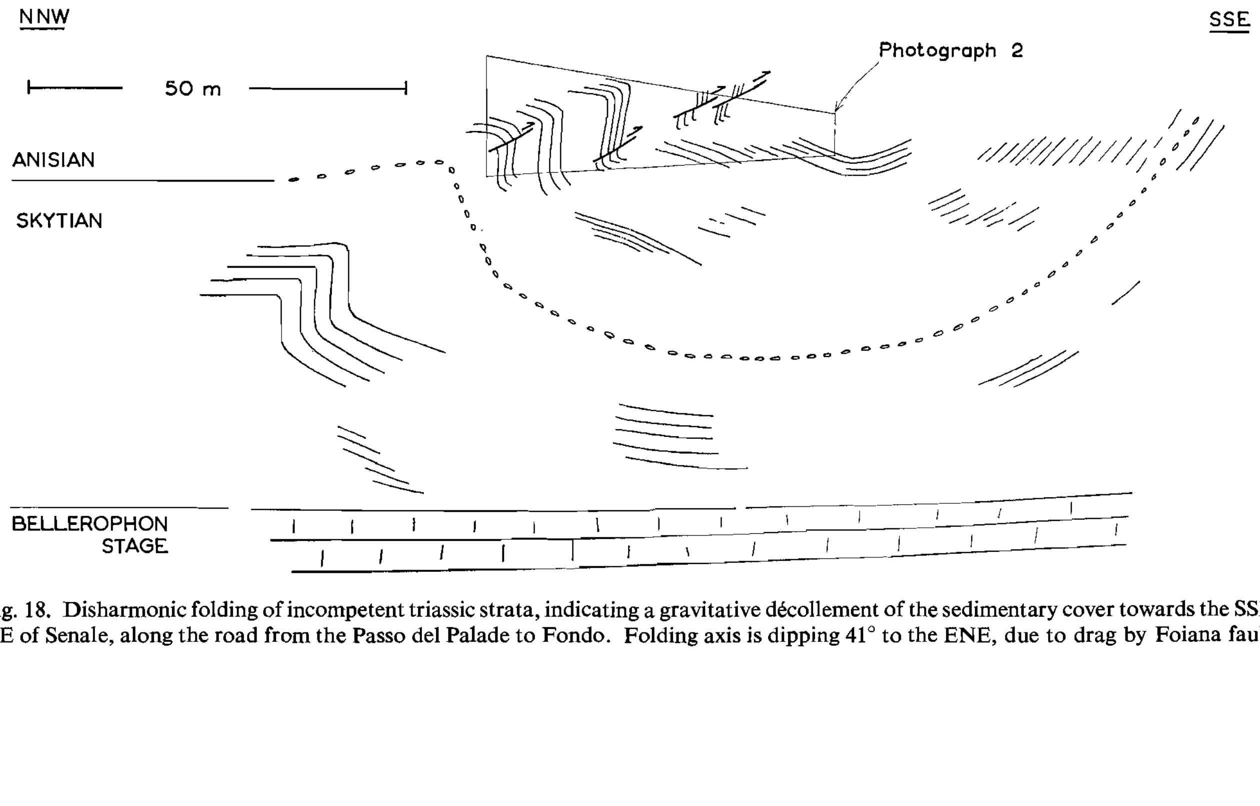


Fig. 18. Disharmonic folding of incompetent triassic strata, indicating a gravitative décollement of the sedimentary cover towards the SSE. NE of Senale, along the road from the Passo del Palade to Fondo. Folding axis is dipping 41° to the ENE, due to drag by Foiana fault.

forms a well traceable horizon. The greatest intensity of folding is reached in the incompetent anisian formation, an alternation of shales and limestones. Here, small faults accentuate the SSE directed displacements of the younger strata, relatively to the older ones.
This style of folding must be a result of the gravitative décollement of the triassic sedimentary cover over the underlying older formations. This décollement took place from the NNW (high) to the SSE (low), or more precisely, from N 346°E to N 166° E, as the fold axis of the resulting folds is 256/10 (see diagrams 4^A and 4^B).
It should be remarked here, that a dipping fold axis (10° to the WSW in this case) is hardly reconcilable with the idea of gravitative décollement. It will be shown, however, that the entire Val-di-Non area was tilted to the SW, after the $\overrightarrow{\text{SSE}}$ folding phase*). The axial dip is due to this later tilting; its original position was subhorizontal.

North of Castelfondo another $\overrightarrow{\text{SSE}}$ deformation mechanism is observed. It concerns the norian 'Hauptdolomit' block of the M. Ori (1371 m), which, by a 2 km long fault, is pushed up against the southern, relatively stable complex of cretaceous 'Scaglia', Jurassic 'Ammonitico rosso', and norian dolomites. At its WSW-ern side, this block is limited by a dextral strike-slip fault; at the other side, the ENE-ern bordering fault is less clearly developed. It probably is situated in the narrow gorge of the Novella river. The tectonic front of this M.Ori (1371 m) block is well exposed north of Castelfondo. It is formed by a 75° NW dipping upthrust fault, which pushed up the 'Scaglia' and 'Ammonitico rosso' of the southern block. On the fault plane striae are found, indicating a pure dip-slip. NE of Castelfondo this fault is less regular, as the 'Hauptdolomit' here fell apart in large blocks. This is due to the greater forces acting on the 'corner' of the advancing block; recent denudation, too, made these blocks tumble down the S-dipping slopes here. The WSW-ern limiting fault, at the left-hand bank of the Rabiola river, is rather well exposed. This dextral strike-slip fault is vertical, striking N 150° E. Near the front of this M.Ori block, it is seen that its 'Hauptdolomit' forms only a 25 m thick sheet and is situated *on top of the 'Scaglia'*, separated from it by a subhorizontal fault, over which it, evidently, was moved towards the SSE. Farther to the NNW, along the Rabiola river, only the N 150° E striking fault is seen yet. The subhorizontal fault disappeared to greater depth. Here, the 'Scaglia' WSW of this fault, shows a drag near the fault plane, indicating its dextral strike-slip character.

The 'Hauptdolomit' and 'Scaglia', involved in this thrusting of the M.Ori block, generally show little deformation. Only near the front of this structure, where, obviously, its movement was obstructed, compression phenomena occur.

In both the vertical walls of the gorge of the Novella river, 1 km north of Fondo, a spectacular fault zone is exposed (see photograph 3). Its tectonic inventory is plotted in diagram 6^A (Figure 19). This low-angle fault zone in the norian 'Hauptdolomit' clearly shows a relative movement of the upper block towards the SSE (mean: N 154° E); this displacement is exhibited by striations and by drag phenomena.
However, the inclination of the faultzone (mean strike and dip 109/22), shows little relation to this movement, and a mechanical interpretation seems difficult for this oblique-slip fault.
It should be borne in mind here, that the sediments of the entire Val-di-Non area are regionally dipping WSW, probably resulting from a tilt of the area. If this tilting took place after the formation of the fault under consideration, its present-day, deviating inclination may be due to this tilting process.
Diagram 6^B of figure 20 shows a rotation over 13°, which eliminates the regional WSW inclination in this part of the Val-di-Non area, the mean dip of the surrounding sediments being 13°. The pole of the fault plane 109/22 is displaced considerably by this rotation, and reaches the position 68/15, the striations on this plane still point to the SSE, their mean value is

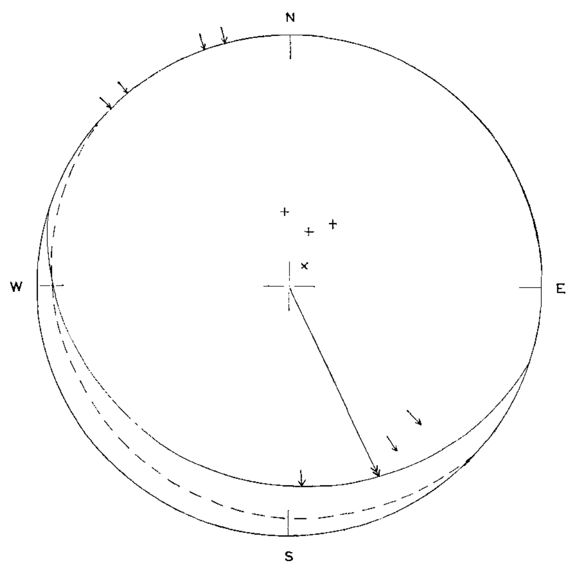


Fig. 19. DIAGRAM 6^A.
Tectonic inventory of the fault zone in norian dolomites, 1 km N of Fondo.
+ Poles of faultplane. Mean fault plane (drawn) 109/22.
× Pole of bedding plane. Bedding plane dashed.
Arrows indicate striae, with relative displacement of the upper block. Their mean value (double arrow) is N 154° E; Oblique-slip fault.

*) '$\overrightarrow{\text{SSE}}$ folding phase', stands for: gravitative décollement of a sedimentary cover from the NNW, down to the SSE, accompanied by folding phenomena, that verge to the SSE. Fold axes extend ENE-WSW.

Photograph 3. Fault zone (dipping 22° to the SSW) in the NW-ern valley wall of the Novella gorge. Norian dolomites 1 km north of Fondo.

SW  NE

← 250 m →

now N 158° E, i.e. the oblique-slip fault is transformed into a dip-slip fault (displacement perpendicular to the strike of the fault plane).
This new situation creates the possibility to explain the discussed fault as an originally 15° SSE dipping normal fault, and it fits, so, perfectly in the system of $\overrightarrow{\mathrm{SSE}}$ deformations, as met till now.
By this reasoning it is made probable, that *the tilting of the Val-di-Non area happened after the* $\overrightarrow{\mathrm{SSE}}$ *deformation phase*. This was suspected already before, while discussing the fold system NE of Senale.
This fault resulted thus by a simple *tension* process, which must be remembered, because it is situated at the 'tail'-side of the large Taio overthrust structure, which will be treated in the next paragraph.

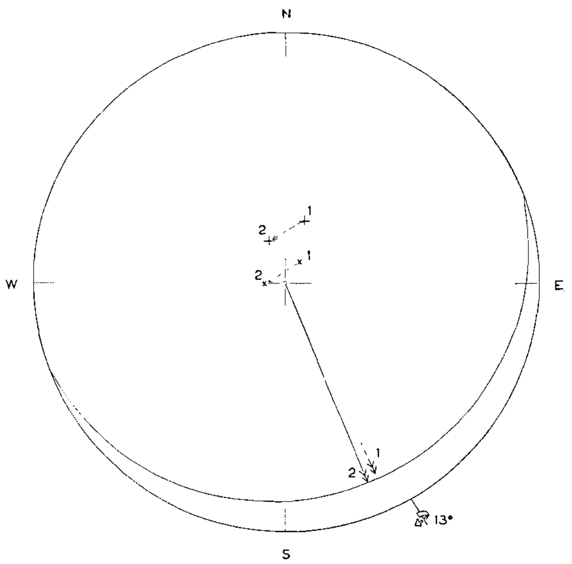


Fig. 20. DIAGRAM 6B.
Data of diagram 6A before (1) and after (2) rotation over 13° around SSE axis, to eliminate regional WSW tilt; dip-slip fault.

Between Ruffré and the Mendola Pass, a NNW – SSE striking fault zone, at least 7 km long, is found. It is well traceable in the field by a scarp of the norian dolomites of the WSW-ern block. At two locations it is well exposed, permitting to determine the relative displacement of the blocks; from abundant striae a subhorizontal movement of the ENE-ern block towards the SSE – a dextral strike-slip fault – is evident. The fault zone is 10 to 15 m (!) broad and it is completely crushed and brecciated. It contains many striated, flat blocks – length up to 50 cm – which are at many instances red-coloured and entirely polished by friction. Strike and dip of the fault zone are variable; generally it is striking N 150° E, the inclination is about vertical or steeply dipping to the NNE. The NNE-ern block seems to have risen relatively to the SSW-ern one in the northern outcrops. Near Ruffré, however, the vertical throw – only a few metres – is just the reverse. The many, probably later, faults in this area may also have caused the change in vertical displacement along this large fault-zone. The amount of the horizontal displacement is unknown. There may exist a southward extension of this fault zone in the steep valley walls of the Adige river; bad and inaccessible outcrops permit no further investigation here. Significant features of this fault are its pronounced dextral strike-slip character, which conflicts directly with the concepts of Trevisan and de Sitter. Secondly, again the well-known – NNW-SSE – deformation direction is represented in it.

East of Fondo and north of Ruffré a number of faults is found. They are mostly completely brecciated, forming fault zones, that reach a width of 1-2 m. The relative displacement of the blocks could be determined in most cases.

Yet one dextral strike-slip fault was observed east of Fondo. The other faults are all normal faults, reflecting tension conditions, which seem to have influenced extensively this area.
West of Fondo, finally, a small fault – throw of some metres – is present, but it is not exposed.
Many of this latter series of faults show a parallelism with the Judicaria and Foiana faults, and may, therefore, be related with them in a way. This is in favour again of the opinion, mentioned before, that the Judicaria and Foiana faults originated under tension conditions.
The mutual relations between the faults north of Ruffré, and their relative age, are not known. Little value, therefore, should be attached to the assumed points of intersection of these faults on the geological map, because they are not exposed in the field.
The minor thrust-structure south of Ruffré, is probably due to sub-recent sliding processes and will be treated in a next paragraph.

Recapitulating the structurally significant features of the Val-di-Non and Mendola Unit, we first of all see the well developed deformation phase, characterized by a gravitative décollement of the sedimentary cover from the NNW to the SSE. It is accompanied by folding (NE of Senale), by overthrusting (north of Castelfondo), and by a simple, low-angle dip-slip fault (north of Fondo).
The tilting of the Val-di-Non area towards the SW, took place after this $\overrightarrow{\text{SSE}}$ deformation phase.
The dextral strike-slip faults, east of Ruffré and east of Fondo, conflict with the tectonic views of Trevisan and De Sitter. They may, on the contrary, be somehow related to the $\overrightarrow{\text{SSE}}$ deformation phase.

Some minor faults are parallel with the Judicaria and Foiana faults; they appear to be normal faults and indicate tensional stresses, acting perpendicular to them and, consequently, perpendicular to the Judicaria fault.

6. The taio overthrust block.
(see sections VI and VIII)

The structures south of the line 'Lago di Cles-Lago di Caldaro' are related to the SSE directed overthrusting of the Taio block. Its features will be treated in this order:
1. Frontal part of the block
2. The WSW-ern limiting fault and accompanying structures
3. The SE-ern limiting fault
4. Structures on top of the block

1. *The frontal part of the Taio overthrust block*, is well exposed in the Valle dei Pilastri, east of Vigo (see photograph 4). Looked at from some distance, it is clearly seen that the rigid plate of norian dolomites thrusted over younger formations towards the SSE. Closer observation tells us that these younger formations consist of folded eocene and upper cretaceous 'Scaglia', and moderately NNW-dipping 'Biancone' (upper cretaceous), 'Ammonitico rosso' (upper jurassic), middle and lower jurassic, and finally the norian dolomites again of the M. Pietro.
The folding is intense around the Castel of Thun, 1 km north of Vigo, and seems to decrease towards the ENE; in the Valle dei Pilastri only one well developed anticlininal and synclinal fold in the 'Scaglia' is found. The situation around the Castel of Thun is more com-

NNW

SSE

Photograph 4. Frontal part of the Taio overthrust block on the northern slopes of the Valle dei Pilastri. In the foreground the village of Vigo; at the extreme left the white Castel of Thun.

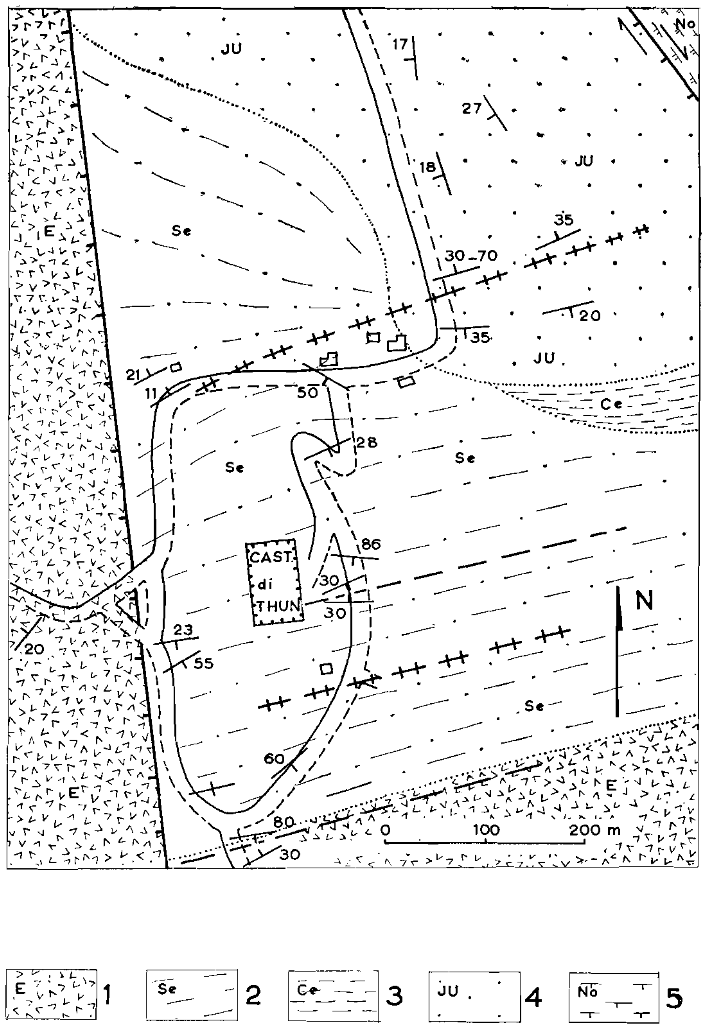


Fig. 21. Detail map C.
Surroundings of the Castel of Thun.
1. Eocene. 2. Upper cretaceous 'Scaglia', 3. Upper cretaceous 'Biancone'. 4. Upper jurassic 'Ammonitico rosso'. 5. Norian 'Hauptdolomit'.

Anticlinal axis.
Synclinal axis
Fault, barbs on downthrown side
Fault with mainly horizontal displacement

plicated (see detail map C of figure 21). Intense folding occurred in the southern half of a triangular area, limited by two about vertical faults at its western and ENE-ern side. The poles of the measured bedding planes in this area are plotted in diagram 16 (figure 22). From this diagram it is readily seen that the folding took place around a WSW fold axis, and must be correlated thus, with the $\overrightarrow{\text{SSE}}$ overthrusting of the Taio block. This triangular area is situated at a 'corner' of the advancing Taio overthrust block, and it will, in this position, be exposed to greater deformational forces, than any other part of the block. A similar phenomenon can be seen at the SW-ern 'corner' of the M. Ori (1371 m) block (see p. 52).

The triangle of the Castel of Thun, must be taken for a partly dislodged slice of the Taio overthrust block, which penetrated the incompetent eocene and upper cretaceous formations; the process was accompanied by the observed folding. The fault ENE of this triangle, permitted the overthrust block to continue its movement still farther to the SSE.

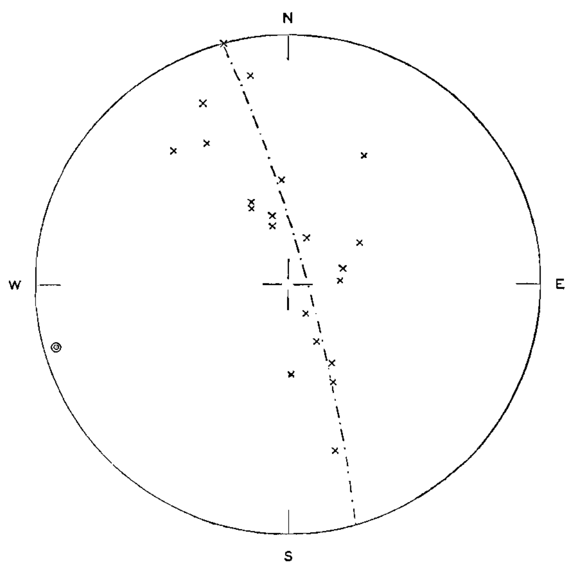
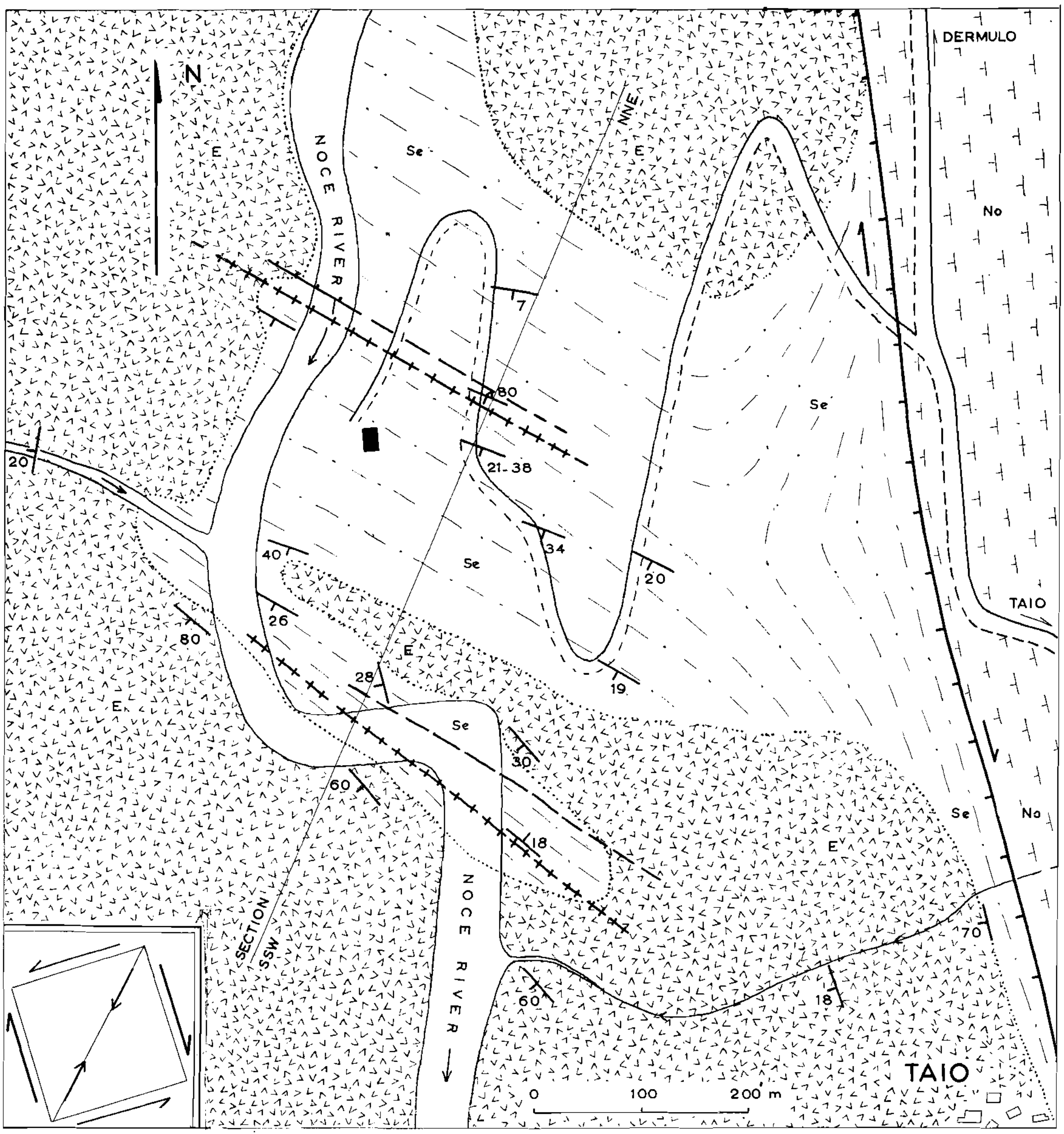


Fig. 22. DIAGRAM 16.
21 Poles of bedding planes and the b-axis derived from them, 255/6. Data collected around the Castel of Thun, 1 km north of Vigo.



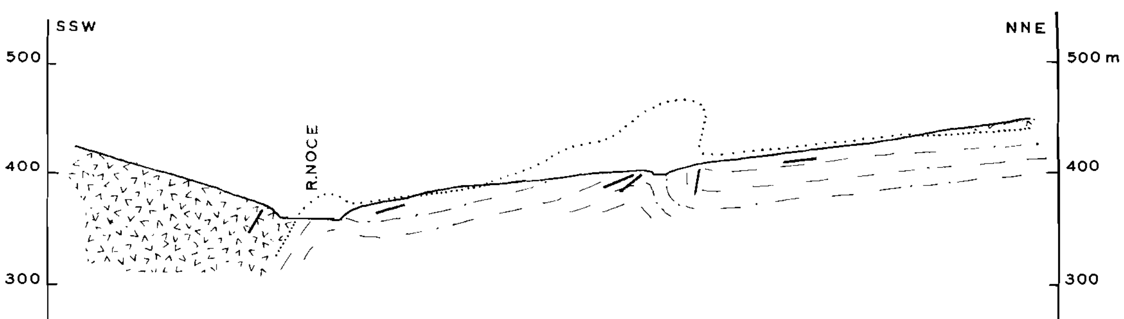


Fig. 23. Detail map B, and SSW-NNE section of folding NW of Taio.
shown. For legend, see fig. 21.
In the SW-ern corner of the map, the stress field responsible for the observed deformations is schematically shown.

2. *The WSW-ern limiting fault* (*the Dermulo-Thun fault*) of the Taio overthrust block – at least 10 km long – is exposed at many places and can easily be followed in the field, because the norian dolomites of the Taio block offer more resistance against weathering than the cretaceous and eocene marls at the WSW-ern side of this fault. North of Rallo, this fault disappears under a thick quaternary cover. The about vertical fault plane itself, does not offer much information on the displacements that took place along them, as striae have vanished by weathering. The cretaceous and tertiary formations WSW of this fault are clearly dragged up by it, demonstrating that a considerable vertical component is present. This dragging up is seen at several places: in the gorge of the Noce river, west and south of Dermulo; north of Taio; east of Mollaro. Its throw increases gradually from north to south, and amounts to about 680 m near Mollaro.

These outcrops led Fabiani (1924 a and 1924 b) to his view that this Dermulo-Thun fault is a 'flexure fault' (It: piega-faglia, a fault initiating as a flexure), and he interprets this flexure as the result of a movement of the Taio block towards the west. It may be mentioned here already, that the fault at the other (SE-ern) side of the Taio block, near Corona, according to Fabiani, should demonstrate an overthrusting of the Taio block towards the east. Apparently the mechanical problem, evoked by these two opposed movements of the same block, did not bother him.

NW of Taio, upper cretaceous and tertiary formations are locally intensely folded, as shown in detail map B and the section of figure 23. Diagram 17 (fig. 24), in which the bedding planes of this structure are collected, shows a fold axis of N 130° E, around which the deformations took place.
This highly deviating direction of folding is thought to be a result of the other displacement, that occurred along the Dermulo - Thun fault: the SSE-directed movement of the Taio block.
The Dermulo – Thun fault is not rectilinear. This includes that the $\overrightarrow{\text{SSE}}$ moving Taio block, did not always fit between its enveloping formations. For instance, the part of the Taio block, on which the village of Taio itself is situated, reaches out markedly to the west. This protrusion of the Taio overthrust block may have produced compression in the cretaceous and tertiary formations of detail map B, during that stage of the overthrusting process, when 'Taio' had not yet reached its present-day position, but was situated still 1 km to the NNW. The relative small mass of cretaceous and tertiary rocks yielded by folding, to let the enormous Taio block pass by. A direction of folding, as found on detail map B (Fig.23), may have resulted from this compression. More evidedence in favour of this view is furnished by a well developed series of about

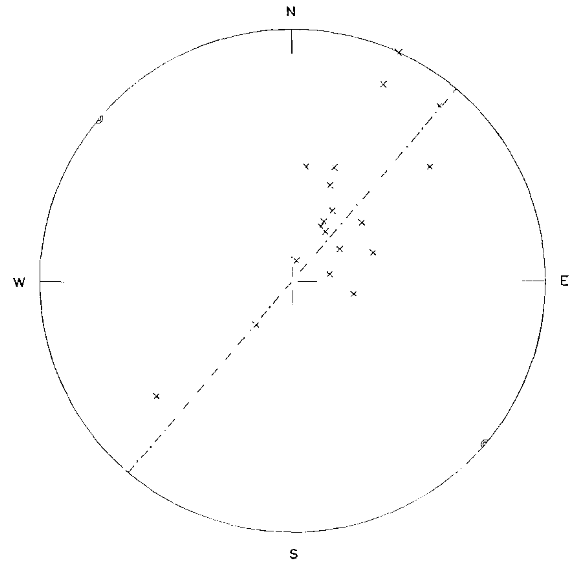


Fig. 24. DIAGRAM 17.
19 Poles of bedding planes and the b-axis derived from them, N 130°E. Upper cretaceous 'Scaglia' and eocene, NW of Taio.

parallel faults (at least 10), which is found in this folded complex. They are striking WSW-ENE. Striae on their fault planes show a relative displacement of the NNW-ern block towards the WSW, i.e. they are sinistral strike-slip faults. This shoving away of the NNW-ern blocks, from the Dermulo – Thun fault towards the WSW, forms another way of yielding of these rocks, to the stresses evoked by the passing by of the – locally too broad – Taio overthrust block.
After all, a simple deformation pattern – schematically shown in the SW-ern corner of detail map B (fig. 23) – underlies the observed features.
The eocene and cretaceous rocks, NW of Taio, were subjected to two sets of shear stresses – a dextral one, acting NNW-SSE, evoked by the movements along the Dermulo – Thun fault, and a sinistral one, acting ENE-WSW, which caused the strike-slip faults in this direction. The shear stresses are symmetrically arranged around a compressive stress, acting NNE-SSW, which produced the folds in this direction.

Halfway Taio and Mollaro, west of the Dermulo – Thun fault, a flat, broad anticline is feebly developed in the upper cretaceous 'Scaglia' and the overlying tertiary marls. This anticline causes the local appearance of 'Scaglia' in the gorge of the Noce river, there. Its fold axis extends N 60° E.
West of the AGIP drilling (1958) of Mollaro, finally, a fault is supposed – the area here is completely covered by alluvial deposits – by which the western block has risen about 200 m, relatively to the eastern one. This assumption is based on the data of the AGIP drilling there (personal information).

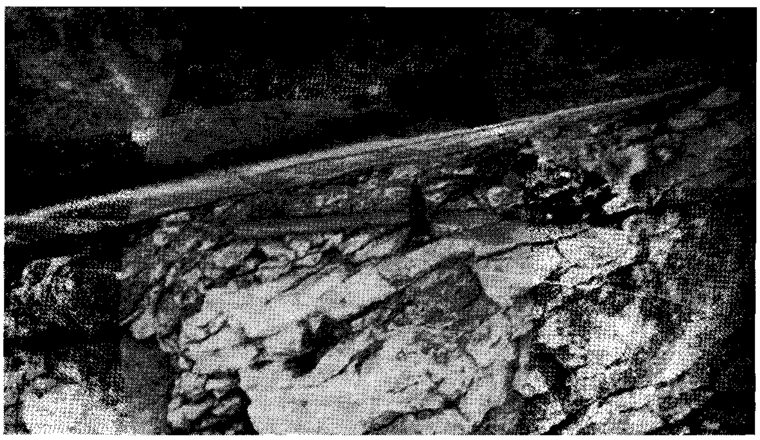
3. *The fault, limiting the Taio overthrust block at its SE-ern side*, rejoiced in a great interest of earlier workers in this region; it is often referred to as the "Corona fault". This interest may find its origin in the fact, that it is situated in the Adige valley walls, and is therefore more easily noticed than better exposed structures more inland.
Vacek & Hammer (1911) connect this Corona fault – quite rightly – with the fault in the Valle dei Pilastri. They attribute, however, a pre-cretaceous age to it, because the youngest involved formation there, is of upper jurassic age.
Folgner (1914) recognized the overthrust character of the Corona fault, but he links it to the Paganella fault (SSW of Mezzocorona; see geological sketch map of the Judicaria region, enclosure I), which raised many objections (Schwinner 1915 b; Vacek 1915; Fabiani 1924 a). Folgner was also troubled by the absence of liassic and rhaetian formations on the Taio block. This fact forms the stratigraphic evidence for the southward overthrusting over many kilometres of the Taio block, as has been exposed on p. 28 of this thesis.
Schwinner (1915 b) – a good observer – discovers the overthrusting mechanism along the southern part (the faults of the Valle dei Pilastri and the Corona fault) of the Taio block, and mentions the SSE-directed movement of it. He takes the important step, that the displacement needs not necessarily have taken place perpendicular to the present-day line of outcrop, or to the strike, of a fault plane.
He recognizes an identical overthrusting ($\overrightarrow{\text{SSE}}$, obliquely to the line of outcrop!) along the *Paganella and Fausior faults* (both SSW of Mezzocorona) and *at many places in the Brenta area*, which will be mentioned yet in the next chapter of this study.
Fabiani (1924 a and 1924 b) and Vardabasso (1926) propose an overthrusting along the Corona fault towards the ESE. They think that deformations in the Val-di-Non area are directed perpendicular to the Judicaria and Foiana faults.

East of the Valle dei Pilastri, which finishes south of the M. d'Arza, the fault, limiting the Taio overthrust block, is mostly covered by scree material of the norian and ladinian dolomites, which form a huge scarp. Its line of outcrop suggests that its inclination has notably decreased, compared to its dip of about 50° in the Valle dei Pilastri (see section VIII). The complex of the stationary block, SE of this Corona fault, is formed by norian dolomites that are covered by a thin stratum of resistant 'Ammonitico rosso', dipping 10°-20° to the N or NW.

At the foot of the Corno di Tres, the Corona fault is exposed. As shown on photograph 5, the low-angle thrust plane separates ladinian dolomites from a brecciated mass of 'Scaglia' (?) and 'Ammonitico rosso'. The thrust plane dips 9° to the NW and it exhibits striae which show a relative movement of the upper block towards N 144° E. This thrust plane is about parallel to the bedding planes of the upper and lower blocks.
Farther to the NE, the thrust plane is covered again by scree material. Its line of outcrop, however, shows clearly its low-angle inclination. Its throw diminishes gradually northward and the fault is thought to finish in the incompetent skythian shales, NW of Termeno, by some minor flexures.
At the ENE-ern side, thus, of the Taio overthrust block, there is not found such a (sinistral) strike-slip fault like the (dextral) Dermulo – Thun fault at its WSW-ern side. That part of the Taio overthrust structure is lacking due to denudation by the Adige river. Missing too, is the frontal part of the Taio block, east of the Valle dei Pilastri; for the low-angle fault between M. d'Arza and Termeno is only the sliding plane, on which the Taio block moved to the SSE, i.e. the eastern extension of the fault plane of section VIII. The original extension of the Taio overthrust block, thus, is still greater and possibly its frontal limit reached the present-day position of Magré or still farther to the ENE.

The very badly exposed area around Cortaccia, does

NNW



SSE

Photograph 5. Thrust plane (light-coloured, subhorizontal plane, seen from below) of the Taio overthrust block, SE of the Corno di Tres. Massive ladinian dolomites (dark) in tectonic contact with brecciated 'Scaglia'(?) and 'Ammonitico rosso' (upper jurassic). Striae reveal a displacement of the dolomites toward N 144° E.

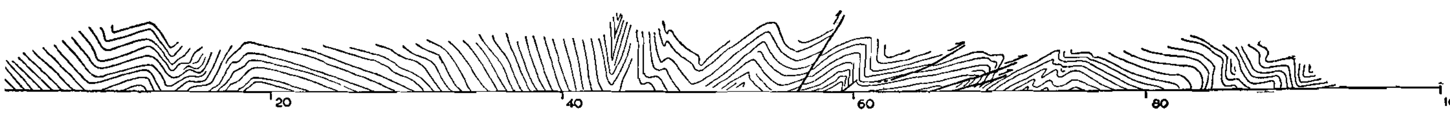


Fig. 25. Detail section of $\overrightarrow{\mathrm{N}}$ folded upper cretaceous 'Biancone', resulting from a décollement from the 263/17 dipping frontal part of the Taio overthrust block (see fig. 27). 250 m NE of Prio.

not permit a thorough investigation of the structures, north of this village. As shown on the geological map, a small $\overrightarrow{\mathrm{SSE}}$ overthrust block is assumed there, below the sliding plane of the large Taio overthrust block. This assumption of a smaller overthrust block north of Cortaccia explains, anyway, the tectonic disturbances and position of stratigraphic formations there, and fits in the general tectonic style of the area.

4. *On top of the Taio overthrust block*, structures are strikingly quiet. Its topography is formed by an enormous dip-slope of norian dolomites, protected at many places against too rapid erosion by thin sheets of upper jurassic and upper cretaceous formations.

Near Coredo, two faults are cutting the Taio block. The WSW-striking fault, extending from Dermulo to Coredo, produced drag phenomena in the SSE-ern block, which indicate a relative sinking of the NNW-ern block (see section VIII). Its throw is thought to amount to $\pm$ 15 m, though correlations in the monotonous 'Scaglia' are difficult. Along the other fault, striking NNW with unknown inclination, a relative rising of the ENE-ern block occurred. The northern half of this fault is not exposed, due to quaternary deposits around Banco. It may partly take over the function of the Dermulo – Thun fault in this more northern part of Taio overthrust blok.

Near Prio, a locally intense folding of the upper cretaceous 'Biancone' – here an alternation of grey limestones and thin, dark shales – offers detailed information on the process of overthrusting of the Taio block, and its additional features.

Only the thin – $\pm$ 20 m thick – formation of the 'Biancone' is affected by this folding. The underlying norian dolomites show no deformation.

250 m NE of Prio, along the road to Vervo, the section of figure 25 can be studied. Striking feature is the $\overrightarrow{\mathrm{N}}$ directed sense of folding, accentuated by small upthrust faults towards the north. The poles of the measured bedding planes in this outcrop, are plotted in diagram 18^{A} (fig. 26) and from them a fold axis is derived of N 83° E (or N 263° E). Looking for a slope, from which this – and the overlying (?) – formation slid down towards the north, we find only the WNW-inclined dip slope of the frontal part of the Taio overthrust block (see section VIII), NE of the Castel of Thun. This dip slope does not quite satisfy us for this purpose, because its mean inclination is 216/17, and we expected to find a dip slope, striking something like N 263° E. Remembering the relief, which once resulted from a rotation eliminating the regional SW-tilt of the Val-di-Non area (tension fault, N of Fondo), we try this rotation also in this case. As shown in diagram 18^{B} of figure 27, this rotation changes the present-day inclination of the dip slope from 216/17 into an inclination of 263/17. This is exactly the value of dip-slope required for the N-directed décollement of the Biancone formation near Prio.

This includes that the back folding of this series took place, before the regional tilting to the SW (N 240° E) of the Val-di-Non area, and immediately after the $\overrightarrow{\mathit{SSE}}$ *deformation phase.*

A smaller outcrop, 150 m NNW of Prio, shows the same folded formation again. The poles of these bedding planes (O) plotted in diagram 18^{A} (fig. 26),

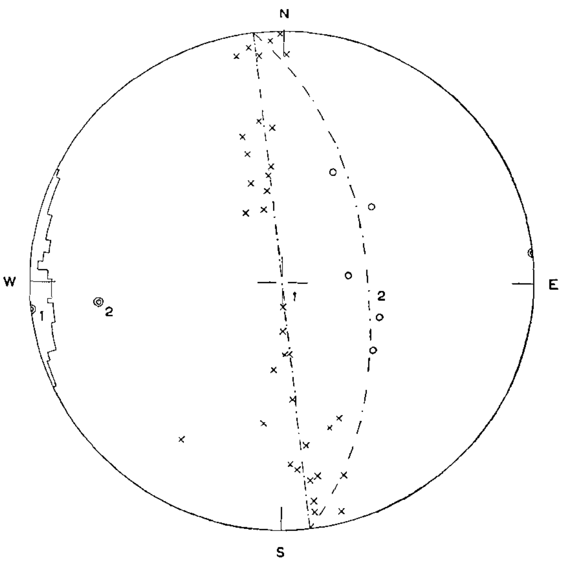


Fig. 26. DIAGRAM 18^{A}.

(×) 35 Poles of bedding planes and the b-axis derived from them (1) N 83°E.
At the border of the diagram, frequency of 8 directly measured b-axes. Folded upper cretaceous 'Biancone' of fig. 25, 250 m NE of Prio.

(O) 5 Poles of bedding planes and the b-axis derived from them (2) 263/28. Folded upper cretaceous 'Biancone' 150 m NNW of Prio. The inclination of this axis is due to creep.

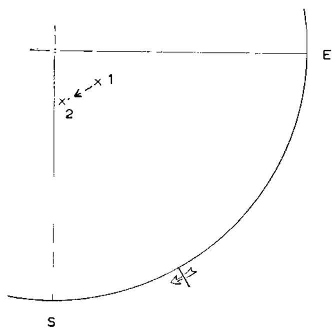


Fig. 27. DIAGRAM 18[B].
Mean pole of bedding planes of the Taio overthrust block, SE of Prio, before (1) and after (2) rotation over 13°, to eliminate regional tilt.
(1):216/17.
(2):263/17

however, furnish a b-axis 263/28. The dip of this fold axis is easily explained by the position of this outcrop on a W-dipping slope: rotation of this structure resulted from simple creep phenomena.

The close resemblance of these structures near Prio to the '*Gipfelfaltungen*' in other parts of the Dolomites is striking. This 'summit folding' – a translation of Gipfelfaltung, proposed by de Sitter (1956 b) – is a much observed phenomenon in the central Dolomites and in the Brenta area (Trevisan 1939 a; Wiebols 1938). It affects mainly post-triassic strata, which are overlying the practically undisturbed triassic dolomites and limestones. After a thorough investigation of these summit foldings, Accordi (1955 and 1957) concluded satisfactory to gravitative processes, by which masses of the upper formations slid down in various directions along gently inclined bedding planes towards the centre of structural depressions. As the central Dolomites are more deeply eroded than our area, the summit foldings are preserved only in these structural depressions, which are now mostly found near the summits of the Dolomite peaks.

The analysis of the structures around Prio, too, shows the gravitative sliding of such younger formations towards the deeper parts of a structural depression, and it demonstrates also, that this downsliding happened shortly after – before the regional tilt – the frontal part of the Taio overthrust was pushed up, to furnish the required inclined sliding plane. It is, thus, not probable that erosion of the area around Prio had taken place yet to such a degree, that the area was largely denudated before the folding of the 'Biancone' occurred. This consideration favours the view of de Sitter (1956 b) on the summit foldings in the Dolomites, as opposed to the concept of Accordi (1955). For the former doubts an erosion of the structural depressions previous to the downsliding process, as advocated by Accordi, in order to clear the way for the downsliding masses.

Summing up the overthrusting of the Taio block, we see again the $\overrightarrow{\text{SSE}}$-directed deformation system clearly represented. Though the overthrust block is not complete at its SE-ern side, where its frontal part and its ENE-ernly limiting fault have been eroded, many particulars inform us on its mechanism.

Its concave (see section VIII) sliding plane, becomes steeper towards the front; it was tilted (see section VI) towards the SW, after the overthrusting movement. Its concave sliding plane bears great resemblance to the 'Buffalo Mountain fault', as described by King (1960; fig. 3[A] of p. 120).

Stratigraphically the 3-4 km overlap of the Taio block is proved by the absence of middle and lower jurassic formations on top of it (see p. 28).

Great value must be attached to the general absence of compression features, excluding the folding phenomena near Taio, the Castel of Thun, and the Valle dei Pilastri. These structures may be regarded as relative small obstructions beside and in front of the moving overthrust block, partly shoved aside by it, partly, however, bringing the overthrusting block to a final stop.

The gravitational character of the mechanism is emphasized by the presence of tension faults near the 'tail' of the overthrust block, (N of Fondo, Dermulo) which, according to their sense of displacement, must be correlated with this $\overrightarrow{\text{SSE}}$-directed deformation phase. The combination of overthrusting and tension faults, as found in our area, cannot be explained by tangential compression.

7. Joints

It is well known, that joint systems in a given area often show the tendency to have a mutual plane of symmetry. In many cases a close relation between the orientation of this plane and deformational directions is obvious. At nine places in the Val -di-Non area joints have been measured in order to investigate, whether their systems, too, show a preferred orientation to a plane of symmetry, and whether such a plane informs us on the deformational history of this area.

The measuring of joint planes was carried out in the following way. In order to obtain a quantitatively correct picture of the frequency of joint planes, all joint planes were measured of a certain area of an outcrop. Dependent on the properties of the joints (spacing, size, number of sets) these areas range from 4 -20 sq. m. For it is to be expected, that by measuring at random, a considerable subjective element enters in the obtained quantities. The poles of the measured

joint planes were plotted simultaneously in a diagram. As soon as distinct concentrations developed in the diagrams, measuring was stopped. Attention was paid also, to additional features like striations and smoothness of the joint faces, quartz and calcite fillings of the joints, and their mutual relations.
This method of measuring is suited in particular for the Val-di-Non area, as the size of the joint planes appeared to be rather uniform in each outcrop. If the size (area in sq. cm) of the joint planes diverges widely, the applied method will give a incorrect picture; for then the few large, i.e. important, joints will be measured less frequent, than the great mass of small joints, and frequency is the only factor, expressed in the diagrams, obtained from the measurements.
In the diagrams 7-15, the concentrations of the joint poles are presented. The joints appear to be about perpendicular to the bedding plane (dashed line).

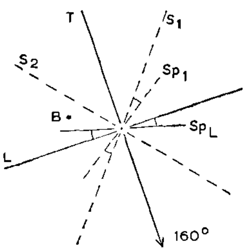


Fig. 28. Symbols for the strike direction of obtained joint sets as used in the centre of the diagrams 7-15.

T	: transversal joints
L	: longitudinal joints
S_1 and S_2	: Sets of shear joints
Sp_1 and Sp_L:	Splay joints, splitting off from S_1 and L respectively.
160°	: Axis of symmetry of the joint systems
B	: Pole of bedding plane

In the centre of the diagrams, a schematic presentation of the strike directions of the obtained joint sets is shown. A genetic significance is attributed to these sets by the author, the symbols of which are shown in figure 28. This interpretation is based on the much observed occurrence of *two systems* of joints, each consisting of two sets:

1. A system of *tension* joints, consisting of
   a. a set of transversal (cross, ac-plane) joints, and perpendicular to it
   b. a complementary set of longitudinal (bc-plane) joints.
2. A system of *shear* joints – consisting of two sets – symmetrically arranged to the ac-plane of deformation, making an angle of <45° with this plane.

It is found, that to any of these sets an additional, minor set may occur, at an angle of about 15° with it. This phenomenon will be referred to as *splay jointing*, or simply splay.
In figure 28 an ideal orientation of joints is shown, as might result from a compression in a N 160°-340° E direction.

Discussion of the diagrams.

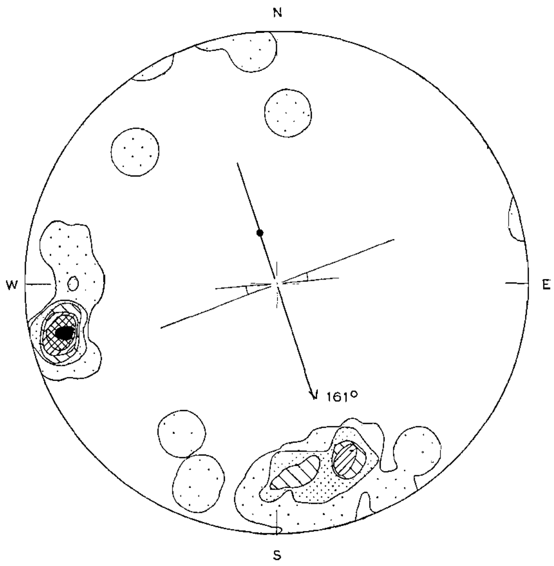


Fig. 29. DIAGRAM 7.
48 Poles of joints in the permian quartz-porphyry near tunnel, 1 km NNW of Tesimo.
Contours: 0–4–8–12–16–20–24%.

DIAGRAM 7.
The massive permian quartz-porphyries show well developed joints, with large, flat surfaces. We distinguish a system of two perpendicular sets, a higher – 24% – concentration of transversal joints (N 162°-342° E), and a – 16% – concentration of longitudinal joints (N 69°-249° E). Subhorizontal striae occur on the transversal joints.
In the outcrop too, splay joints (N 85°-265° E) are observed, splitting off from the longitudinal joints at an angle of 16°.

DIAGRAM 8.
Like in diagram 7, here an identical system of transversal (about N 159°-339° E) and longitudinal (N 61°-241°E) joints is exhibited. Splay joints occur probably at both sides of the transversal joints.
The highest – 24% – concentration is formed by a deviating set of joints, 44/35. These SE dipping joint planes, show many striae, indicating a dip-slip movement of the upper block downward. Closely related to these movements are striae on some of the transversal joints, as these striae are dipping 35° to the SE too.
It is suggested here, that the joints 44/35 represent shear planes, which originated in a later stage. For

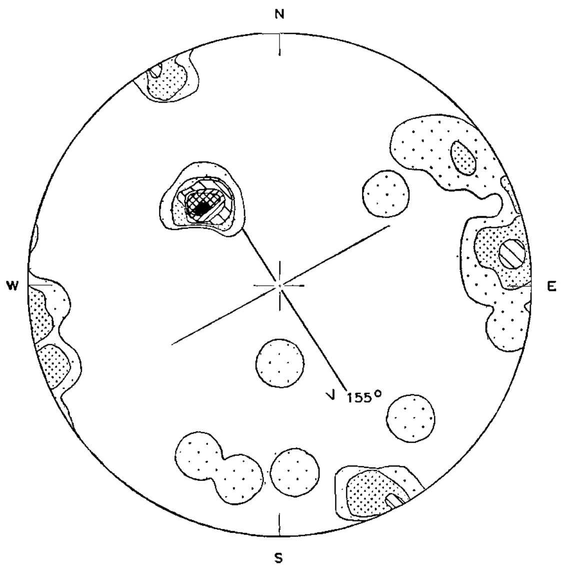


Fig. 30. DIAGRAM 8.
50 Poles of joints in the permian quartz-porphyry along road from the Passo della Mendola to S. Paolo.
Contours: 0–4–8–12–16–20–24%.

they strike parallel to the local, steep walls of the Adige valley and the movements along them indicate a downward gliding of the topographically high quartz-porphyries towards this valley. The shear planes are caused thus, by a local stress field in these massive porphyries, which resulted from the increased relief energy at the scarp of the Adige valley. These movements used, and are partly guided by, the already existing transversal joints. The 35° SE-dipping striae on them resulted from these down gliding movements, and they are thus of younger age than the transversal joint planes themselves.

DIAGRAM 9.
The two clearly developed sets of shear joints intersect at an angle of 80°. The bisector of this acute angle extends N 154°-334° E.

DIAGRAM 10.
Again, clearly a system of shear joints developed in these dolomites. A set of transversal joints is present

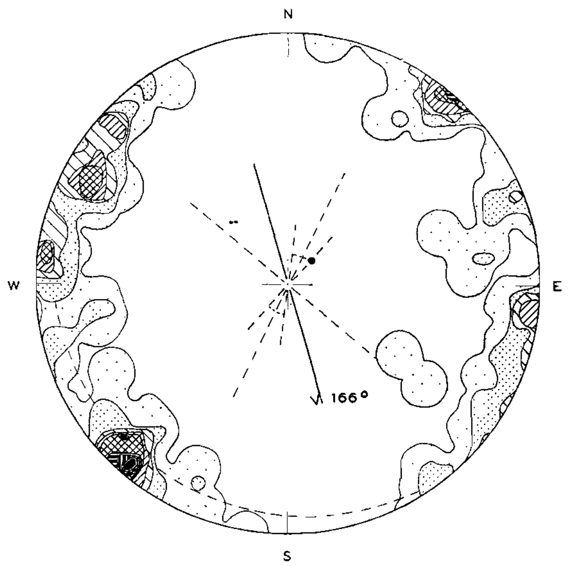


Fig. 32. DIAGRAM 10.
100 Poles of joints in the ladinian dolomites E of Tret, along the road from Fondo to the passo delle Palade.
Contours: 0–2–4–6–8–10–12–14–16%.

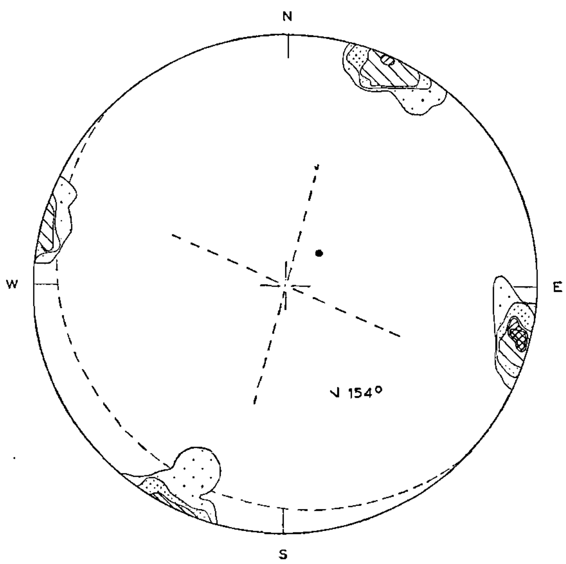


Fig. 31. DIAGRAM 9.
24 Poles of joints in the ladinian dolomites north of Tret, along the road from Fondo to the Passo delle Palade.
Contours: 0–8–16–24–32–40%.

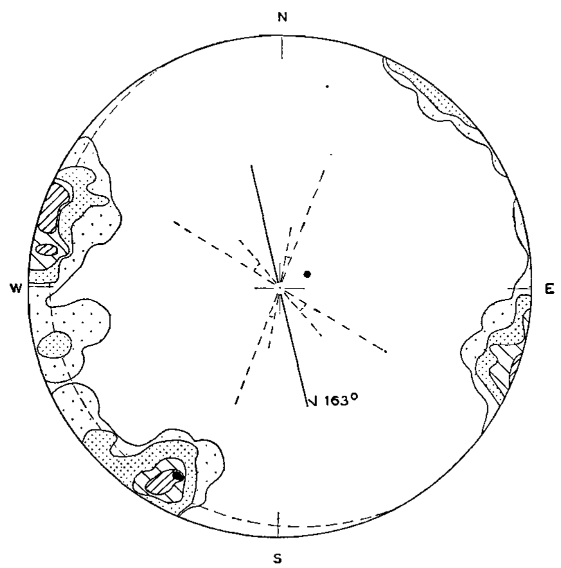


Fig. 33. DIAGRAM 11.
50 Poles of joints in the norian dolomites, 2 km north of Fondo, along the road to the Passo delle Palade.
Contours: 0–4–8–12–16–20%.

too, forming the bisector of the acute angle of 76° between the two sets of shear joints. Quantitatively, the transversal joints do not form a very pronounced concentration in this diagram. In the outcrop, however, some very large joints must be attributed to this set.
At both sides of the set of shear joints, which strikes N 26°-206° E, splay joints developed, making angles of 16° and 19° with it.

DIAGRAM 11.

A similar development of joints, as found in diagram 10, is seen here: a system of shear joints, intersecting at an angle of 79°, its bisector coinciding with a set of transversal joints.

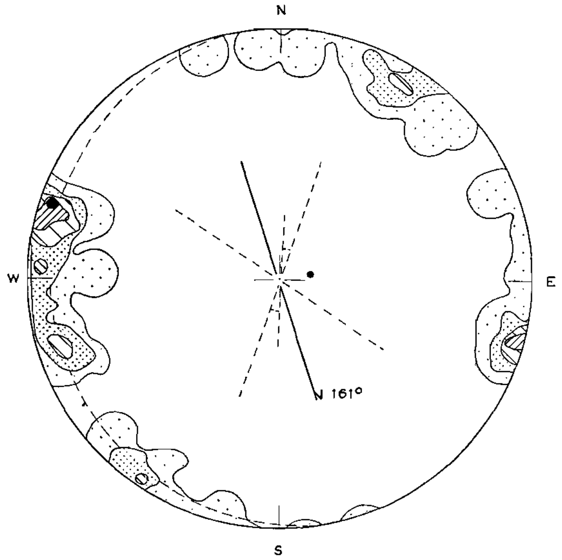


Fig. 34. DIAGRAM 12.
50 Poles of joints in the norian dolomites 500 m NE of Fondo, along the road to the Passo edlle Palade.
Contours: 0–4–8–12–16–20%.

Splay joints were seen six times in the outcrop; they formed at angles of 18° and 11° with both the sets of shear joints.

DIAGRAM 12.

A similar development of joints, as found in the two preceding diagrams. The sets of shear joints intersect at an angle of 75°. Splay joints formed at an angle of 16°.

DIAGRAM 13.

The two sets of joints, developed in this outcrop, are perpendicular to one another and are taken thus, for a system of transversal joints, with their complementary longitudinal joints.
The small concentration of N 176°-356° E striking joints may be caused by splay – at an angle of 25° – of the transversal joints.

DIAGRAM 14.

A system of two well developed sets of shear joints is

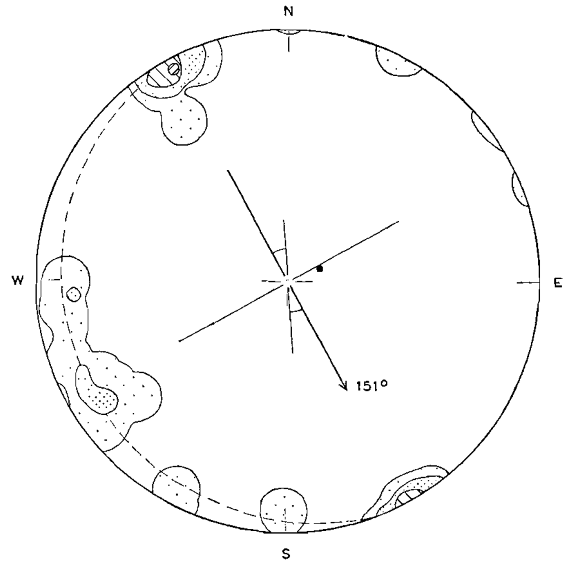


Fig. 35. DIAGRAM 13.
22 Poles of joints in the ladinian dolomites at the Passo della Mendola.
Contours: 0–10–20–30–40%.

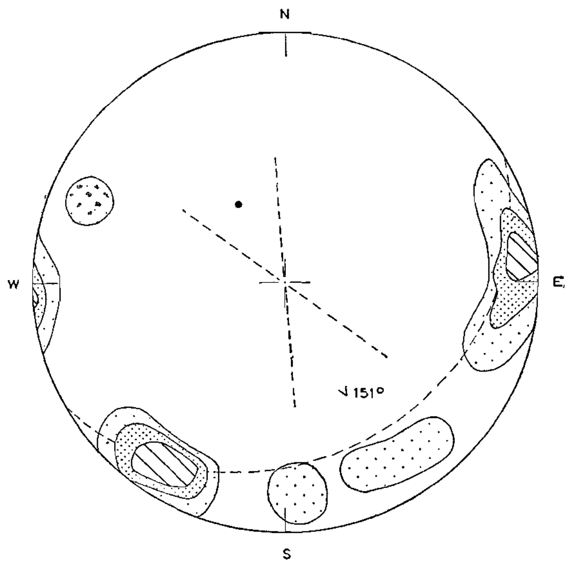


Fig. 36. DIAGRAM 14.
35 Poles of joints in the ladinian dolomites, 600 m west of Cagno.
Contours: 0–6–11–17–23%.

seen in this outcrop. Some of these joints are of very large size. The sets intersect at an angle of 50°.

DIAGRAM 15.

Four large sets of joints developed in this outcrop. Closer observation informs of the interesting phenomenon, that they may be classified as two systems, each consisting of two sets, which are perpendicular to each other. The first system (single lines in centre of figure 37) is composed of sets striking N 165°-345° E and N 75°-255° E, and, by this orientation it bears

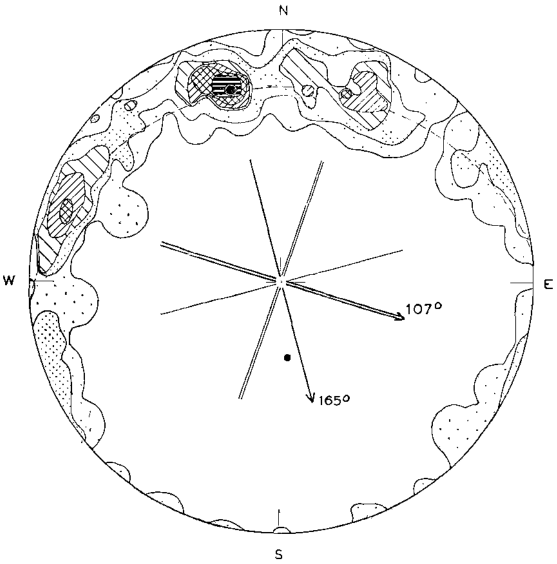


Fig. 37. DIAGRAM 15.
100 Poles of joints in the skythian and anisian formations west of Bagni di Caprile, along the road to the Passo delle Palade. Contours: 0–2–4–6–8–10–12–14%.

great resemblance to systems formerly regarded as transversal and longitudinal joints. The second system (double lines in centre of fig. 37) is orientated asymmetrically to the first system. Its sets strike N 19°-199° E and N 107°-287° E, i.e. parallel and perpendicular to the Foiana fault, which is situated at a distance of 500 m from this outcrop under consideration. It is obvious, that this deviating system of joints can be interpreted as a feature, accompanying the Foiana faulting process, which produced also the upward drag of these strata a 200 m farther to the west.
The tensional character of the N 107°-287° E striking joints is expressed by their calcite-coated planes.

Reviewing the discussed joint diagrams of the Val-di-Non area, we first of all observe, that *they all respond to one general pattern, the plane of symmetry of which strikes NNW-SSE.* The additional *deviating systems* of joints could be explained by stress fields of *local* importance.
The observed pattern of joints is usually explained as a result of compression of the rocks in NNW-SSE direction; the sets of tension joints are parallel and perpendicular to this direction of compression; the direction coincides with the bisector of the acute angle between the sets of shear joints.
This demonstrates, that the stress field of the NNW-SSE directed folding and deformation phase – present in many other structural features of the Val-di-Non area – is also reflected in the observed joint pattern.
It emphasizes thus the regional importance of this orogenic phase and its stability of direction over extensive areas.
It is not easy to tell, which factors rule the development of tension joints in one case, and of shear joints in the other. It is anyway, not purely a matter of rock properties, for both systems occur alternatingly in the dolomites.
Remarkable, however, is the absence of shear joints in the diagrams 7, 15(?), 8, and 13, i.e. in all outcrops that are situated along the steep Adige valley. It is reasonable to suppose, that this zone favours the occurrence of tensional stresses in the deeply eroded rocks of the valley walls. More interesting is, however, that the Adige valley between Merano and Bolzano must have formed the *hinge zone*, around which the regional tilting of the Val-di-Non area toward the WSW took place; during this tilting, undoubtedly *tension* occurred in the nearby formations. The rectilinear development of the Adige valley itself, might be explained by its position in this hinge zone.

The development of splay joints, additional to a major set of joints, forms a problematic point. It should be stated first of all, that their concentrations in the diagrams can not be taken for a natural dispersion of the set of joints, to which they are additional, as might be caused for instance by an undulation of a joint plane. For these splay joints can actually be seen in the outcrops, diverging abruptly from a shear or tension joint, at an angle of about 15°. Their occurrence in the Val-di-Non area, however, is irregular and does not permit any assumptions regarding the stresses, responsible for their development.

In conclusion it can be stated that, if carefully handled, joint systems may furnish useful information on the tectonic history of a region.

8. Sub-recent collapse structures

In the Val-di-Non area the Judicaria fault is in most cases situated in SE or ESE inclined slopes. In the Marano valley, for instance, we find it in the steep left-hand bank it this river. There are many indications, that the WNW inclination of the Judicaria fault here, has notably been decreased by creep. The easily eroded shales of the Gardena formation, south of Bagni di Mezzo, even permit larger mass movements downslope, than are usually associated with creep. Minor rumples in these shales bear witness of such movements under the influence of gravity.
A similar situation exists along the southern half of the Foiana fault. The more rapid erosion of the soft cretaceous 'Scaglia' and eocene marls, compared to the ladinian and norian dolomites at the other (WNW-ern) side of this fault, tends to increase the relief intensity in this area. Downsliding of masses is greatly favoured by the inclination of the dolomites parallel to its slopes (see sections of fig. 15). So here too, the Foiana fault plane is bended towards the ESE from its original more or less vertical inclination; the folding

of the incompetent 'Scaglia' and eocene marls, ESE of this fault, is an accompanying feature of this process.

The megabreccias near Cloz and farther northward along the Foiana fault, were briefly mentioned in a preceding paragraph (chapter III, b, 4). They may be regarded as the ultimate stage of the gravitative deformations of the Foiana fault, as described above. For in these instances, the downslope moving ladinian dolomites did not only bend the Foiana fault to the ESE, but they even crossed this fault, urged so, in order to decrease their potential energy.

The name of these structures – megabreccia, after Longwell (1951) (see also Koop (1952), who studied similar gravitatively displaced flaps in southern France) – indicates their large size and partly brecciated status. Coherence, however, is not lost altogether in the dolomites, and it is at many places hard to tell them apart from the dolomites 'in situ', at the WNW-ern side of the Foiana fault. Characteristic for the megabreccias is their greater tectonic disturbedness, shown by numerous faults and faultzones cutting them. Furthermore, the direction of strike and the inclination of the strata are highly irregular.

While moving down their dip-slope, over the cretaceous and eocene marls, after they passed the Foiana fault, the megabreccias covered a distance of at least 1,5 km (being the length in the direction of movement of the flaps, west of Brez). Their thickness is thought to range from a 100 to possibly 200 metres. The sliding plane, on which these flaps moved down, is covered by the scree material, which is abundantly supplied by the overlying brecciated dolomites.

Morphologically, the outlines of the megabreccias are easily traced, as they form clearly elevated 'tongues' on the flat topography of the eocene marls (see section IV of enclosure II). The scars, left behind by these landslide masses in the ladinian dolomites on the M. Luco horst, complete the morphologic picture of this type of collapse structures.

These megabreccias have a *sheet-like* extension, quite different from an other kind of gravitative denudation, met south of Cagno. At the SW-ern side of the Lago di Cles a large natural quarry in norian dolomites and carnian shales forms the scar, from which enormous *blocks* of this dolomite slid and tumbled down into the former gorge of the Noce river, the present-day Lago di Cles.

The dimensions of this vertically walled quarry are $\pm$ 800 $\times$ 200 $\times$ 200 m. Some of the blocks may reach a volume of a million cubic metres. In this case, the carnian shales performed a lubricating function during the initial – sliding – stage of the movements.

South of Ruffré, finally, a landslide structure is probably present. A slip-sheet of norian dolomites slipped down the dip-slope (dipping about 10° to the west); in this instance the carnian shales acted as a lubricating layer. The dolomites of this slip-sheet – a term used by Harrison and Falcon (1934, 1936) in their interesting papers on gravity collapse structures in Iran – are markedly more disturbed and crushed than the surrounding rocks. The unexpected east-dipping of the carnian strata east of Ruffré, may possibly be related to this downslope movement of masses.

c. SEQUENCE AND DIRECTIONS OF THE DEFORMATIONS

The many tectonic events, which influenced the Val-di-Non area, will be briefly recapitulated in this paragraph in their original chronological order (see fig. 38) as far as this sequence could be deduced from the field observations.

a. The $\overrightarrow{\text{SSE}}$-deformation phase.

It is represented by:

1. General trend of the central alpine schists.
2. Direction of minor sub-horizontal fold axes in the quartz-phyllite series.
3. Folds, NE of Senale.
4. Synclinal fold, west of Tregiovo.
5. Overthrusting, north of Castelfondo.
6. Low-angle dip-slip fault, north of Fondo.
7. Dextral strike-slip fault near Ruffré (?).
8. Overthrusting of the Taio block, which, on its turn, caused during its movement.
   the folds in the Valle dei Pilastri, and around the Castel of Thun,
   the folds, NW of Taio.
9. Overthrusting, north of Cortaccia.
10. Broad anticlinal fold between Taio and Mollaro.
11. Orientation of the joint pattern.

The gravitative, SSE-directed character (décollement of the sedimentary cover) of this deformation phase is shown by many of these features (viz. 3, 5, 6, 8, and 9) and it is not contradicted by the other ones.

a'. $\overrightarrow{\text{N}}$-directed back folding near Prio.

It resulted from the décollement towards the north, of the upper cretaceous, and the overlying formations, from the upthrusted, north-dipping frontal part of the Taio block.

b. Relative sinking of the ESE-ern block, along the Judicaria fault.

Minor movements along and near this fault occurred all through the sedimentary history, treated in this study. They gave rise to facies differences at both its sides. In particular during upper cretaceous and tertiary times, these displacements became more marked. The eocene conglomerates even suggest that the Judi-

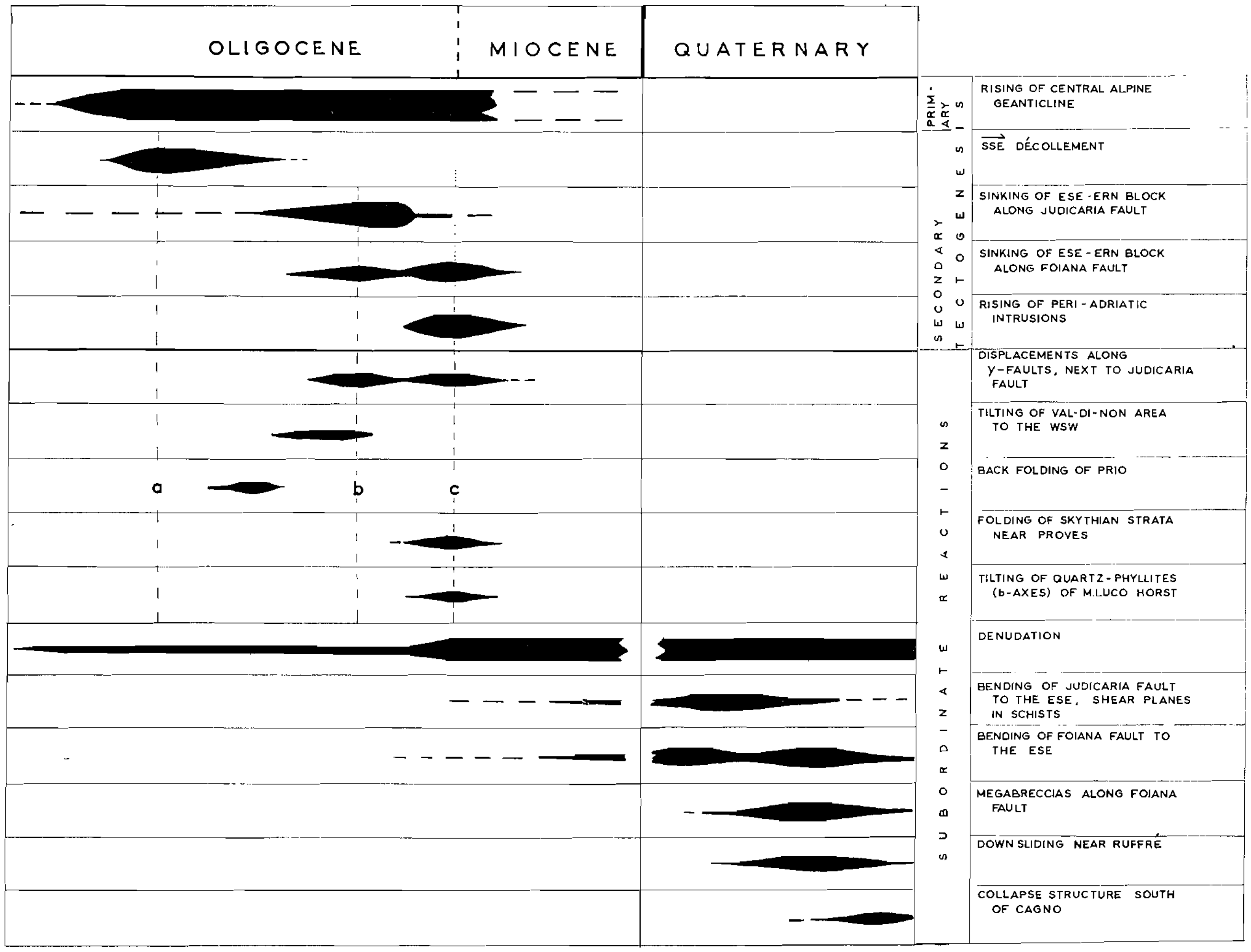


Fig. 38. Scheme of sequence and interrelations of the deformations in the Val-di Non area. The subphases a, b, and c, as discussed in the next chapter, are indicated.

caria line may have formed an important fault scarp at that time.
The major displacement along the Judicaria fault took place in late oligocene time (see p. 32 of this thesis). It was accompanied by important features, which may be expected during the conditions, of tension, ruling this faulting process:

1. Origin and first displacements along the auxiliary fault of the Judicaria fault, the Foiana fault, by which also the ESE-ern block sinks, relatively to the WNW-ern one.
2. Origin of the antithetic faults parallel to the Judicaria line, by which the sedimentary wedges and fault troughs formed.
3. Tilting of the entire Val-di-Non area towards the WSW.
4. Small normal faults, about parallel to the Judicaria fault, as found near Fondo and Ruffré.

The relative age of this series of events is demonstrated by the upward drag by the Foiana fault, of the fold axis NE of Senale (diagram 4^A of fig. 16). Furthermore the structures of the two forementioned phases of deformation are all tilted to the WSW (e.g. fault, north of Fondo; sliding plane and frontal part of the Taio block; fold axis of the Prio back folding; fold axis of diagram 4^B).

c. *Rising of the tonalite intrusions of the M. Croce and along the Judicaria fault.*

Accompanying features of this process – the upward pushing of the M. Luco horst – are mainly confined to the northern half of the Val-di-Non area:

1. Powerful reactivation of the antithetic faults next to the Judicaria fault. The northern sedimentary wedges and fault troughs, comprised between the antithetic faults and the Judicaria fault, are mechanically crushed.

2. Near Proves, the sedimentary trough is elevated at its ESE-ern side by the rising M. Luco horst; it causes the WNW-ern folding of the skythian strata there.
3. The rising of the M. Luco horst is opposed to the original displacement along the Judicaria fault; the sinking of the ESE-ern block is slowed down abruptly by it.
4. Tilting of the quartz-phyllite series and the originally subhorizontal b-axes, to the SW.
5. Reactivation of the Foiana fault, by which its throw increases in the northern half of the Val-di-Non area.

The dating of these movements during the last stage of the major displacements along the Judicaria fault, was deduced from the fault systems of diagram 1 (fig. 8 and 9).

Moreover, the tonalites sought their way upward along the peri-adriatic line, but the intrusions are at many places mylonitized, which means that the displacements had not yet finished completely, after the intrusion.

Arguments have been advanced (p. 32) that the tonalite intrusions occurred on the turn from oligocene to miocene times.

Bending of the Judicaria and Foiana faults towards the ESE, set in immediately after their origin, as soon as a notable difference in specific gravity of the rocks at either side of the faults arose. It continues to recent times, while deeper parts of its structures are exposed by the gradual denudation.

Along the Foiana fault, this bending is locally prevented by the rigidity of the quartz-porphyry plate.

In sub-recent times collapse phenomena took place, favoured by constant denudation, by which the way was cleared for their downsliding and/or down tumbling. The megabreccias along the Foiana fault, reactivated the ESE-ward bending of this fault.

The relative age of the discussed deformations is schematically presented in figure 38.

CHAPTER IV.

Structural Considerations

a. STRUCTURAL EVOLUTION OF THE VAL-DI-NON AREA

The sequence of tectonic events, as derived from the field data in the Val-di-Non area (see fig. 38), is a detailed one. It informs us also on the relative importance of these happenings. So it was seen, for instance, that the Foiana depression must be classified as an accompanying feature of the Foiana fault, being caused only by the upward drag along this fault and the later gravitative reactions of the sedimentary cover. The sedimentary fault troughs along the Judicaria fault originated as subordinate structures along this fault. *The major events – in their original chronological order – determining the structure of our area, are formed by:*

a. The $\overrightarrow{SSE}$-directed deformation phase,
b. The origin of the Judicaria fault, and
c. The intrusion of the tonalitic massifs.

All other features could be explained as accompanying subordinate reactions.

Each of these three major tectonic events demonstrates very pronounced characteristics. The $\overrightarrow{\text{SSE}}$-directed deformation phase can only be understood as the gravitative decollement of the sedimentary cover, which includes the presence of a relatively more elevated region NNW of the Val-di-Non area.

The Judicaria fault originated as a large normal tension fault, apparently independently of the direction of the preceding deformation phase. Both these tectonic events, however, have in common the relatively elevated position of the region NW of the Val-di-Non area.

A theory on mountain building, dealing with this part of the alpine orogene, should not conflict with the observed sequence and characteristics of these tectonic events.

In the first paragraph of chapter III, a brief summary was given of the tectonic meaning attributed to the peri-adriatic line by the major orogenic theories. These theories may be classified into three types, viz.

1. contraction or tangential compression theories (e.g. Staub, De Sitter),
2. convection current ('Verschluckung') theories (e.g. Kraus), and the
3. undation theory (Van Bemmelen).

Considering firstly tangential compressive forces (acting NNW-SSE) as being responsible for the deformations, listed in the preceding paragraph under a, 1-11, we are confronted by the contradiction of the simultaneous presence of tensional stresses, acting in precisely the same direction. These tensional stresses are, for instance, responsible for the dip-slip normal fault, north of Fondo (diagrams 6, of fig. 19 and 20) and for the normal fault between Dermulo and Coredo (see section VIII).

Furthermore, tangential compressive forces in the crust, cannot have caused a fold series as found NE of Senale, where folded anisian and skythian formations are found on top of the undisturbed, hard Bellerophon limestones. Neither can they have caused the constantly observed $\overrightarrow{\text{SSE}}$-directed sense of folding, accompanied by the typical 'voraneilen der jüngere Schichten', which might be translated as 'the moving-ahead of the younger formations'.

Both in the tangential compression theory, as advocated by Staub (1949) and de Sitter (1956 b), and in the convection current theory, as advanced by Kraus (1951), the Judicaria fault is taken for a sinistral strike-slip fault, along which the south-alpine Dolomitic block was pushed a 40 km farther to the north, than the Bergamasc Unit, WNW of the Judicaria fault, Neither stratigraphic, nor any tectonic evidence in favour of such a sinistral strike-slip faulting could be traced. On the contrary, only dextral strike-slip faults of different strike are present in the Val-di-Non area, which are presumably to be correlated with the SSE-directed deformation phase.

In the convection current theory ('Verschluckung'), the moving-ahead of the younger formations is apparently included, for hereby the older formations are supposed to be sucked towards the centre of the orogene, sliding thus below the younger ones, which are staying on their place by a neither clearly described, nor understood mechanism.

Moreover, the occurrence of tonalitic intrusions all along the peri-adriatic line, is in flat contradiction to the 'Verschluckung' hypothesis. For the latter considers just this alpine suture as the place where the convection currents should drag *down* considerable masses of redundant crustal material. The general *uprising* of tonalitic intrusions along this lineament does not fit in this picture.

In his undation theory, adapted to the east alpine orogenesis, Van Bemmelen supposes the formation of a mid-tertiary geanticline in the central alps (van Bemmelen 1957, 1960 b and c). His concept, that the eastern part of the peri-adriatic line developed as a rift at the southern flank of this geanticline, proved to be right in the 'Gailtaler' Alps (Van Bemmelen 1957). To the west, this Drau Rift grades into a normal fault of great throw, the Pusteria fault and the northern Judicaria fault. The observations of Dietzel (1960) in the Merano region, our northernly adjacent area, also appeared to fit in the orogenic scheme of Van Bemmelen.

The mid-cretaceous orogenic phase in the eastern alps, is followed by the mid-tertiary orogenic phase, which started the rising of the central alpine – Tauern – geanticline (van Bemmelen 1960 c). Such rising vertical movements (van Bemmelen's primary tectogenesis) may be caused by the buoyancy of an 'asthenolith', an accumulation of mobile magmatic and migmatic material at the base of the crust, of relatively low specific gravity. Such accumulations originate from deep-seated migmatisation and differentiation (rheomorphism).

The rising of the central alpine geanticline evokes gravitative reactions at various levels in the crust, the secondary tectogenesis after van Bemmelen (1960 c). According to the level ('Stockwerk') in which these reactions occur they may be classified as epidermal, dermal, and bathydermal processes, each characterized by its own typical kind of deformation.

Epidermal reactions comprise erosional and tectonic denudation of the sedimentary cover, which tends to slide down the slopes of the geanticline.

The dermal reactions are confined to the crystalline basement, underlying the sedimentary cover. Tensional features seem to prevail near the crest of the geanticline, shown by blockfaulting. On its flanks considerable compression may occur in the basement rocks.

The bathydermal reactions, finally, concern the rheomorphic material of the asthenolith, which tends – as fast as its mobility allows – to spread out sideways under the geanticline. It will invade the overlying basement and, if structures permit so, it may even reach the surface.

Of great importance is Van Bemmelen's opinion, that these deformations do not affect simultaneously a certain part of the orogene, but that a definite chronologic order is to be expected. The epidermal tectonic denudation (décollement) sets in early; compression of the basement rocks may require a greater accumulation of potential energy in the more competent crust, and the bathydermal reactions are generally of a later stage, after the asthenolith has obtained a greater volume and a higher level.

The reason for discussing Van Bemmelen's concepts here, will become clear, when we start testing his theory in view of the available field data of the Val-di-Non area. The foregoing testing of both other theories has led directly to negative results. On the other hand, when entering into details, Van Bemmelen's prognosis is in good accordance with our data, as will be demonstrated by the following reconstruction of the sequence of orogenic subphases, which have affected the Val-di-Non area (see figure 39).

Subphase a.

On the SSE-ern flank of the central alpine geanticline, gravitative décollement of the sedimentary cover set in in post-eocene time, giving rise to the $\overrightarrow{\text{SSE}}$-directed deformations, as mentioned in the preceding paragraph under a, 1-11.

Folding occurs in the older and more incompetent formations (Tregiovo series, skythian and anisian shales). It suggests a $\overrightarrow{\text{SSE}}$-ward movement of the younger, more competent triassic dolomitic masses; this tendency is displayed too, by the overthrusting blocks of Castelfondo and Taio.

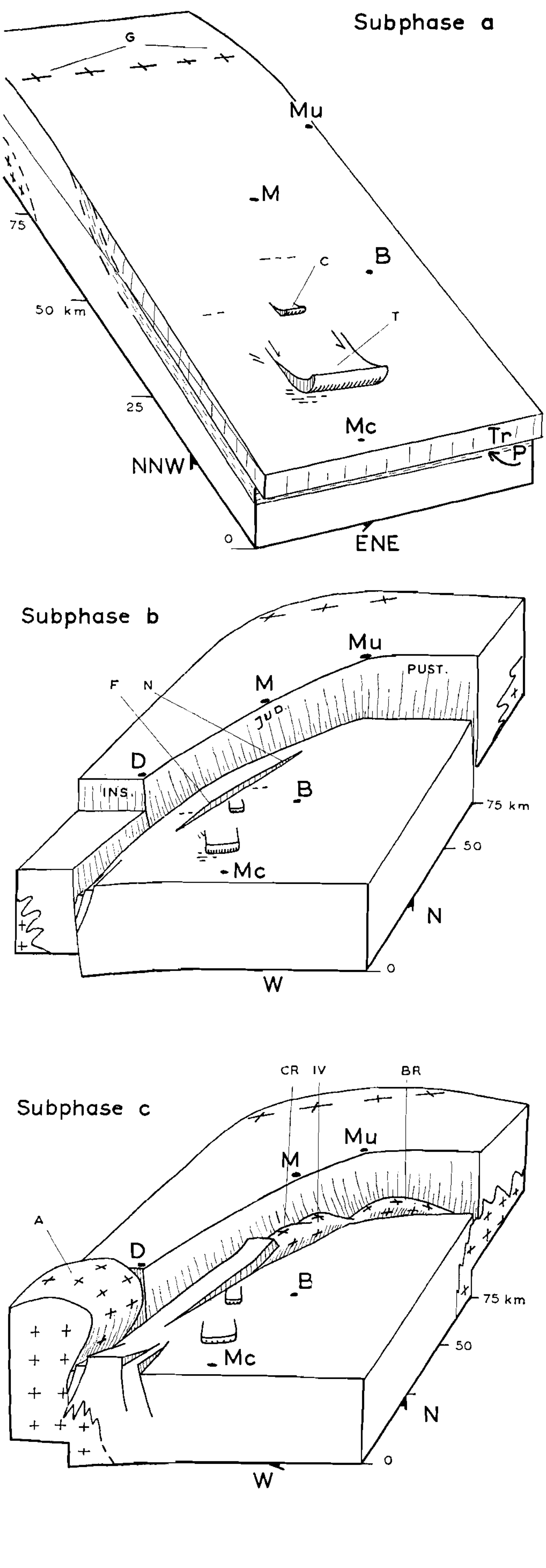
Tension faults in these dolomites – and the lack of compression phenomena – demonstrate that this overthrusting does not result from a shoving forward of these dolomites by a pushing force at their 'tail'. Only gravity, acting by means of the potential energy, present in every particle of the slightly inclined overthrust block, could make this block slide downward mechanically so undisturbed, causing simultaneously tensional stresses at its 'tail', and compression phenomena near its frontal part, where the overthrusting movement was obstructed and finally arrested.

The slope angle, required for the sliding down of sedimentary strata, forms an interesting point of discussion.

Promising experiments of Hubbert and Rubey (King Hubbert and Rubey 1959; Rubey and King Hubbert 1959) suggest, that this slope angle needs not be greater than a 1° to 3°, if the transported column of sediments is of great thickness.

According to Rubey and Hubbert (op. cit.; p. 197, table 3) the angle of 1° to 3,3° corresponds with a $\lambda_,$ of 0,97 to 0,90 respectively, $\lambda_,$ being the fluid pressure – overburden ratio.

In their well-known papers they state that the frictional resistance to sliding of large sedimentary complexes is greatly reduced by the pressure of interstitial fluids in the formation, which serves as a sliding horizon. A *status of flotation* of the overburden is reached, when the pressure of these fluids comes up to the value of the geostatic (weight of the overburden) pressure, i.e. when the $\lambda_,$ (fluid pressure – overburden ratio) approximates 1,0. It is known since long, by observations made in oil wells, that abnormally high pressures exist



in depth and that this λ_r may indeed reach very high – 0,9 to 1,0 – values (op. cit.; p. 169-170).

Specially in shale complexes such abnormally high fluid pressures may originate, as they form a *self-sealing mechanism*, as soon as compaction affects them, which evokes a tremendous decrease of their permeability. For a fluid trapped in these shales, escape becomes gradually more difficult, when compaction continues by constant and rapid sedimentation. Finally thus, the weight of the overburden is borne for a considerable part, by this trapped interstitial fluid.

As soon as a regional slope – for instance on the flank of a geosyncline or a geanticline – approximates the critical angle of 1° to 3°, some parts of the sedimentary complex will start sliding downward. Movements will select those parts of the complex, where frictional resistance is lowest, i.e. where the interstitial fluid pressure is highest. Folding and overthrusting will take place where downslope movements are obstructed; the deformations die out sidewards.

An irregular deformation pattern is achieved thus, which is usually referred to as being ruled by 'selective tectonics'.

In the Val-di-Non area, the role of sliding horizon is performed by the shaly formations of the upper permian and the lower half of the triassic. On top of it, the sedimentary series of triassic dolomites and younger formations – together at least about 2500 m thick – slided to the SSE.

During this subphase, the general WSW-ENE trend of the schists of the basement complex initiated, accompanied by the forming of small b-axes in the quartz-phyllite series; probably the post-crystalline kataclastic deformations in the already mesozonally and katazonally metamorphosed schists must be attributed to this subphase.

Fig. 39. Schematic block diagrams, showing the structural evolution of the Val-di-Non area. Synchronous denudation and deformation of the fault planes have deliberately been omitted. Vertical scale exaggerated.

Subphase a. SSE-directed décollement of sedimentary strata from the mid-tertiary central alpine geanticline (G). Incompetent formations near the base of the triassic (Tr) served as sliding plane. The overthrust blocks of Taio (T) and of Castelfondo (C), and some fold trends are indicated.

Subphase b. Origin of the peri-adriatic faults, the Insubric (Ins), Judicaria (Jud), and Pusteria (Pust) faults; parallel to the Judicaria fault, the Foiana (F) and Nova (N) faults. Note antithetic faults, accompanying the Judicaria fault.

Subphase c. Intrusion of the peri-adriatic tonalitic massifs (crosses) of Adamello (A) ,M. Croce (Cr), M. Ivigna (Iv), and of Bressanone (Br).

Mu: Mules M: Merano B: Bolzano D: Dimaro Mc: Mezzocorona Tr: triassic P: permian.

Subphase b.
The continuous rising of the central alpine geanticline, called forth reactions on its flanks. They culminated in the origin of a large fault, the peri-adriatic lineament, by which the Southern Alps are separated from the Central Alps. This normal fault is tied to the southern flank of the generally E-W extending alpine geanticline, i.e. parallel to the trend of the orogene. The fault proceeded probably in western direction, a phenomenon displayed by more structural features in the Alps.
The direction of the Judicaria fault, which forms part of the peri-adriatic line, deviates from the general E-W trend. Its NNE-SSW direction formed a marked zone of weakness, as is shown by its long history, during which it caused facies differences at both its sides. Near Mules thus, the peri-adriatic line deviates from its E-W direction and follows this zone of weakness over about 80 km. When, near Dimaro, the Judicaria fault threatens to withdraw too far from the alpine geanticline, the original direction makes its appearance again, and the Insubric fault originates.
As we know now better the sequence of deformations in our area, we are able to guess the throw of the Judicaria fault more exactly, than was tried in the preceding chapter II, b, 2. There we concluded to a vertical throw of about 8,5 km, deduced from section V, where katazonally metamorphosed schists WNW of the Judicaria fault, are found next to eocene formations at its ESE-ern side. This amount was composed of the estimated thicknesses of the sedimentary column, the quartz-phyllite series, and the mesozonal and katazonal schists.
The Judicaria and Foiana faults originated about simultaneously and have the same function in the alpine orogene: the vertical shearing-off of the southern Alps from the rising central Alps. The next subphase c produced movements along the Judicaria fault (rising of the M. Luco horst) which tended to decrease the original throw of the Judicaria fault (see sections I-V), as it was determined before (8,5 km).
We may therefore rather consider the *Judicaria system* (combination of Judicaria and Foiana faults together), instead of both faults apart. This means that we have to extrapolate the formations east of the Foiana fault towards the west, up to where they reach the Judicaria fault. By this procedure the influence of the later rising of the M. Luco horst is eliminated.
Using the top of the permian quartz-porphyry plate, we find it to reach the Judicaria fault at 500 m above sea level in section I.

In the other sections (II-V) the formations are seen to be inclinated increasingly towards the west; the extrapolation there would culminate in a value of some 3 km below sea level in section V. The W-inclination, however, was found to be caused by the regional WSW-tilting of the Val-di-Non area, an accompanying feature of subphase b (origin of the Judicaria fault), confined to the Val-di-Non and Brenta areas. East of the Adige valley this tilting is not encountered and a hinge zone is supposed in this valley. This local tilting mechanism therefore, tends to increase the throw of the Judicaria fault and must be counted out to make a good estimate of the throw of the Judicaria system.

Along the Adige valley, in sections II-V the top of the quartz-porphyries is situated at 500 m above sea level, and it is therefore this altitude, which has to be transferred horizontally towards the west, up to where it meets with the Judicaria fault. Tilting and rising of the M. Luco horst have now been eliminated, and in all sections the virtual top of the quartz-porphyries is found at 500 m above sea level.
The former estimate of the throw (8,5 km) in section V is to be decreased thus with 1,3 km, this being the required vertical displacement of the south-alpine block to elevate the top of the quartz-porphyries up to 500 m above sea level.
The resulting *7,2 km of vertical throw* may be regarded as the amount of rising of the central Alps in respect to the southern Alps, along the combined Judicaria and Foiana faults. Allowance should be made for the roughly estimated thickness of meso- and katazonal schists.

Subphase c.
During the displacements along the peri-adriatic line, a stage was reached, at which the buoyant tonalitic juices found their way cleared to rise diapirically to the surface along this fault and rift zone. The pressure in the central alpine tumor was released considerably by this sidewards escape of rheomorphic material, so the displacements along the peri-adriatic lineament reached their final stage.

In testing van Bemmelen's views on the mid-teriary orogenic phase, it appears that his assumption of a rising central alpine geanticline during this period does not strain the data, obtained from the structures of the Val-di-Non area. On the contrary, his concept of a primary and secondary tectogenesis renders it possible, to co-ordinate the observed sequence of deformations (fig. 38) into one, mechanically comprehensible scheme, in which all collected details show to full advantage (see fig. 39).

b. COMPARISONS WITH THE GEOLOGY OF THE SURROUNDING AREAS

It is hardly to be expected, that the presented picture of the structural evolution of the Val-di-Non area should be only of local importance. At least in the surroun-

ding areas, the influence of the rising central alpine geanticline must be observable, and some reflection of the well defined sequence of deformations, and of their individual properties must be present there.
The adjoining areas will be briefly discussed in this paragraph.

The Merano region (north of the Val-di-Non area).
Dietzel (1960), in his study on this region, proposed an identical faulting mechanism of the Judicaria fault, followed by the intrusion of the tonalites of the M. Croce and M. Ivigna.
Tertiary fold axes in the skythian strata, north of Plazzoles, are orientated WSW-ENE (op. cit.; p. 37) and they may directly be correlated with our $\overrightarrow{\text{SSE}}$-directed deformation phase. The axes plunge 10° to the WSW, clearly due to the regional tilting as found in the Val-di-Non area (op. cit.; fig. 26, p. 37).

In his diagram of figure 26, Dietzel (1960) collected 106 poles of bedding planes, partly derived from an area next to the Foiana fault. The influence of subordinate folding phenomena, caused by the Foiana fault (as found in our area, e.g. between Cagno and Revo, see fig. 15 of this thesis) is easily read from his diagram, in which *two* girdles of poles of bedding planes are seen. They must be attributed thus, to two folding processes, apparently the $\overrightarrow{\text{SSE}}$-directed deformation phase and a subordinate folding, parallel to the Foiana fault.
Dietzel's assumption*) of *one* mean b-axis (azimuth N 220° E, dipping 10° to the SW) for these 106 poles, cannot be accepted therefore, setting aside the deviating orientation of it.

The Central Dolomites.
In many respects, the central Dolomites bear great resemblance to the eastern half of the Val-di-Non area. In its northern half, tectonic disturbances in the triassic dolomites, which largely build up its scenery, are scarce. Intense folding occurs in the underlying permian and lower triassic shales. In the southern half of the Dolomites, tectonic activity increases, the dolomites forming S-directed overthrusts, resulting in a more or less regular imbricate structure with clearly southward directed upthrusts. This deformation scheme of the Dolomites, is proposed by Signorini (1951 and 1955), who concludes to a gravitative décollement of the sedimentary cover of this south-alpine unit, to the S and SSE. He finds that many structures in the Dolomites do not tally with a regional tangential stress in the sediments and that many of their tectonic irregularities are better explained by a gravitative décollement.

*) A construction as described on p. 47, was not carried out, for it should definitely have furnished at least two major concentrations of intersecting bedding planes, i.e. two b-axes instead of one.

An identical view on the Dolomitic tectonics is favoured by Fallot (1950 and 1955).
The presence of a central alpine geanticlinal ridge, north of the Dolomites, is made therefore probable by the observed S to SSE directed gravitative deformation mechanism in the region east of the Val-di-Non area.

The Brenta area. (south of the Val-di-Non area).
Four authors, who worked in this area, will be mentioned here. The information they give, however, is rather contradictory.
Trevisan (1939 a) proposed an already mentioned mechanism of sinistral strike-slip faulting, the principle of which is shown, for instance, in his figure 25 (op. cit.; p. 94), which is reproduced here in figure 40.

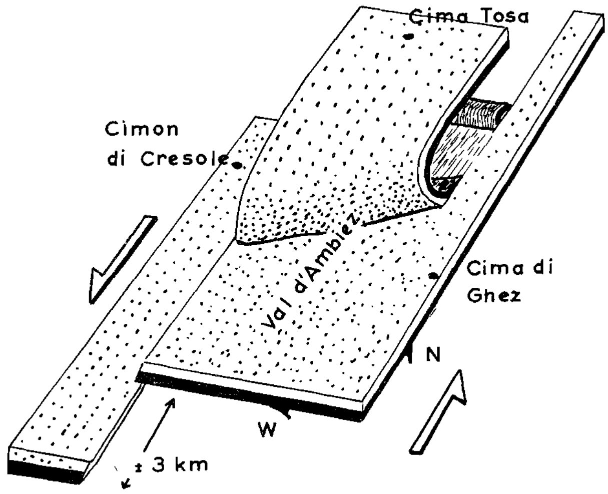


Fig. 40. Reconstruction of a stratigraphic horizon in the Brenta area (copied from Trevisan 1939, fig. 25, p. 94).
It shows a WSW-ENE striking fold, cut by N-S running faults, along which a sinistral strike-slip faulting over 3 km should have taken place.

Trevisan (op. cit.; p. 106) assumes two tectonic phases responsible for the structure of the Brenta area:

1. a folding phase with E-W directed fold axes, followed by
2. the sinistral strike-slip faulting phase, along N-S orientated faults, about parallel with the Judicaria fault.

By the latter faulting process, the E-W orientated fold trends were accentuated, according to the principle shown in figure 40.
Closer observation of Trevisan's geological map and text figures – including the one reproduced in fig. 40 – learns that the first tectonic phase has, in general,

WSW-ENE orientated fold axes, instead of E-W ones. They belong mainly to SSE-ward directed folds and overthrusts, so a relation with our $\overrightarrow{\text{SSE}}$ directed deformation phase is obvious.

We are fortified in this opinion by the observations of Schwinner (1913 and 1915), who reports many instances of SSE-directed folds and overthrusts in the western Dolomites. Apart from his correct interpretation of the sliding plane of the Taio overthrust block, and similar structures SSW of Mezzocorona (the Paganella and Fausior SSE-directed overthrusts, see p. 58 of this thesis), he found SSE-ward directed folds in great number in the Brenta area, e.g. near San Lorenzo, north of Stenico, near the Castel of Camosci, etc.).

The $\overrightarrow{\text{SSE}}$-deformations are cut off by the N-S faults, which are related to movements along the Judicaria fault and to the rising of the Adamello intrusive tonalite. The older age of the SSE-deformation phase, relatively to the N-S faults, demonstrates a sequence of deformations as found in our area.

Wiebols (1938) thinks this sequence to be just the other way around or synchronous; he assumes a S-ward moving of the complexes comprised between the N-S faults. Vecchia (1957) simply denies the existence of deformations with WSW-ENE fold axes in the Val-di-Non and Brenta areas, and interprets them as SSW-NNE fold axes, in order to fit them in his tectonic scheme with orogenic stresses acting perpendicular to the Judicaria fault.
Sub-recent deformations of the many fault planes in the Brenta area presumably played an important role, as the relief intensity here, is notably greater than in the Val-di-Non area. The different functions, attributed to the faults by the various authors, may partly be due to such phenomena.

The Bergamasc Alps.
This region has thoroughly been studied by the geological institute of the Leyden University. The region covers a strip – a 140 km long – south of the Insubric fault and west of the Adamello tonalitic intrusion. Summarizing papers were published by Dozy (1935 a and b), De Sitter and De Sitter-Koomans (1949), and De Sitter (1956 b).
The structures of this region are characterized by the fact, that they form the southern slope of the *central Alps, which have been uplifted to enormous heights* (De Sitter-Koomans 1949, p. 190). Fold axes are orientated W-E to WSW-ENE. Overthrusts occur in great number, generally exhibiting a southward sense of movement.
Originally, De Sitter-Koomans (1949) thought the folds and overthrusts to be due to lateral tangential compression. Later on (De Sitter 1954 and 1956 a), this author refers to two thrust sheets (the M. Generoso and the Camino thrust masses) as examples of southward sliding nappes under the influence of gravity. Fallot (1950) considers all overthrusts and folds of the Bergamasc Alps to be caused by a gravitative décollement from north to south.
This is strongly suggested, indeed, by the sections of de Sitter (1949), for his distinction between the two mentioned sliding nappes and the other thrust sheets, caused by lateral compression, seems to be rather subjective and arbitrary.
His descriptions too, evoke mechanical difficulties, which are solved more elegantly by the assumption of S-directed gravitative sliding phenomena. For instance, when describing the Grigna thrust sheets, de Sitter (1949; p. 191), states: 'The same compressional force has sheared off the Triassic limestone blanket from the basement rock in the north and has deposited them in a series of partially piled up thrustsheets on the central platform'.
The Insubric fault, separating the Central Alps from the Bergamasc Alps, shows a remarkable resemblance in many details, with the structures met along the Judicaria fault, as was pointed out in chapter III, b. 2 of this thesis. This makes a similar function of these faults in the alpine orogene very probable.

This short excursion to adjoining areas of the Southern Alps, demonstrates that the $\overrightarrow{\text{SSE}}$-deformation phase, as observed in the Val-di-Non area, may be found back over great distance east and west of this area. It shows the regional importance of the central alpine geanticlinal rising in mid-tertiary times, reflected by a S – to SSE – ward gravitative décollement of the sedimentary cover on its southern flank. The peri-adriatic lineament, exhibits equal features over all its length of more than 600 km.
The wide-spread occurrence of tonalitic intrusions, rising along its fault plane, is one of the characteristics, pointing to a sequence of phases, as found in the Val-di-Non area (subphases b and c).
The sequence of deformations in our area, is also suggested, by the observations of Trevisan (1939 a) in the Brenta area and by Dietzel (1960), in the Merano area. In other parts of the Southern Alps, the tracing of this sequence is greatly hindered by the *parallelism of the peri-adriatic line to the local deformation trends.*
In the Val-di-Non and Brenta areas, however, the sequence can be ascertained, thanks to the lucky circumstance, by which the direction of the *Judicaria fault intersects obliquely the regional folding trends.*

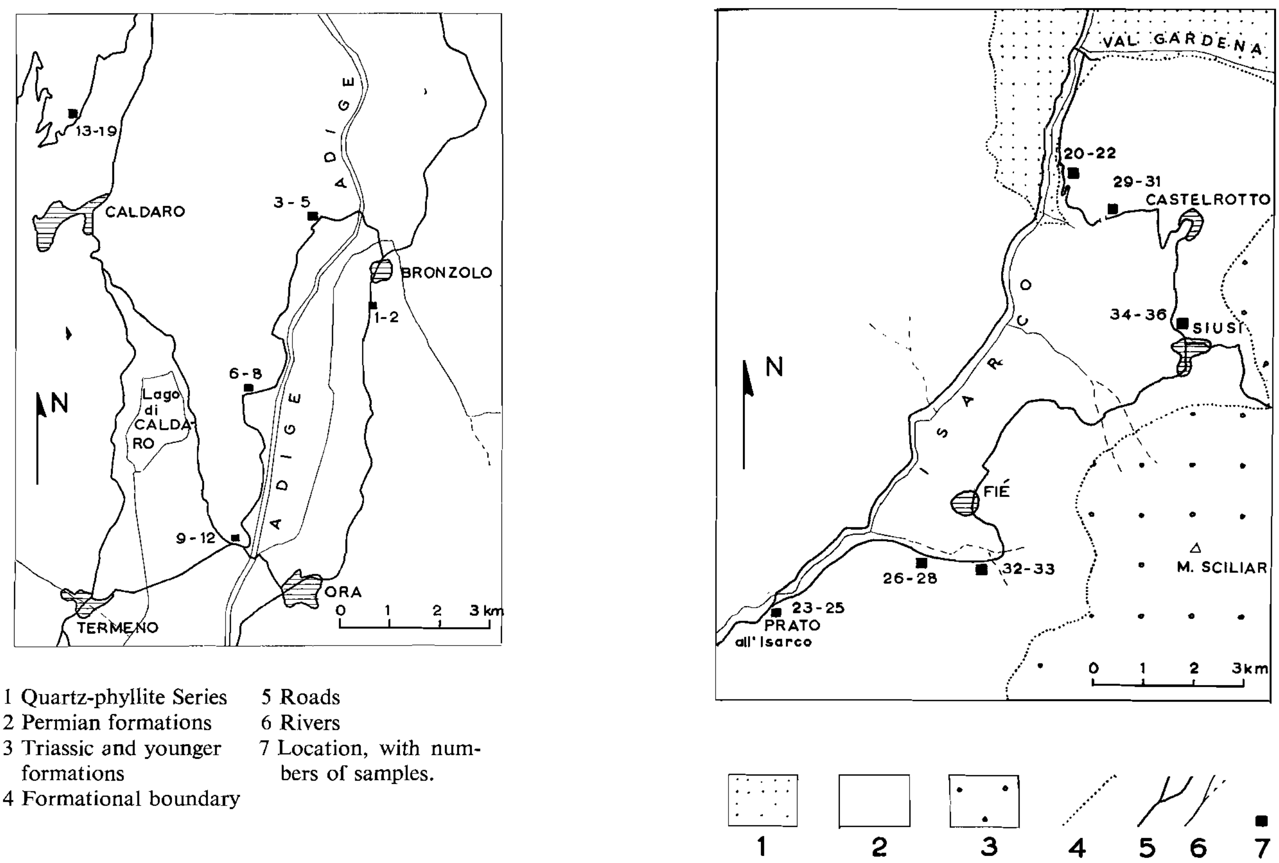
Paleomagnetism of the lower permian effusives

Apart from the tectonic survey of the Val-di-Non area, an investigation was started on the paleomagnetic properties of the lower permian volcanic series around Bolzano. A similar paleomagnetic research of these rocks was carried out by Dietzel (1960). However, a notably different direction of magnetization has been found by Dietzel, publishing of the results obtained by the present author seems therefore justified.
The investigation forms part of paleomagnetic studies on european permian rocks of the Geological Institute of the Utrecht State University.

a. Sampling
In total 39 oriented samples were collected and measured. They may be classed into some groups, viz.:

1. Samples 1-19.
They were taken in the Adige Valley south of Bolzano (see fig. 41). In this part of the valley the upper, acid half of the quartz-porphyry plate is exposed, which is slightly (10° to 14°) dipping to the south or SSW. This inclination may be deduced from the sequence of the formations on a geological map (e.g. the geological sketch map of the Judicaria region, in the NW-ern corner of enclosure I). In the walls of the Adige valley too, looked at from some distance, a rough stratification of thick, slightly south-dipping layers may be observed in this porphyry plate.

The upper, acid half of the quartz-porphyries reaches a thickness of 500-700 m here.



1 Quartz-phyllite Series
2 Permian formations
3 Triassic and younger formations
4 Formational boundary
5 Roads
6 Rivers
7 Location, with numbers of samples.

Fig. 41. Locations in the permian quartz-porphyries, from which the paleomagnetic samples 1-36 were taken.

2. Samples 20-36.
This series may be divided into six groups (5 $\times$ 3 and 1 $\times$ 2).
They were taken from several levels in the volcanic series, starting (samples 20-22) at their melaphyric base and finishing at their top of upper quartz-porphyries (samples 34-36). Together they build up a vertical profile through the entire lower permian effusive series.
These six groups were collected in an area NE of Bolzano as tectonic disturbances here seem to be less frequent than in the Val-di-Non area. The total thickness of the volcanic series here, between samples 20-22 (base) and the samples 34-36 (top) amounts to about 600 m (Heissel and Ladurner, 1936; p. 8-11). Along the road from Prato all'Isarco-Fié-Siusi-Castelrotto to the Val Gardena (see fig. 41) the porphyries are almost continuously exposed, and the outcrops are considerably fresher than in the only vertical section of the Val-di-Non area, at the northern slopes of the M. Luco. NE of Bolzano the volcanic series dips gently to the south, according to Heissel and Ladurner (1936), and as may be deduced also from the line of outcrop of the formational boundaries of the base and the top of the permian formation, marked in figure 41. Moreover this inclination could be stated directly at the location, from which the samples 20-22 are derived.
For here, at the base of the effusive system, in the melaphyric tuffs and flows, intercalations of breccias are found; they dip 15° to the SSE.

3. Samples 37-39.
These samples were collected by students of the Geological Institute of Utrecht, participating in an excursion in the Lugano region, some 200 km west of the Val-di-Non area. The samples were taken about 500 m north of the village of Melide, situated at the borders of the Lake of Lugano, on the peninsula of Morcote.
According to observations of Rode (1941), and de Sitter (1939) the permian volcanic series there consists of a pyroxene bearing porphyrite. Data on the strike and dip of the flows could not be retraced from their papers.
In general much attention was paid to the collecting of only fresh, not weathered samples.
The petrography of the ignimbrites was treated in chapter II, d of this thesis, and will not be repeated here. In that chapter also the age of the effusives was discussed at length. It was concluded that the extrusions took place in the lower half of the permian.

b. Measuring
Measuring of the collected samples was carried out in collaboration with the Geophysical Department of the Royal Netherland's Meteorological Institute in De Bilt, Holland, under the supervision of Professor Dr J. Veldkamp.

The samples were prepared for measuring, by building them into cubes (10 cm ribs) of plaster, in order to handle them more easily during the measurements. The samples are placed in an oriented position into the cubes in such a way, that its ribs (a, b, and c) are parallel to respectively the vertical, N-S, and E-W directions of the original position of the sample in the field.

The actual measurements took place by means of an astatic magnetometer. For more details on this apparatus and the method of measuring, we refer to As and Zijderveld (1958) and to As (1960).

From the measurements the direction of magnetization is derived, expressed in its components along the a, b, and c ribs of the cube. By a simple conversion these vertical, N-S, and E-W components may be expressed in a declination and an inclination. Usually, a direction of magnetization is represented by plotting these data into a stereographic projection. The declination is taken from north to east, the inclination is considered positive, when the direction of magnetization points downwards, and consequently pierces the lower half of the stereographic projection.

The directions of magnetization thus obtained from the samples are presented in the diagrams of figure 42. The exact data (declination and inclination) are given in column 4 of table V.
The majority of these directions is situated in the upper hemisphere of the SE-ern quadrant of the stereographic projection.

c. Corrections
Investigations on remanent magnetism of volcanic rocks (e.g. As and Zijderveld, 1958; Dietzel, 1960; Van Everdingen, 1960; Nijenhuis, 1960) revealed, that the direction of magnetization of a specimen is often the resultant of two components.
Progressive demagnetization, by means of exposing the samples to an alternating magnetic field (50 c/s), showed that in many instances these components are of different stability.
The unstable component may be removed during the first stage of the demagnetization; further demagnetization tends to diminish only the magnetic *intensity* of the stable component, the *direction* of magnetization of the rock sample is not – or hardly – affected any more by it. From the course of this process of progressive demagnetization, when plotted in a graph (see for instance fig. 43), it may be concluded whether and at which stage, the unstable component is completely removed.
From these laboratory tests it is suggested, to regard the unstable component with low coercive force as a viscous remanent magnetization (Cox and Doell 1960);

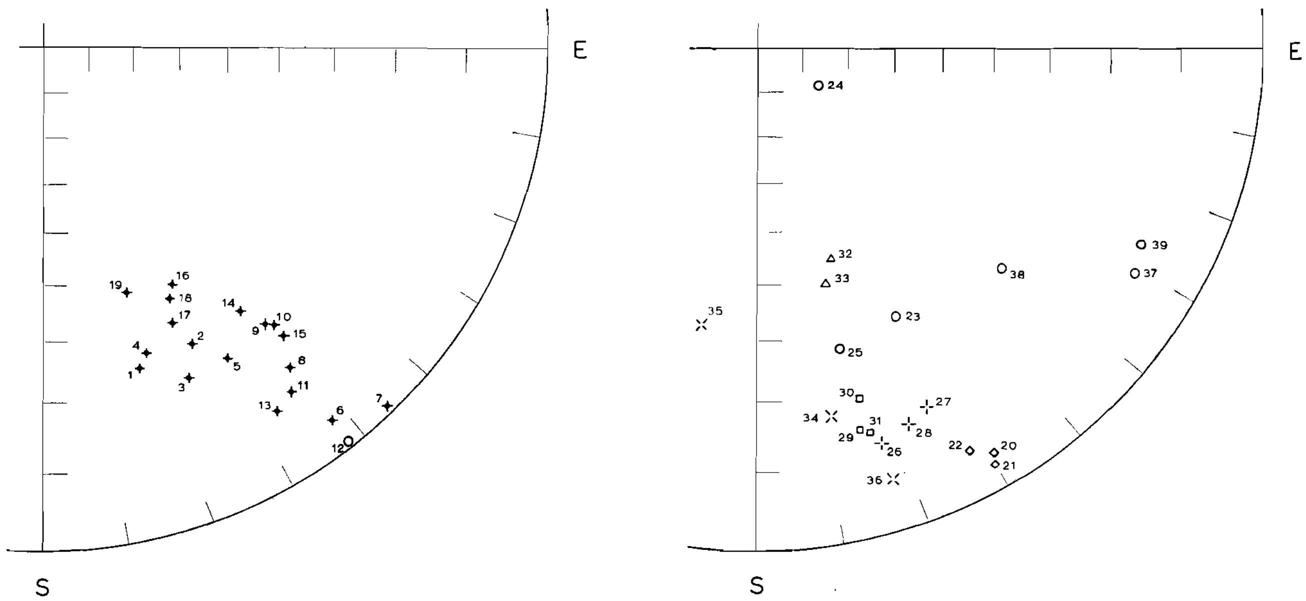


Fig. 42. Paleomagnetic diagrams, showing the directions of magnetization, before demagnetization and tectonic correction. Different symbols are used for the various groups of samples, mentioned on p. 74 and 75. Circles indicate a positive inclination (lower hemisphere of the stereographic projection).

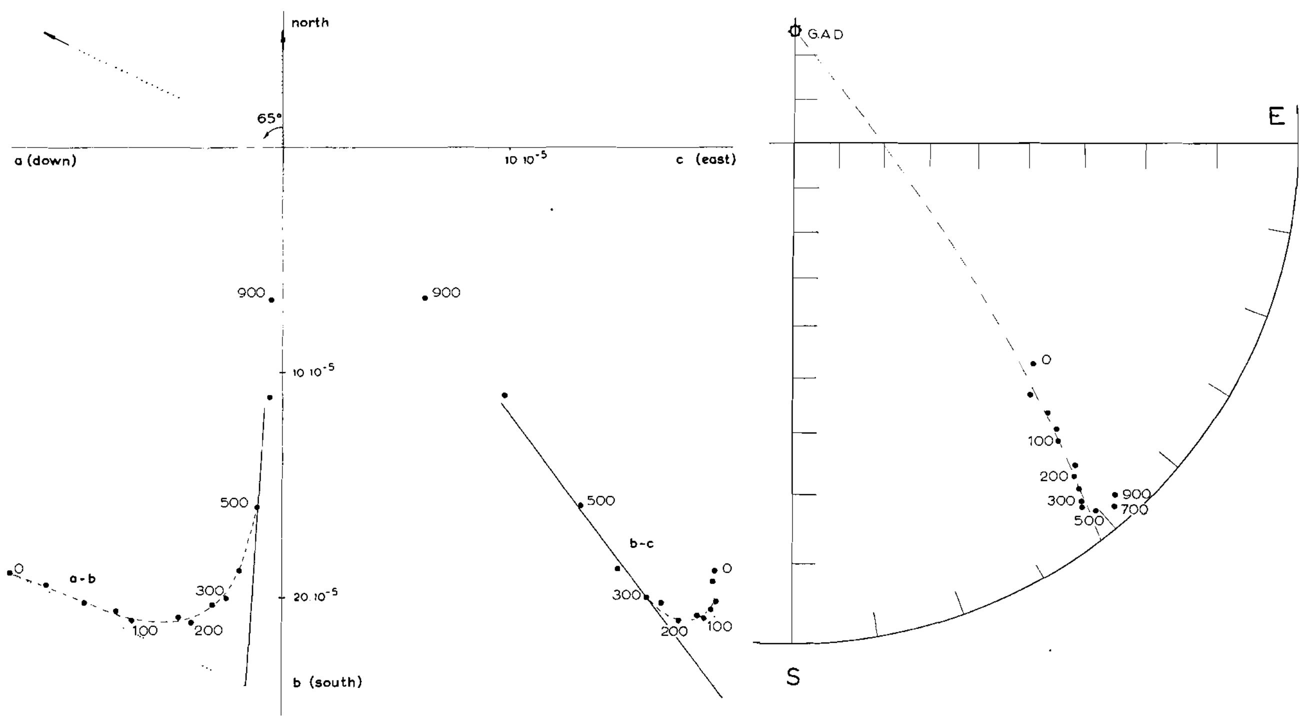


Fig. 43. Progressive demagnetization of sample 38, using alternating fields from 0–25–50–75–100–150–200–250–300–400–500–700 to 900 oersted.

DIAGRAM: In the lower hemisphere of the stereographic projection, the direction of magnetization moves away from the present-day geocentric axial dipole field (G.A.D.), along a great circle through this point.

GRAPH: The a (vertical) and c (E–W) components plotted against the b (N–S) component.

Dashed line: course of progressive demagnetization

Drawn line: stable direction of magnetization

Dotted line: removed, unstable magnetization. Its reconstruction (in the upper part of the graph) produces a vector dipping 65° to the north, i.e. the position of the present-day axial dipole field.

Scale unit in e.m.u.

it is more easily affected by alternating field demagnetization than the stable component, caused by thermoremanent magnetism of the volcanic rock.
In general we are interested in the thermo-remanent magnetization of a rock sample, as it represents the declination and inclination of the magnetic field, which was active during the effusion of the rock series under consideration. The unstable ('soft') component probably entered the rock in later – possibly sub-recent – times. This is strongly suggested by the direction of this unstable component, which is found to scatter around the direction of the recent axial dipole field of the earth (As and Zijderveld 1958; Dietzel 1960).

The graph and diagram of figure 43 show the instructive progressive demagnetization of sample 38. In order to explain the procedure of demagnetization, this sample will be treated more elaborately; moreover, its curve of demagnetization is representative for the majority of the investigated specimens. The following features of figure 43 need our attention:
1. The graph of the progressive demagnetization may be divided into two parts, one from 0 to 500 oersted, and the other from 500 to 900 oersted. The latter part runs straight towards the origin of the co-ordinate system, which means that the *direction* of the magnetization does not change anymore by continued demagnetization, and that only its *intensity* is decreased by it. This is a characteristic of a stable direction of magnetization (thermo-remanent magnetization).
The initial part of the graph, during the demagnetization from 0-500 oersted, is regularly curved, which indicates the removal of an unstable component.
2. During the demagnetization from 0-500 oested, in the stereographic projection, the direction of magnetization tends to move away from the position of the present-day axial dipole field of the sampling site, the inclination of which dips 65° to the north. This means, that the removed unstable component was largely formed by a magnetization in the direction of this present-day dipole field, and originated probably in recent times.
From the produced graph too, the removed, unstable component can approximately be reconstructed (dotted lines in fig. 43).
It furnishes a direction of magnetization, which dips 65° to the north. This is precisely the inclination of the present-day axial dipole field of Lugano, the location from which this sample is derived.

Only by means of a demagnetization curve, may it be decided, whether a stable (lower permian) direction of magnetization is present; its direction may be read from the graph.
In a similar way the other samples were treated. The obtained *stable* directions of magnetization are plotted in the diagrams of figure 44, their values are presented in column 6 of table V. In column 8 of this table the intensity (in oersted) of the applied alternating magnetic field is given, at which the stable component got rid of its unstable one.
Comparison with the diagrams of figure 42 yields two important facts. Firstly, the *concentration* of the individual groups *has notably increased*, i.e. the stable directions of magnetization of each group lay closer

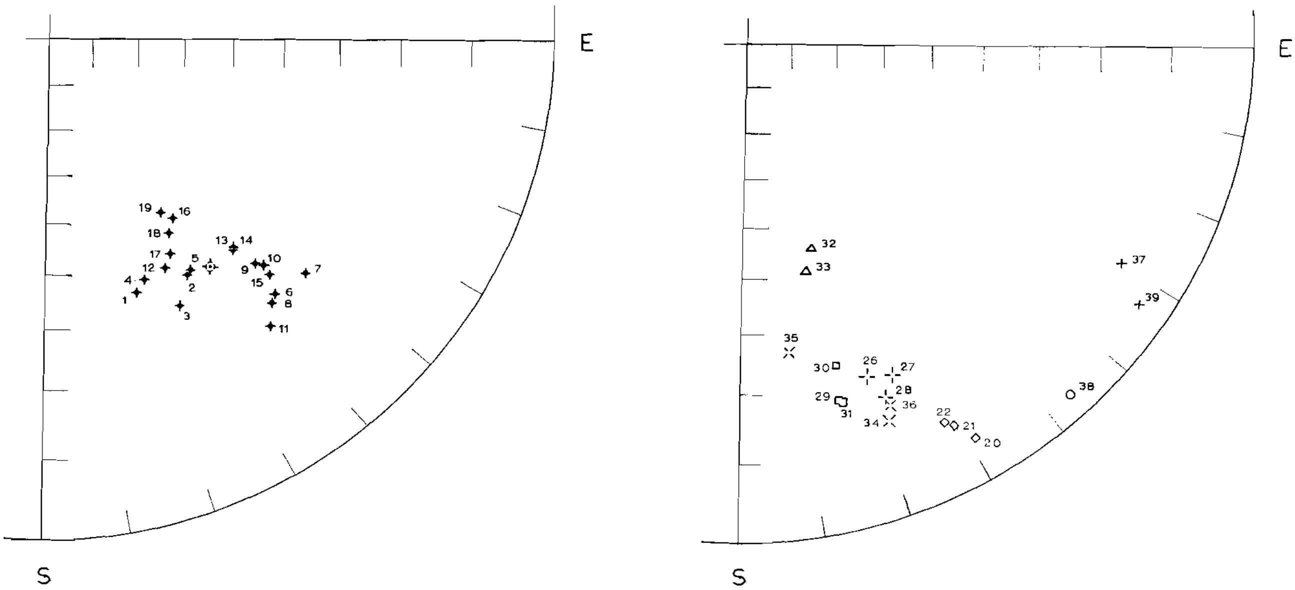


Fig. 44. Paleomagnetic diagrams, showing the stable directions of magnetization, after demagnetization, but before tectonic correction Compared with the diagrams of fig. 42, a higher concentration in the individual groups (same symbols) is remarked.

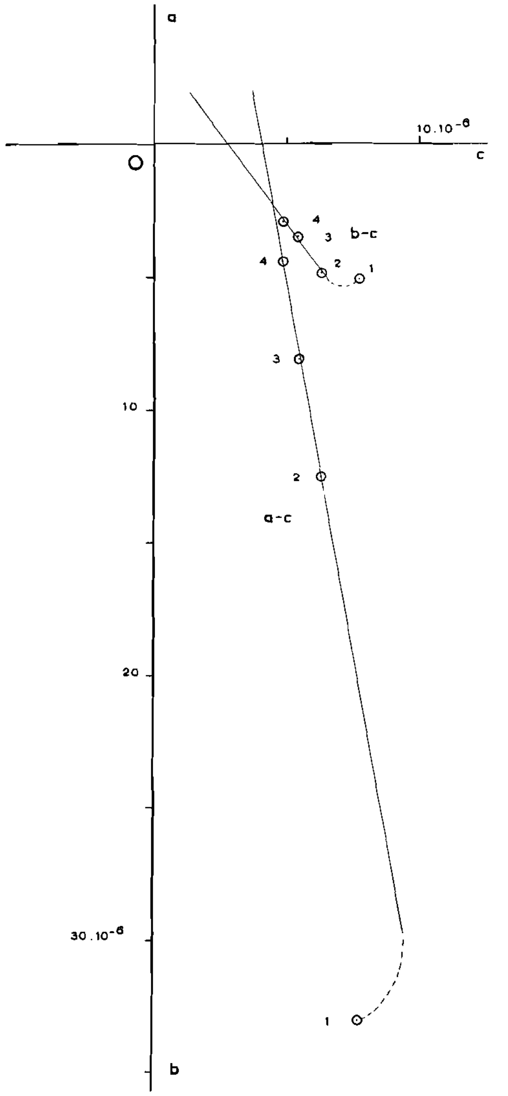


Fig. 45. Progressive demagnetization of sample 24, using alternating fields of 0 (1), 310 (2), 620 (3), and 900 (4) oersted. a and b components are plotted against the c component. Scale unit in e.m.u.
No stable direction of magnetization is furnished by this sample, as the resulting vector stays variable (the a-c and b-c curves do not pass through the origin 0).

together in the diagrams of figure 44, than their original measurements of figure 42 did.
Secondly, almost all stable directions of magnetization *moved away from the present-day axial dipole field* of Bolzano, as compared to their original position in the diagrams of figure 42. This shows that the majority of the samples was more or less affected by this dipole field, which caused an additional 'soft' remanent magnetization beside the stable lower permian direction.
The samples 23-25 are not marked in the diagrams of figure 44. This is due to the fact that their curve of demagnetization does not furnish a stable component. In figure 45, the demagnetization of sample 24 – representative for this group – shows the rectilinear course of this process; however the direction of magnetization stays variable, because the rectilinear curve does not pass through the origin of the co-ordinate system. Further demagnetization is not possible, 900 oersted being the maximum of the produced alternating magnetic field; besides, during the demagnetization the magnetic intensity of the sample had decreased to a hardly measurable value. On these grounds it is justified and necessary to eliminate these samples from the diagrams, in which only stable directions are collected.

Another correction to be applied to the directions of

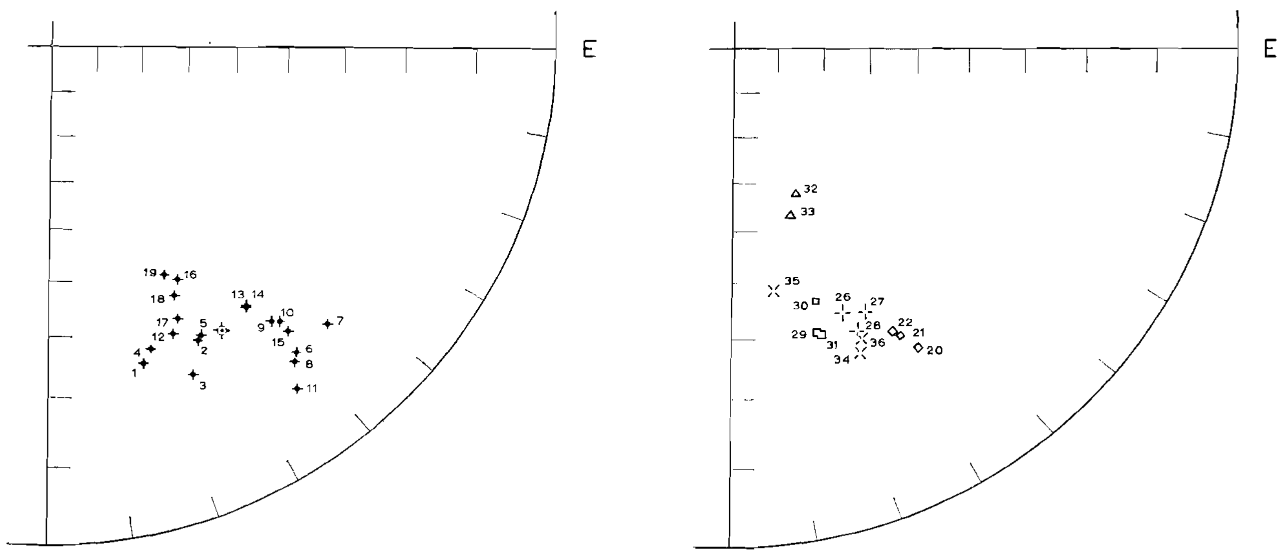


Fig. 46. Paleomagnetic diagrams, showing the stable directions of magnetization, after their tectonic correction.

magnetization is the 'tectonic correction' for the present-day inclination of the extrusive flows. These inclinations are mentioned in table V, column 2.
In the diagrams of figure 46 the stable directions of magnetization are presented, after they have been rotated over the same angle, as required to bring their corresponding extrusive flows into a horizontal position. The values of declination and inclination are given in column 9 of table V.
The samples 37-38 are not marked in these diagrams, because a tectonic correction for these specimens from the Lugano area could not be retracted wih sufficient accuracy. It seems to be small, according to the structures at that place (Rode 1941, de Sitter 1939).

d. Trend

For each group of samples (stable components, tectonically corrected) the mean direction of magnetization was determined; these mean directions are shown in figure 47; the values of declination and inclination are given in column 11 of table V. For reference the letters A-E are added (column 10).
Their alphabetic order indicates the relative age of the groups, from old to young. Group F comprises the samples 1-19 from the upper (younger) half of the effusive system.
It is seen from figure 47 that the mean directions of the groups lie close together. Important feature is that they show no trend, i.e. there is no systematic change discernable of the direction of magnetization during the effusion of the volcanic series, as might be shown by a line connecting the groups A-E in figure 47.
The observed scatter is explained best by irregular secular variations, which are displayed by the geomagnetic field.

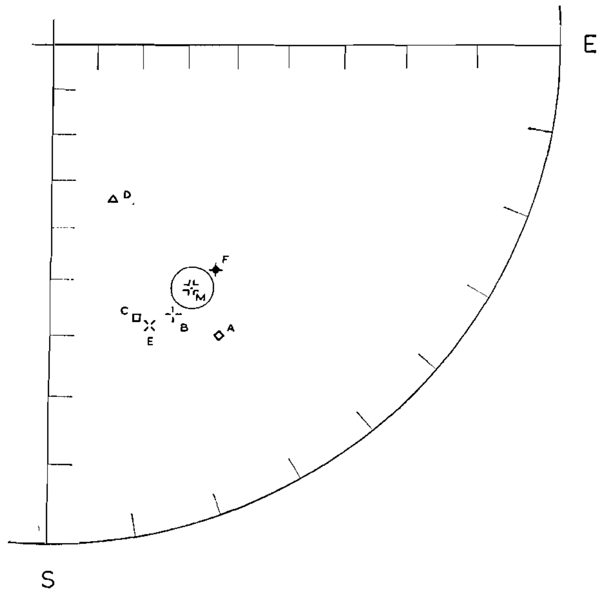


Fig. 47. Paleomagnetic diagram, showing the mean stable directions of magnetization of the various groups, ranging from A (base of the effusive series) up to E (top of the effusive series). F: upper half of the effusive series. Data tectonically corrected. M: mean direction of magnetization of the 33 stable, tectonically corrected samples. The radius of the circle of confidence amounts to 4° (P = 0,05).

It is known that the earth's magnetic field has changed a great deal within historic times. Measurements of this field in London, for instance, revealed (Billings 1960) a change in declination of as much as 35° in 200 years, between 1600 and 1800 (see fig. 48). Such variations may have caused the scatter observed in figure 47.

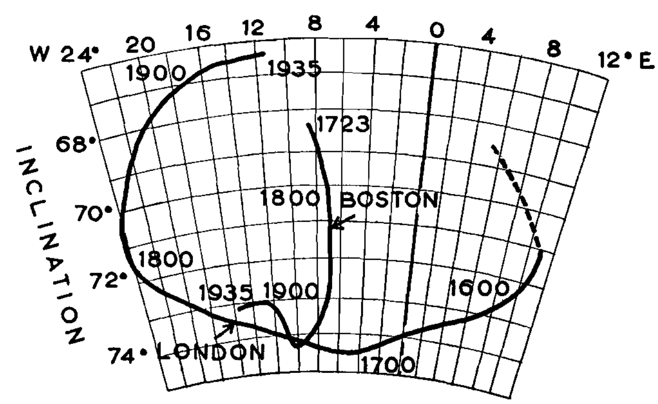


Fig. 48. Variations of magnetic declination and inclination within historic time at London and Boston (copied from Billings, 1960).

e. Mean direction of magnetization of the lower half of the permian.

The mean value was calculated of the 33 stable directions of magnetization (tectonically corrected), as given in column 9 of table V. The resulting mean direction of magnetization is:
Declination N 150° E
Inclination –31°
According to Fischer's equation

$$\cos \alpha_{(1-P)} = 1 - \frac{N-R}{R} \left\{ \left(\frac{1}{p}\right)^{1/N-1} - 1 \right\} (P = 0{,}05)$$

the α of the cone of confidence comes to 4°. These data are shown in figure 47.

This direction of magnetization differs considerably from the value obtained by Dietzel (1960), who found a declination N 164° E, and an inclination of −10,5°.*) This is most remarkable, for the rock investigated by him, is the same quartz-porphyry of the lower half of the permian; sampling was carried out by Dietzel in an

*) Recalculation of Dietzel's table 8, column 11 (op. cit. p. 49) gives an inclination of −10,5, instead of −7,5, as stated by Dietzel (op. cit. p. 51).

adjacent area, the Merano region, where the tectonic position of this rock series has not notably changed. The same methods of measuring and instruments were used by him.
A comparison of the primary measurements, before demagnetization and tectonic correction (diagrams of fig. 42 of this thesis, and fig. 29 of Dietzel, 1960) tells us that already a marked difference is observable in the *initial stage* of both investigations. For in the present study the primary directions of magnetization are found in the upper hemisphere of the stereographic projection, whereas in Dietzel's figure 29 their majority occupies the lower hemisphere, and their scatter is notably greater.
This difference is found through all stages of both investigations and leads finally to the different result (direction of magnetization and permian pole) obtained by both authors.
It is, therefore, not caused by a different method of the measuring, but it must be imputed to a difference in the initial material with which both investigations started. Dietzel's samples seem to contain a greater additional component, caused mainly by the present-day magnetic field.

It was shown (fig. 43), that additional 'soft' components may be removed by progressive demagnetization. Conclusive for the stability of the remaining component is the graph, representing the process of demagnetization.
Not all graphs given by Dietzel show clearly that additional components have been removed. In fact, only one of his graphs (op. cit. fig. 35) does provide a satisfactory picture; the stable direction of magnetization of that sample has a declination of N 167, 5° E, and an inclination of —27°; that is quite near to the mean direction of magnetization found by the present author.
The different behaviour of Dietzel's samples might be explained by the circumstance that most of his samples contained a 'harder' additional component, caused by the present-day magnetic field, for it is not completely removed by the progressive demagnetization (up to 900 oersted).
It is tentatively suggested here, that Dietzel's samples were taken from a more weathered rock. By the chemical changes, accompanying weathering, a new remanent magnetization may originate (chemical magnetization) parallel to the present-day magnetic field (Cox and Doell, 1960). The stability of this newly acquired magnetization is great (high coercive force) and it is affected in a similar way, as the thermo-remanent magnetization, by alternating demagnetizing fields; this implies that the two magnetizations cannot completely be separated.

This line of reasoning provides an explanation for the observed different results, obtained from the same lower permian rocks, and the position of Dietzel's mean direction of magnetization, closer to the present-day position of the magnetic field of the geocentric axial dipole in N. Italy.

f. The lower permian pole

From the obtained mean direction of magnetization, the position of the geocentric axial dipole during the lower half of the permian may be calculated. It was situated at
118,6° longitude, west of Greenwich, and
51,4° northern latitude.
The semimajor and semiminor axes (δm and δp respectively) of the 95% confidence oval about this pole position amount to 5° and 2,5° (see figure 49).
The typical absence of reverseals, found in about all permian rocks, is met with again in the volcanic series of Bolzano and Lugano.
The position of the lower permian pole of Bolzano

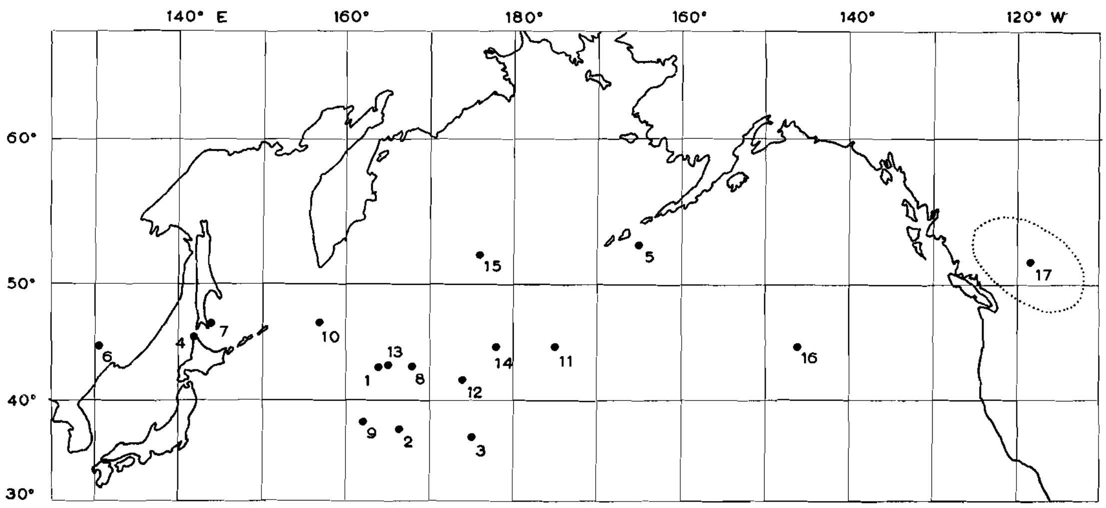


Fig. 49. Permian pole positions, derived from european sampling sites. Numbers refer to table VI.

differs notably (50° over a great circle) from the average of permian poles, obtained so far from other european sampling sites. The latter form a cluster, the centre of which is situated at about 167° E and 40° N. Rather deviating positions are occupied also by poles, based on the volcanic rocks of the Estérel (S. France), the numbers 4, 5, 6, and 7 in figure 49 and in table VI. At least two essentially different explanations for the deviating position of the lower permian pole of Bolzano may be advanced.

1. The volcanic series of Bolzano was laid down during a very short period. In this period (e.g. about 100 to 200 years) the magnetic field deviated considerably from the magnetic field of the permian axial dipole, due to a long-termed secular variation.
Indeed, the ignimbritic character of the effusions (see chapter II) suggests a catastrophic, fast process, and the possibility cannot be excluded a priori, that the whole effusive series was deposited in a geologically very short time.
It is remarkable though, that similar other european ignimbritic effusions in permian times, like the Oslo, and Nideck volcanic rocks, did not produce deviating permian poles. By taking samples of the rock series at different levels of the deposit, and using their mean direction of magnetization, the influence of secular variations seemed to be removed. This implies that these ignimbrites were deposited in a space of time, many times longer than the periods of the secular variation.
The observed scatter in the diagrams may be regarded as being effected by secular variations (figure 46). This goes in particular for the mean values of the individual groups, as presented in figure 47, which suggest irregular variations of the permian magnetic field, during the deposition of the volcanic series under consideration. They may be explained as secular variations. It is not probable that the scatter is due to measuring errors, for the concentration in the groups A-F is very pronounced.

2. The deviating position of the permian pole of Bolzano may be due to geotectonic causes, which are probably connected to some stage of the alpine orogenesis. Continental drift or similar processes are thought of, in which large masses are participating.
Though a tectonic correction for the samples, taken near

TABLE VI

Permian pole positions 1–17 from european sampling sites, as represented in Fig. 49.

	Sampling site	Age*)	Pole position				Author
	ENGLAND						
1	Exeter volcanics	?	E	164	43	N	Creer, Irving, and Runcorn, 1957
2	Mauchline sedim.	?	E	166,5	37	N	du Bois, 1957
3	Mauchline volc.	?	E	175	36	N	„
	FRANCE						
4	Estérel, pyromeride R 4	L?	E	142	46	N	Roche, 1957
5	„ , dolerite	L?	W	165	52,5	N	Irving, 1959 a
6	„ , rhyolite	L?	E	130,5	45	N	Rutten, van Everdingen, and Zijderveld, 1957
7	„ ,	L?	E	144	47	N	As and Zijderveld, 1957
8	Nideck porphyry	M?	E	168	43	N	Nairn, 1957
9	Montcenis, sedim.	M	E	162	38	N	„
	NORWAY						
10	Oslo volcanics	L	E	157	47	N	van Everdingen, 1960
	GERMANY						
11	St. Wendel, sedim.	L	W	175	45	N	Nairn, 1957
12	Nahe volcan.	L	E	174	42	N	Schmucker, 1959
13	„	M	E	165	43	N	Nijenhuis, 1960
	RUSSIA						
14	Ufimskij and Kazanskij sedim.	U	E	178	45	N	Khramov, 1958
15	Tartarskij, sedim.	U	E	176	52	N	„
	ITALY						
16	Merano porphyries	L	W	146	45	N	Dietzel, 1960
17	Bolzano „	L	W	118,5	51,5	N	van Hilten, 1960

*) U: Upper permian M: Middle permian L: Lower permian ?: not differentiated

Lugano (samples 37–39, fig. 44) is not precisely known, their position near the SE-ern border of the diagram suggests that they must be correlated rather with the direction of magnetization, as found near Bolzano by the present author (declination N 150° E, inclination —31°) than with the direction of magnetization, which is found in the other european sampling sites (declination about N 190° E, inclination small). The Lugano area is situated at a great distance – 200 km – from the Val-di-Non area. A synchronous volcanic activity in both areas, both confined to the same period of secular variation, seems very improbable. The Lugano area, however, might have undergone a similar geotectonic displacement as the Val-di-Non area.
The other series of rather deviating permian poles, derived from european sampling sites – 4, 5, 6, and 7 in figure 49 – are from the Estérel, S. France. This region may also be influenced by alpine geotectonic movements.
The other european permian poles of fig. 49 are derived from regions outside the sphere of influence of the alpine orogenesis; they form a distinct cluster.

Deciding on the available data, *a geotectonic cause for the deviating pole position of the lower permian volcanic series of Bolzano and Lugano seems probable.* The arguments will be briefly summarized:

1. The effusion of the volcanic rocks lasted longer than the period of one secular variation, for such variations are reflected by the scatter in the diagrams of figure 47 (mean directions of magnetization of the vertical section).

2. The changing chemistry displayed by the volcanic series, ranging from basaltic near its base towards acid in higher levels, suggests an evolution of the effusive processes, for which a given space of time is required.

3. It would be very unlikely, if the volcanic activity of Bolzano and Lugano – at a distance of 200 km from one another – took place during a deviation of the permian magnetic field, caused by one and the same secular variation.
Other permian ignimbritic effusions too, showed to last longer than the period of one secular variation.

4. The relation between alpine-influenced regions and deviating positions of their permian pole is spectacular. The regions outside the sphere of influence of the alpine orogenesis, provide a cluster of well concentrated permian poles.

Beside the well-known differences in ancient pole positions of *inter*continental origin, we are confronted now with an *intra*continental difference, a development of the problem, which does not simplify things.

g. Tentative testing of a continental drift hypothesis.

Assuming for a moment the geotectonic (continental drift) displacements responsible for the mentioned deviating pole position, we might set up the following way of reasoning.
The permian pole position of Europe, north of the Alps, is well known, and is situated at about 167° E and 40° N. We may transfer the pole of the Bolzano volcanic series to this position. Next we can start calculating, where in permian times the volcanic series of Bolzano was situated, relative to central Europe. For by the inclination of the direction of magnetization of these rocks (—31°) we are informed on their distance from the permian pole by the relation $\mathrm{tg}\, I = 2 \cot \varphi$. This distance comes up to 73° and forms a small circle on the globe; part of it is being shown in figure 50, by dashed line A.

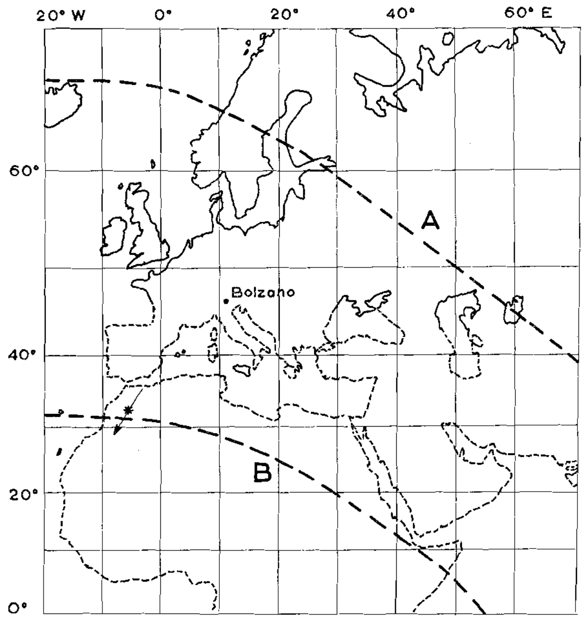


Fig. 50. Reconstruction of the position of the Bolzano volcanic series in permian times, with respect to a fixed position of central and northern Europe.
The reconstruction shows the possibilities given by a reversed (A) and a normal (B) magnetic field during the permian.
Asterisk indicates the position of the Dolomitic sedimentary basin in early mesozoic time, according to Carey (1958). Arrow gives the reconstructed orientation – in permians times – of the present-day geographic North of the volcanic series.

This first approach to the problem does not make much sense, for it is known that central Europe did not change its shape after the hercynian orogenesis.
A second approach may be tried, by considering a reversal of the permian magnetic field during the effusion of the volcanics of Bolzano. It permits us to draw another small circle over the globe, now at a

TABLE V

Paleomagnetic data on the lower permian volcanic rocks of the Bolzano and Lugano areas.

Sample	Strike and dip of the flow	Position in effusive system	Directions of magnetization in declination (D) and inclination (I), and the magnetic intensity in 10^{-5} e.m.u.											
			Figure 42 Primary measurements			*Figure 44* Stable directions, before tectonic correction			Required magnetic field in oersted	*Figure 46* Stable directions tectonically corrected		*Figure 47* Mean stable directions of groups (tectonically corrected)		
			D	I	10^{-5} e.m.u.	D	I	10^{-5} e.m.u.		D	I	Group	D	I
1	2	3	4		5	6		7	8	9		10	11	
1			163	− 23	94,1	163	− 23	94,1	0	160,5	− 33,5			
2			153	− 23	75,3	153	− 23	75,3	0	149,5	− 32,5			
3			156	− 19	7,4	156	− 19	7,4	0	153,5	− 23,5			
4			161	− 25	6,1	161	− 25	6,1	0	158	− 35			
5			149	− 19	7,2	152	− 24	3,9	500	148	− 33			
6			142	− 4	12,1	141	− 14	2,8	900	138	− 21,5			
7			136	− 1	8,5	135	− 14	2,2	900	132	− 20,5			
8			142	− 13	4,7	142	− 13	4,7	0	139,5	− 21			
9	101/12		141	− 20	5,7	141	− 20	5,7	0	137,5	− 27,5			
10		upper, acid half of volcanic series (thickness 500–700 m)	140	− 19	8,3	140	− 19	8,3	0	136,5	− 26	F	144	− 31,5
11			144	− 10	6,3	144	− 10	6,3	0	142	− 18			
12			142	+ 1	7,1	157	− 26	2,4	900	153	− 36			
13			147	− 9	1,9	143	− 24	0,8	900	138,5	− 32			
14			143	− 24	4,2	143	− 24	4,2	0	138,5	− 32			
15			140	− 17	3,6	140	− 17	3,6	0	137	− 24,5			
16			151	− 34	5,2	151	− 34	5,2	0	145	− 43			
17			155	− 28	5,6	155	− 28	5,6	0	150	− 37,5			
18			153	− 32	5,8	153	− 32	5,8	0	148	− 41			
19			161	− 36	6,3	153	− 36	2,3	900	147	− 45			
20		BOTTOM	149	− 4	70,0	149	− 5	63,0	375	148	− 20			
21	70/15		150	− 3	18,2	151	− 8	15,3	310	150	− 23	A	150	− 22,5
22			152	− 6	39,6	152	− 9	30,3	375	150,5	− 24,5			
23			153	+ 28	1,1									
24			123	+ 74	3,4									
25			165	+ 27	0,7									
26			162	− 11	1,2	159	− 20	1,1	190	157	− 30,5			
27			155	− 14	3,5	155	− 18	3,2	375	153,5	− 29	B	155	− 29
28			158	− 12	3,6	158	− 16	3,6	310	156	− 27			
29	90/12	(Total thickness of profile 600 m)	165	− 14	16,5	165	− 17	15,5	310	163,5	− 29			
30			164	− 18	21,7	163	− 23	20,1	375	162	− 34	C	162	− 31
31			163	− 13	7,0	164	− 17	6,2	375	162,5	− 28,5			
32			161	− 42	9,1	161	− 44	6,7	375	156,5	− 55	D	158	− 53,5
33			164	− 38	10,2	164	− 40	7,7	375	161	− 51,5			
34			168	− 17	9,2	158	− 12	2,2	900	157	− 23,5			
35		TOP	192	− 31	8,1	171	− 26	7,2	310	170	− 38	E	160	− 29
36			162	− 6	6,6	157	− 14	2,8	620	156	− 25,5			
37			121	+ 8	20,4	120	− 8,5	10,5	700					
38	?	Lugano	132	+ 24	29,6	137	+ 2	20,8	500					
39			117	+ 9	52,8	123	− 4	50,3	350					

distance of $180° - 73° = 107°$ from the european permian pole (see fig. 50, dashed line B).
Though this second line is situated not nearer than the first one to the present-day position of the volcanic series – Bolzano being situated on the permian equator – it is separated from it by a zone in which large displacements are assumed by Carey (1958), whose interesting paper throws a new light on alpine facies distribution and orogenesis in general. A review of his ideas will not be tried here, but one of its features may be mentioned.
It concerns the position of the sedimentary basin of the southern Alps, in early mesozoic times. According to Carey (see op. cit. fig. 31) it was situated south of the present-day position of Gibraltar (indicated by asterisk in fig. 50), and therefore very close to the dashed line B of figure 50, which represents the possible positions of the volcanic series of Bolzano during their deposition. *This unexpected coincidence of the position of the Bolzano region during its permian and early mesozoic sedimentary stage, found indepently by two different methods, might appear to be significant.*

Additional it may be remarked that the large-scale displacements as assumed by Carey (1958) do not conflict directly with the structural evolution of the Val-di-Non area, as exposed in the preceding chapters. These displacements took place in a period previous to the mid-tertiary alpine orogenesis, and are not accompanied by general lateral compression, as Carey's investigations are based on an 'expanding earth' theory. His attractive ideas on some crucial points of orogenesis and geotectonics, permit also a solution for the problems around the different paleomagnetic pole positions, as derived from european and american sampling sites (Carey 1958, p. 212 and fig. 13). Van Bemmelen too (1960 c), does not a priori reject large-scale displacements, which may be caused by megacircuits in the mantle.

The large translation of at least 2000 km, must have been accompanied by a considerable rotation (around a vertical axis) of the Bolzano volcanic series. For the declination of the direction of magnetization tells us that the present-day direction of the geographic North was pointing towards the SW in permian times (see arrow in figure 50). This implies that a dextral rotation over 150° (or a sinistral one over 210°) took place during the transfer from the depositional site (South of Gibraltar) towards the present-day position near Bolzano.
Carey does not give details on the amount of accompanying rotations. From his figure 31a (op. cit. p. 252) it may be deduced that mainly sinistral rotations occurred. For instance Corsica and Sardegna rotated over about 90°, and the Apennine belt of Italy over some 135°, both anti-clockwise.
It is clear that the assumption of geotectonic displacements needs further evidence. This might be furnished for instance by a paleomagnetic investigation of the permian ignimbrites of Corsica (Bodenhausen 1955). The 90° sinistral rotation as proposed by Carey, should be observable in the results of such an investigation.

In this way, paleomagnetic research becomes an important means for the testing of geotectonic theories, in particular if it is handled according to a well-planned method of prognosis-diagnosis, as advocated by van Bemmelen (1960 a).

CHAPTER VI

General conclusions

STRATIGRAPHY

On top of the hercynian-folded quartz-phyllites the lower permian deposits start with the well-known volcanic series, which is locally underlain by a coarse conglomerate. The effusion of the quartz-porphyries took place in a fluidized condition (ignimbrites) and confined itself to a volcano-tectonic depression, the existence of which lasted all through the permian. The carboniferous age of the volcanic series, advocated by italian workers, is contested: the effusion happened during the lower half of the permian.

The development of the triassic runs parallel to that of the central Dolomites. Many facies changes reveal a depositional environment of small depth. During the middle ladinian offshoots of the central Dolomitic basaltic volcanism covered the monotonous 'Nonsberg'-dolomites. After a stratigraphic break during the upper ladinian, the carnian 'Raibler Schichten' are locally present in various developments. The massive norian dolomites conclude the triassic formations, apart from a local occurrence of rhaetic rocks.

During the rhaetian, jurassic, upper cretaceous, and tertiary facies differences occurred in the Judicaria zone of the Brenta and the Val-di-Non areas; the mutual boundaries of these various facies run parallel to this fault. Opinions on the character of these facies-changes differ on one point: according to Trevisan (1939 a), the boundaries are formed by sinistral strike-slip faults; Vecchia (1957) thinks the boundaries to be more gradual passages. Teichmüller (1929) found flexures, accompanied by breccias in the early senonian deposits. Together these features may be regarded as preliminary movements in the Judicaria zone, which seems to be a zone of weakness (lineament) with a long history.

There appear to be no stratigraphic grounds for the large scale (30 km) sinistral strike-slip faults as advocated by Trevisan (1939 a). There are, on the contrary, some stratigraphic features in the Val-di-Non area, which seem to conflict with Trevisan's concepts. (see p. 33).

TECTONICS.

Apart from the above mentioned facies changes along the Judicaria lineament, no traces were found of an alpine orogenic phase preceding the mid-tertiary one. The tectonic inventory of the Val-di-Non area calls for a division into three, mid-tertiary orogenic subphases, and a minor, sub-recent one, during which collapse structures originated.

A more complete list of the mid-tertiary deformations is given in chapter III, c and in fig. 38.

Subphase a shows the gravitative décollement of the sedimentary cover to the SSE, from the rising central alpine geanticline. It represents the folding phase with axial directions running parallel to the general trend of the alpine orogene, ENE-WSW in this region; it is encountered all through the southern Alps (Central Dolomites, Brenta area, and the Bergamasc Alps). Its gravitative character and SSE direction are deduced from various features, as the 'moving-ahead of the younger formations' (german: 'voraneilen der jüngeren Schichten'), verging (german: 'Vergenz') of the folds, direction of overthrusting, accompanied by compression at the front of the overthrusting block, and tension phenomena at its 'tail'.

The joint pattern is oriented symmetrically to the deformations of this subphase.

Subphase b. During this subphase the southern Alps do not participate any longer in the continued rising of the central Alps; they are separated from them by the peri-adriatic suture. From Mules to Dimaro this suture had a different direction (NNE-SSW), following thus a marked zone of weakness of the crust (lineament) which is marked by facies changes in the overlying sedimentary complex.

During this subphase the Judicaria fault and its auxiliary (Foiana) fault originated. These NNE-SSW running fauls cut obliquely the ENE-WSW trending folds of subphase a.

Contrary to the assumptions of de Sitter (1947, 1956 a, and 1956 b) and of Trevisan (1939 a), these faults are accompanied by tension phenomena, reflected by the antithetic faults next to the Judicaria fault, and by the tectonically undisturbed condition of the sediments, immediately adjacent to them (see chapter III, b2 and IV, a). The sinistral strike-slip function, attributed to these faults by de Sitter, Trevisan, and Kraus (1951) is not consistent with these facts; no traces of such strike-slip faulting could be found in their vicinity.

Suphase c. The relatively light, rheomorphic material, at the base of the crust under the central alpine geanticline (viz. a tonalitic magma), spread out laterally, and

rose along the previously formed peri-adriatic suture. In the Val-di-Non area these intrusive rocks are exposed in the tonalitic massif of the M. Croce and at several places along the Judicaria fault. The findings of Karl (1959) proved the consanguinity of the crystallizations of the tonalitic granites of the Tauern (centre of the geanticline) with the tonalites of these peri-adriatic massifs.
The tonalite of the M. Croce pushed upwards the M. Luco horst between the Judicaria and Foiana faults. Thereby the vertical throw of the northern part of the Foiana fault increased, and the northern fault-troughs along the Judicaria fault were mechanically crushed. The elevation of the M. Luco horst called forth gravitative reactions in its sedimentary cover, resulting in small folds (near Proves), and finally the sliding down of megabreccias into the Foiana depression in subrecent times.

This structural evolution of the Val-di-Non area is in all details in agreement with the views of van Bemmelen (1960 b, and 1960 c), regarding the mid-tertiary orogenic phase in the eastern Alps. All stages of 'secondary tectogenesis' distinguished by this author (epidermal, dermal, and bathydermal) are encountered. This secondary tectogenesis is the gravitative reaction to the primary tectogenesis, casu quo the mid-tertiary rise of the central alpine geanticline.
Only the recognition of the gravitative origin of the many diverse phenomena of tectonic deformations in the Val-di-Non area does provide a mechanically acceptable and coherent picture of its structure and of its geological history.

PALEOMAGNETISM.

The lower-permian pole derived from samples of the Bolzano area, is situated at 118,6° W, and 51,4° N. Only stable directions of magnetization (33 samples) were used for its determination.
This position deviates considerably from the position of permian poles, derived from other european sampling sites (Table VI, and fig. 49).
The available data suggest that this deviation is not due to a temporary (e.g. secular variation) deviating magnetic field during the effusion of the investigated quartz-porphyries; it is probably effected by some alpine geotectonic process.

Appendix

A. GENERAL ASPECTS OF THE VAL-DI-NON AREA

After world war I this part of northern Italy, which originally belonged to Austria and was named Süd-Tirol, was assigned to Italy. Many of its inhabitants still use the german language in some parts of the Val-di-Non area, for instance in the Adige valley and north of the language boundary, which runs south of the villages of Proves, Lauregno, and Senale.
After world war II, Austria and Italy agreed upon an autonomous status of the former Süd-Tirol. However, a continuous, partly stimulated, migration of italians towards these regions has gradually diminished the original majority of austrian inhabitants, and a separation from Italy will hardly be probable at this stage. In recent years the austrian government, aware of the changing equilibrium in its former province, tries to force a decision by putting the case before the United Nations.

In the Adige valley, and in the tertiary and upper-cretaceous depression along the Foiana fault – a wide zone from Fondo towards the SSW – a rather flat, cultivated area is found. In particular apple orchards are frequently seen, while at many places in the Adige valley vinyards cover extensive slopes. The latter are concentrated around the well-known wine centres of Terlano and Caldaro.
Confined again to the Adige valley – but also along the roads meeting in Fondo – an almost continuous stream of tourists is on the move during the summer. Many of them stay a while in this beautiful environment (Lago di Caldaro, Passo della Mendola, Coredo, Fondo and its surroundings) and bring some prosperity to these places.

In the remaining parts of the Val-di-Non area the population is mainly agricultural. Husbandry is concentrated around the small villages and the individual farms. Cattle of each hamlet is herded collectively, mostly at some distance from the villages, where conditions are more favourable. Extensive areas are covered by woods, which are regularly thinned out; a number of sawing-mills turn the trees into timber.

Generally, the roads are in good condition and they permit crossing the area by car in many directions. The Val d'Ultimo and the Marano valley, however, are rather isolated; they may be reached from the Adige valley by a steep, winding road.
The Strada della Mendola (Mendola-road, from the Adige valley up to the Passo della Mendola) rejoices an international fame, because with its 15 hairpins it serves a yearly racing course. Up till now the record is held by a 3,3 L Lancia, which covered the vertical stratigraphic profile from quartz-porphyry up to the norian 'Hauptdolomit' (difference of altitude 952 m) with a mean velocity of 101 km/h.

B. MORPHOLOGY

The morphology of the Val-di-Non area may be described from east to west, by which some typical morphological units – extending in roughly N-S running zones – are revealed (see figure 51).

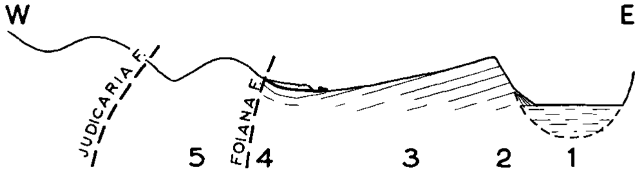


Fig. 51. Schematic morphological E-W section across the Val-di-Non area.
1 Glacial valley of the Adige.
2 Cuesta of the Mendola scarp
3 Dip-slope of the Val-di-Non — Mendola Unit.
4 Megabreccias along the Foiana fault
5 Irregular topography of the M. Luco horst and the central alpine schists.

1. THE ADIGE VALLEY. Its width ranges from 2 to 3,5 km and its steep walls reach an altitude of 1500 to 2000 m above the valley floor. At their foot huge talus cones are easily distinguishible, in particular when the valley walls are formed by the triassic dolomites.
The valley floor is built up of alluvial and some morainic deposits and it is practically flat. The Adige river has been canalized in this part of its course.
During the ice ages, the mighty Adige glacier made its way through this valley; it was, however, in no way confined to this narrow passage, for erratics near the top of the M. Roèn (2116 m) reveal, that the glacier extended far beyond this valley, covering the entire Val-di-Non area (von Klebelsberg 1935, p. 553). Only

the M. Luco peak might have remained above its surface.
It was pointed out (p. 64) that the rectilinearity of the Adige valley may be the result of its function as a hinge zone, around which the Val-di-Non area was tilted regionally to the WSW. The Lago di Caldaro is formed by a depression in an abandoned branch of the Adige river.

2. A STEEP CUESTA is formed by the western Adige valley wall. The gently WSW dipping formations are abruptly cut off here. Only the Prisciano river does penetrate deeply into this cuesta, attaining the Foiana fault north of the Passo delle Palade, and isolating thus the M. Vicale from the southern massif.
In the southern part of the cuesta, the morphology is governed by the front of the Taio overthrust block (see e.g. photograph 4).

3. THE DIP-SLOPE of the Val-di-Non – Mendola Unit occupies the larger part of our area. It is formed by the generally WSW-dipping formations. Only the upthrusted frontal part of the Taio overthrust block does change this regular pattern; a NW-dipping slope is found there. In a similar way the overthrust block north of Castelfondo may be distinguished morphologically.

4. THE MEGABRECCIAS along the Foiana fault form a marked morphological feature. Both on the topographic map and in the field their sheet-like forms – slightly (about 40 m) elevated above the flat surface of the Foiana depression – may be noticed. They blur the presence of the Foiana fault, which forms a clear topographic depression in the more northern part of the Val-di-Non area.
Like the Judicaria fault, the Foiana fault is always encountered at the western side of the accompanying topographic depressions or valleys.

5. THE RIDGE OF THE M. LUCO HORST forms a notably elevated zone in the topography of the Val-di-Non area; it is bordered by the Judicaria and Foiana faults, which caused depressions at its sides.
From north to south we meet with the following summits: the *M. Croce* (just outside the northern margin of the map), separated from the *M. Luco* by the softer quartz-phyllites, which produced a depression, the Passo di Plazzoles. The *M. Ori* (1877 m) is the southernmost topographic culmination, as the quartz-porphyries are dipping away here under their sedimentary cover. A thick morainic deposit south of Mione prevents the morphological recognition of the underlying formations.

Summing up, there is an evident relation between the morphology of the Val-di-Non area and its geological history, in particular the mid-tertiary orogeny. Locally this influence is blurred by glacial deposits.

C. ECONOMIC GEOLOGY

Ores.
PbS and ZnS ores.

Two different metallizations are found in the Val-di-Non area. The first type is a vein deposit, the other one a bedded ore deposit.

VEIN DEPOSITS: They are confined to the quartz-phyllite series between San Pancrazio and Plazzoles. Along the Rio dei Prati a number of small galleries of abandoned mines is situated, which are entering heavily mylonitized and brecciated fault zones in the phyllite series. Locally these fault zones are enriched in galena and sphalerite ores, but their further exploitation does not seem to be profitable any more.
This occurrence is to be correlated with the near by ore deposits of the Adige valley, and in particular with those of the quartz-phyllites and permian quartz-porphyries around Trento, which have been thoroughly investigated by Maucher (1956 and 1959). Microscopical and field-geological evidence is adduced by him, which demonstrates the connection between these metallizations and the permian volcanism.

BEDDED ORE DEPOSITS are seen in some layers of the dolomitic limestone of the Bellerophon Stage throughout the Dolomitic region. Their great extension, together with their being limited to one stratigraphic formation, clearly shows their syngenetic, sedimentary origin, as is advocated by Maucher, who observed also the presence of sedimentary textures in these deposits. Compared to the vein deposits, they show a general agreement in their chemical composition, though the bedded deposits of the Bellerophon Stage are far more monotonous. Andreatta (1949) favours a hydrothermal point of view with regard to these bedded ores; the presence of some (0,2 %–3 %) MnO in the Bellerophon dolomites might have acted as a catalytic agent.
In the Val-di-Non area these ores have been worked at several places: north of Preghena, east of Rumo, near Lauregno, and in the Adige valley.

An attractive synthesis of the discussed lead – zinc mineralizations is given by Maucher (1959), who proposes a permian metallogenetic period responsible for the ore veins, closely connected with the permian volcanism. The bedded, syngenetic ores may be taken for a final stage of this period, during which subaquatic exhalations gave a uniform and widespread extension to ore bearing solutions. These solutions may also partly or completely have originated by late permian weathering of the fore-mentioned ore veins. For more details on these ores we refer to Maucher (1956 and 1959).

U ores.

Explorations by the CNRN (Comitato Nazionale per le Ricerche Nucleari, Roma) in this area revealed some minor uraniferous deposits in the Gardena sandstones. Though particulars on the mineralizations of the Val-di-Non area have not yet been published, it may be expected that they will not differ essentially from the uraniferous deposits of the Val Daone and of the Val Rendena, described by Mittempergher (1958b and 1958c). A sedimentary origin for these mineralizations is put forward; metamorphic and diagenetic processes are thought to have caused a partial neoformation of pitchblende.
An original relation with organic matter in the sandstones is probable.

Coal.

The Gardena sandstones are locally enriched in organic matter, which may take the extension of coal streaks. These have been worked at some places in the Val-di-Non area, for instance near Proves and in the Adige valley near Tesimo.

Building-stone.

The permian quartz-porphyries and the limestones of the upper jurassic 'Ammonitico rosso' are commonly used as building materials in this part of the Dolomites. At several places in the Adige valley a natural cleavage (jointing) of the hard quartz-porphyries makes this rock naturally productive of paving-stone; regular cubes (8 cm ribs) are transported directly from the quarries, mostly without previous workmanship.
The limestones of the 'Ammonitico rosso' are used generally as a buildingstone by the local population. Many buildings in Merano, Bolzano, and Trento have entirely been made of this stone. Already after a few years its originally white green colour has changed into pink by weathering. On top of the Taio overthrust block this rock is obtained from a great number of scattered quarries. Because of the great resistance of this rock against weathering, it is largely responsible for the origin of the extensive dip-slopes in this area.

Oil.

A drilling was started by the AGIP in 1958, west of Mollaro (indicated on geological map and section VI). The present author does not know which formation is assumed to be oil bearing; however structures do not promise any favourable conditions. Oil seepages are known in the upper course of the Rio dei Pilastri (von Klebelsberg 1935, p. 323, and local rumours); they have not been found by the present author. They are probably caused by the bituminous basal layers of the cenomanian, the 'scisti neri'.
The drilling of Mollaro was continued down to the effusive series of the permian, which was reached at a depth of 1612 m below sea level. No oil deposits have been reported in the drilled formations.
Some data of this drilling (personal communication) have been used in section VI.

Miscellaneous.

NE of Mollaro the 'scisti neri' (black shales) at the base of the cenomanian formation are worked for the extraction of the pharmaceutical oil ichthyol. Particulars on the quality of this product are reported by Castelli (1924).

At various places in the northern part of the Val-di-Non area springs are found, the waters of which are exploited by the local population either as mineral waters, or for its curative properties. In this connection the villages of Bagni di Mezzo and Bagni di Caprile may be mentioned.

Two barriers have been built in the investigated area, by which two artificial lakes are dammed up, the Lago di Cles and the lake SW of S. Pancrazio. Both are used for the generation of electricity. The electricity plant of the Lago di Cles is encountered between Dermulo and Taio; the water of the lake near S. Pancrazio is transported down to Lana in the Adige valley, where a generating station has been built.
The position of the barrier of the lake near S. Pancrazio (200 m west of the Judicaria fault) resting upon the intensely faulted central alpine schists (see fig. 7) is remarkable.

List of illustrations and tables

List of Italian-Austrian topographic names

mentioned in this thesis. This list is added for the benefit of the reader, who studies the austrian literature on this area.

Adige	Etsch	Merano	Meran
Bagni di Caprile	(Bad) Gfrill	Mules	Mauls
Bagni di Mezzo	Mittler Baden, Mitterbad	Nalles	Nals
Bolzano	Bozen	Ora	Auer
Bressanone	Brixen	Palade, Passo delle	Gampenpass, Gampfenpass
Caldaro	Kaltern	Paolo, San	St. Pauls
Caldaro, Lago di	Kalterer See	Plazzoles	Plazzers
Castelrotto	Kastelruth	Proves	Proveis
Cevedale M.	Zufall Sp.	Redagno	Radein
Corona	Graun	Roèn M.	Roën Höhe
Cortaccia	Kurtatsch	San Pancrazio	St. Pankraz
Croce M.	Kreuzberg	San Paolo	St. Pauls
Egna	Neumarkt	Sciliar M.	Schlern
Fié	Völs	Senale	Unsere liebe Frau im Walde
Foiana	Völlan	Siusi	Seis
Gardena, Ponte	Waidbruck	Terlano	Terlan
Gardena, Val	Grödener, Grödner Tal	Termeno	Tramin
Isarco	Eisack	Tesimo	Tisens
Lauregno	Laurein	Trento	Trient
Luco M.	Laun Höhe, Laugenstock	Val-di-Non	Nonsberg, Nonsberger Mulde
Macaion M.	Gantkofel	Val d'Ultimo	Ultental, Ultnertal
Magré	Magreid	Valsura, Rio	Falschauer Bach
Marano, Rio di	Marauner Bach	Vedetta Alta	Hochwart
Mendola, Passo della	Mendelpass		

Bibliography

Accordi, B. (1955) - Le dislocazioni delle cime (Gipfelfaltungen) delle Dolomiti: Annali Univ. Ferrara, N. Ser., sez. IX, Sci. geol. e pal., v. II, 2, p. 65-189.

——, (1957) - Nuove ricerche sui corrugamenti di vetta (Gipfelfaltungen) delle Dolomiti Occidentali: Boll. Soc. geol. Ital., v. LXXVI, fasc. 1, p. 223-243.

——, (1959) - Il Permiano superiore delle Dolomiti e le sue relazioni con l'orogenesi ercinica: Estudios geol., v. XV, p. 1-17, Madrid.

Andreatta, C. (1937) - Studio petrografico del complesso eruttivo di Monte Croce in Alto Adige: Period. di Min., v. VIII, p. 311-432.

——, (1948) - La "Linea di Peio" nel massiccio dell'Ortler e le sue miloniti: Acta geol. alpina, 1, Bologna, p. 1-63.

——, (1949) - Origine dei giacimenti nel Permiano superiore del Trentino e influenza del manganese sulla metallizzazione a galena argentifera: Mem. Ist. geol. Univ. Padova, v. XVI.

——, (1949) - Notizie sulla costituzione del complesso effusivo permiano del Trentino - Alto-Adige: Rendic. d. Soc. Min. It., v. VI, p. 3-8.

——, (1950) - Il complesso dei porfidi quarziferi atesini: Publ. 29 dell'Ist. di Min. e Petr. Univ. Bologna, Relazione Congr. Int. del Porfido 1950, Trento.

——, (1952) - Polymetamorphose und Tektonik in der Ortlergruppe; N. Jb. Min., Mh., p. 13-28.

——, (1953) - Syntektonische und posttektonische magmatische Erscheinungen der Ortlergruppe in Beziehung zum alpinen Magmatismus: Tscherm. min. petr. Mitt., v. 3, p. 93-114.

Andreatta, C. e Pirani, R. (1954) - Analisi strutturali di rocce metamorfiche, VIII, Compagini di parascisti di catazona (Val di Peio, Gruppo dell'Ortles); Period. di Min., XXIII, p. 125-145.

Argand, E. (1916) - Sur l'arc des Alpes occidentales: Ecl. geol. Helv., v. 14, p. 145-191.

As, J. A. and Zijderveld, J. D. A. (1958) - Magnetic cleaning of rocks in palaeomagnetic research: Geoph. Journ. Roy. Astr. Soc., v. 1, 4, p. 308-319.

As, J. A. (1960) - Instruments and measuring methods in paleomagnetic research: Meded. en verh. Kon. Ned. Meteor. Inst. no. . . . (in press).

Beloussov, V. V. (1958) - On the origin and types of folding: Sowjetskaja geol., 1, 1, p. 40-64.

Bemmelen, R. W. van (1930) - The origin of Lake Toba (North Sumatra): 4th Pac. Sci. Congr. Proc., v. II, A.

——, (1957) - Beitrag zur Geologie der westlichen Gailtaler Alpen (Kärnten, Oesterreich) (erster Teil): Jhrb. geol. B. Anst., 100, p. 179-212.

——, (1958) - Stromingsstelsels in de silikaatmantel: Geol. & Mijnb., Nwe Ser., 20e jaarg., p. 1-17.

——, (1960-a) - Die methode in der Geologie: Mitt. der Geol. Ges. in Wien, 53, p. 35-52.

——, (1960-b) - Zur Mechanik der ostalpinen Deckenbildung: 50th Ann. meeting Geol. Ver., Würzburg March 1960. Geol. Rundsch. (in press).

——, (1960-c) - New views on E-alpine orogenesis: section 18, Copenhagen Int. Geol. Congress.

Billings, M. P. (1960) - Diastrophism and mountainbuilding: Bull. geol. Soc. Am., v. 71, 4, p. 363-397.

Blaas, J. (1903) - Notiz über das Mendelgebirge: Centralbl. für Min., Geol., Palaeont., p. 451-452.

——, (1909) - Aus dem Marauner Tal: Verh. k. k. geol. R. Anst., p. 300-302.

Bodenhausen, J. W. A. (1955) - Géologie de la région au Nord du Golfe de Porto (Corse): Doct. thesis of the Amsterdam Univ., mededeling 222 v. h. Geol. Inst.

Bois, P. M. du (1957) - Comparison of palaeomagnetic results for selected rocks of Great Britain and North America: Adv. in Physics, v. 6, p. 177-186.

Bordet, P. (1958) - A propos des 'ignimbrites': C. R. Somm. Soc. géol. France, p. 77-80.

Cadisch, J. (1946) - On some problems of alpine Tectonics: Experientia, v. 2/1, p. 1-16.

Carey, S. W. (1958) - A tectonic approach to continental drift: Continental Drift Symposium, Hobart, Tasmania.

Castelli, G. (1924) - Gli scisti bituminosi di S. Romedio nel Trentino: Boll. Soc. geol. It., v. XLIII, p. 35-41.

Cornelius, H. P. (1928) - Zur Altersbestimmung der Adamello und Bergeller Intrusion: Sitzungsber. Akad. Wiss., Math.-naturw. Klasse, Abt. I; Bnd 137, Wien.

Cornelius H. P. und Cornelius M. (1925) - Bericht über geologische Untersuchungen an der insubrische Linie im unteren Veltlin: Anz. Akad. Wiss. in Wien, Math.-Naturw. Kl., 62, p. 209-211.

Cornelius H. P. und Furlani-Cornelius M. (1931) - Die Insubrische Linie vom Tessin bis zum Tonalepass: Denkschr. Akad. Wiss., Math.-Naturw. Kl., Bnd 102, p. 207-301.

Cox A. and Doell R. R. (1960) - Review of paleomagnetism: Bull. geol. Soc. Am., v. 71, p. 645-768.

Creer K. M., Irving E. and Runcorn S. K. (1957) - Palaeomagnetic investigations in Great Britain VI, Geophysical interpretation of palaeomagnetic directions from Great Britain: Phil. Trans. Roy. Soc., ser. A, v. 250, p. 144-156.

Dal Piaz, G. (1926) - Il cinfine alpino-dinarico dall'Adamello al massiccio di Monte Croce nell'Alto Adige: Atti Acc. Sci. Veneto-Trentino-Istriana, v. XVII, p. 3-7, Padova.

Dal Piaz, G. B. (1942) - Geologia della bassa Valle d'Ultimo e del massiccio granitico di Monte Croce: Mem. Mus. Stor. Nat. di Venezia Trident., v. V, fasc. 2, Trento.

Dietzel, G. F. L. (1960) - Geology and permian paleomagnetism of the Merano region (Province of Bolzano, N. Italy): Doct. thesis Utrecht, Geologica Ultraiectina, no. 4.

Dozy, J. J. (1935-a) - Ueber das Perm der Südalpen: Leidsche geol. meded., p. 41-61.

——, (1935-b) - Beitrag zur Tektonik der Bergamasker Alpen: Ibidem. p. 63-84.

Everdingen R. O. van, and Zijderveld J. D. A. (1959) - Paläomagnetismus in den Rhombenporphyren von Oslo und in den Rhyoliten, Doleriten und Sedimenten des Estérels: Geol. Rdsch., 48 p. 195-205.

Everdingen, R. O. van (1960) - Palaeomagnetic analysis of Permian extrusives in the Oslo Region, Norway: Doct. thesis Utrecht, in 'Studies on the igneous Rock Complex of the Oslo Region': Skrifter utgitt av Det Norske Vid. Akad., Oslo, I. Mat.-Naturv. Kl.

Fabiani, R. (1919) - Sul Terziario dell'alta Val di Non (Trentino): Atti Acad. Ven.-Trent.-Istr., v. X, p. 117-123.

——, (1923) - Giacitura ed età degli scisti bituminosi di Mollaro in Val-di-Non: Riv. Sci. Nat. 'Natura', 14, p. 33-41, Pavia.

——, (1924-a) - Osservazioni sulla stratigrafia a sulla tettonica dei massicci montuosi del Bondone e del Roèn: Atti d. Acad. Ven.-Trent.-Istr., v. XV, Padova.

——, (1924-b) - Cenni preliminari sulla geotettonica dei massicci montuosi del Roèn e della Paganella (alpi Tridentine): Boll. Soc. geol. It., v. XLIII, p. 200-204.

Fallot, P. (1946) - Phénomènes de Décoiffement dans les groupes du Puez et du Sella (Dolomites du Tyrol): C. R. Soc. géol. France, 11.
——, (1950) - Remarques sur la tectonique de couverture dans les Alpes Bergamasques et des Dolomites: Bull. Soc. géol. France, T. 20, p. 183-195.
——, (1955) - Les dilemnes tectoniques des Alpes Orientales: Ann. Soc. géol. de Belgique, T. LXXVIII, p. 147-170.
Folgner, R. (1914) - Zur Tektonik des N.-Etschbuchtgebirges: Verh. k. k. geol. R. Anst., Wien.
Furlani, M. und Henny, G. (1920) - Du prolongement vers l'Est du synclinal du Canavèse et de l'anticlinal insubrien: Ecl. geol. Helv., v. XVI, p. 93-97.
Gaertner, H. R. von (1960) - Ueber Gebirgszusammenhänge in den Mitteleuropäischen varistischen Ketten (Geosynklinale und Lineament): 50th Ann. meeting Geol. Ver., Würzburg. Geol. Rdsch. (in press).
Gianotti, G. P. (1958) - La serie permo-carbonifera delle Alpi centro-orientali: Studi e Ric. d. div. geom. d. CNRN, v. I, 37 p.
Goguel, J. (1959) - Le rôle de la pression fluide dans les déformations tectoniques: Bull. Soc. géol. France, 7e Sér., T. 1, p. 571-573.
Guembel, W. (1877) - Vorläufige Mittheilung über das Vorkommen der Flora von Fünfkirchen in sog. Grödener Sandstein Südtirols (Ulmannia Sandstein): Verh. k. k. geol. R. Anst., 23, Wien.
Hamann, P. J. (1959) - Bestimmung der Bewegungsrichtung an Verwerfungen mit Hilfe des Schmidt'schen Netzes: Notizbl. hess. L.-Amt Bodenf., 87, Wiesbaden, p. 188-191.
Hammer, W. (1902-a) - Die krystallinen Bildungen im Bereiche des Blattes Cles: Verh. k. k. geol. R. Anst., Wien, p. 127.
———, (1902-b) - Die kristallinen Alpen des Ultentales, I Das Gebirge südlich der Faltschauer: Jhrb. k. k. geol. R. Anst, Bnd 52, p. 105-134.
Harrison, J. V. and Falcon, N. L. (1934) - Collapse structures: Geol. Mag., LXXI, p. 529.
——, (1936) - Gravity collapse structures and mountainranges, as exemplified in SW Iran: Quart. Journ., London, 92, p. 91-102.
Heim, Alb. (1919) - Geologie der Schweiz, II: Tauchnitz, Leipzig.
Heinrich, E. W. M. (1956) - Microscopic Petrography: Mc Graw-Hill Book Cy.
Heissel, W. (1957) - Zur Tektonik der Nordtiroler Kalkalpen: Mitt. geol. Ges. Wien, 50, p. 95-132.
Heissel, W. and Ladurner, J. (1936) - Geologie des Gebietes von Villnöss - Gröden - Schlern - Rosengarten: Jhrb. geol. B. Anst., 86, p. 1-64.
Hellbardt, G. (1959) - Das astatische Magnetometer und seine Verwendung zur Messung sehr schwacher Gesteinsmagnetisierungen: Geol. Jhrb., Bnd 75, p. 319-346.
Heritsch, F. (1915) - Die Bauformel der Ostalpen: N. Jhrb. f. Min. usw., p. 47-67.
——, (1939-a) - Die Südalpen; (bearbeitet von O. Kühn): In Schaffer's Geologie von Oesterreich, Wien.
——, (1939-b) - Karbon und Perm in den Südalpen und in Südosteuropa: Geol. Rdsch., 30, Stuttgart, p. 529-588.
Hubbert, M. K. and Rubey, W. W. (1959) - Role of fluid pressure in mechanics of overthrustfaulting: Bull. geol. Soc. Am., v. 70, p. 115-166.
Hummel, K. (1928) - Die Dolomitisierung der mitteltriadischen Kalke in Südtirol: Zschr. Deut. geol. Ges., Bnd 80, p. 287-290.
——, (1932) - Zur Stratigrafie und Faziesentwicklung der südalpinen Mitteltrias: N. Jhrb. f. Min. Geol. u. Pal., Beil-Bnd 68.
Hupé, P. (1958) - Aperçus sur le réseau rhegmatique de la croute terrestre: Bull. trimestr. du S.I.G. du B.R.G.G.M., 10e année, No. 40.
Irving, E. (1959-a) - Palaeomagnetic pole positions, a survey and analysis: Geoph. Journ. roy. Astr. Soc., v. 2, 1, p. 51-79.
——, (1959-b) - Magnetic cleaning: Geoph. Journ. roy. Astr. Soc., v. 2, 2, p. 140-141.
——, (1960) - Palaeomagnetic pole positions, Part I. Pole numbers 1/1 to 1/144: Geoph. Journ. roy. Astr. Soc., v. 3, 1, 96-111.
Karl, Fr. (1959) - Vergleichende petrographische Studien an den Tonalitgraniten der Hohen Tauern und der Tonalitgraniten einiger periadriatischen Intrusivmassen: Jhrb. geol. B. Anst., Bnd 102, p. 1-192.
Khramov, A. N. (1958) - Paleomagnetic correlation of sedimentary rocks: GOSTOPTEHIZDAT, Leningrad, 218 p.
King, Ph. B. (1960) - The anatomy and habitat of low-angle thrust faults: Am. Journ. Sci., 258 A, p. 115-125.
Klebelsberg, R. von (1911) - Zur Geologie des unteren Marauner Tals (Ulten, Südtirol): Verh. k. k. geol. R. Anst., p. 54-60.
——, (1935) - Geologie von Tirol: Borntraeger, Berlin.
Knetsch, G. (1957) - Gravitative denudation: Geol. Rdsch., 46, p. 557-563.
Kober, L. (1914) - Alpen und Dinariden: Geol. Rdsch., 5, p. 1-21.
Koop, O. J. (1952) - A megabreccia formed by sliding in southern France: Am. Journ. Sci., 250, p. 822-828.
Kraus, E. (1951) - Die Baugeschichte der Alpen (two parts): Akademie-Verlag, Berlin.
——, (1956) - Ueber die Strukturen der orokinetische Narbenzonen: Mitt. geol. Ges. Wien, Bnd 48 (Klebelsberg-Festschrift), p. 113-128.
Kulp, J, L., (1959) - Geological time-scale: Abstr. geol. Soc. Am., Progr. 1959 ann. meetings, Pittsburgh, p. 76-A.
Künzli, E. (1899) - Die Contactzone um die Ulten-Iffingermasse bei Meran: Tscherm. Min. u. Petr. Mitt., v. XVIII, Wien.
Leonardi, P. (1949) - Contributi alla conoscenza della flora delle Arenarie di Val Gardena (Permiano medio-inferiore) dell' Alto Adige: Mem. Ist. geol. Padova, v. XVI.
——, (1951) - Flora e Fauna delle arenarie di Val Gardena (Permiano medio) delle Dolomiti Occidentali: Mem. Ist. geol. Padova, v. XVII.
——, (1953) - Flora continentale ladinica delle Dolomiti: Mem. Ist. geol. Padova, v. XVIII, 22 p.
——, (1955) - Breve sintesi geologica delle Dolomiti occidentali: Boll. Soc. geol. It., v. LXXIV, p. 1-80.
Lepsius, R. (1878) - Süd-Tirol.
Longwell, C. R. (1951) Megabreccia developed downslope from large faults: Am. Journ. Sci., v. 249, p. 343-355.
Lugeon, M. et Henny, G. (1915) - La limite alpino-dinarique dans les environs du massif de l'Adamello: C. R. Acad. Sci., Paris, T. CLX, p. 365-367.
Marshall, P. (1935) - Acid rocks of the Taupo-Rotorua Volcanic District: Trans. roy. Soc. of N. Zealand, 64, p. 323-366.
Maucher, A. (1956) - Erzmikroskopische Untersuchungen an Blei-Zink-Lagerstätten im Raume von Trento (N. Italien): Mitt. Geol. Ges. Wien, Bnd 48 (Klebelsberg Festschrift), p. 139-153.
——, (1959) - Erzlagerstättenbildung und permischer Vulkanismus in Raume von Trient (Norditalien): Geol. Rdsch., 48, p. 131-140.
Mittempergher, M. (1958-a) - La serie effusiva palaeozoica del Trentino - Alto-Adige: Studi e ricerche Div. Geom. d. CNRN, v. I, p. 61-145.
——, (1958-b) - Il giacimento uranifero di Val Rendena: Ibidem.
——, (1958-c) - Il giacimento uranifero di Val Daone: Ibidem.
Mutschlechner, G. (1933) - Cephalopodenfauna im Grödner Sandstein: Verh. geol. B. Anst., p. 136.
Nagata, T. (1953) - Rock magnetism: Maruzen Co, Tokyo.

Nairn, A. E. M. (1957) - Observations palémagnétiques en France, Roches permiennes: Bul. Soc. géol. France, sér. 6, vol. 7, p. 721-727.
——, (1960) - Paleomagnetic results from Europe: Journ. of Geology, 68/3, p. 285-306.
Nijenhuis, G. H. W. (1960) - A palaeomagnetic study of the permian volcanics in the Nahe region (SW Germany): Geol. & Mijnb. (in press).
Patriciu V. und Teichmüller, R. (1930) - Die kretazischen Oelschiefer und Globigerinenkalke des Nonsbergs und der nördlichen Brentagruppe: Zeitschr. Deut. Geol. Ges., Berlin, Bnd 82, p. 241-251.
Pia, J. (1925) - Die Gliederung der alpinen Mitteltrias auf Grund der Diploporen: Anz. Akad. Wiss., Wien, Jhrg. 62, p. 214-217.
Pichler, N. (1959) - Neue Ergebnisse zur Gliederung der Unterpermischen Eruptivfolge der Bozener Porphyr-Platte: Geol. Rdsch., 48, p. 112-130.
Potonié, H. (1921) - Lehrbuch der Palaeobotanik: Borntraeger Verlag, Berlin.
Price, N. J. (1959) - Mechanics of jointing in rocks: Geol. Mag., p. 149-167.
Reynolds, D. L. (1954) - Fluidization as a geological process and its bearing on the problem of intrusive granites: Am. Journ. Sci., 252, p. 577-614.
Roche, A. (1957) - Sur l'aimantation des roches volcaniques de l'Estérel: C. R. Acad. Sci. Paris, v. 244, p. 2952-2954.
Rode, K. P. (1941) - The geology of the Morcote Peninsula and petro-chemistry of the porphyry magma of Lugano: Schw. Min. Petr. Mitt., XXI, p. 194-312.
Rosenberg, G., (1959) - Geleitworte zu den Tabellen der Nord- und Südalpinen Trias der Ostalpen: Jhrb. geol. B. Anst., Bnd. 102, p. 477-479.
Rubey, W. W. and Hubbert, M. K. (1959) - Role of fluid pressure in mechanics of overthrust faulting: Bull. geol. Soc. Am., v. 70, p. 167-206.
Rutten, M. G. (1959) - Ignimbrites or fluidised tuff flows on some mid-Italian volcanos: Geol. & Mijnb. (Nwe Ser.), Jrg. 21, 396-399.
Rutten, M. G., Everdingen O. R. van, and Zijderveld, J. D. A. (1957) - Palaeomagnetism in the permian of the Oslo Graben (Norway) and of the Estérel (France): Geol. & Mijnb., (Nwe Ser.), 19e Jrg., p. 193-195.
Salomon, W. (1905) - Die alpino-dinarische Grenze: Verh. k. k. R. Anst., p. 341-343.
Sanford, A. R. (1959) - Analytic and experimental study of simple geologic structures: Bull. geol. Soc. Am., v. 70, p. 19-52.
Saucier, H., Millot, G. et Jost. R. (1959) - Les coulées rhyolitiques du Nideck (permien, Vosges) sont-elles des ignimbrites?: Geol. Rdsch., 48, p. 95-99.
Schaffer, F. X. (1951) - Geologie von Oesterreich: 2e Auflage, Fr Deuticke, Wien.
Schmidegg, O. (193 6)- Steilachsige Tektonik und Schlingenbau auf der Südseite der Tiroler Zentralalpen: Jhrb. geol. B. Anst., 86, p. 115-149.
Schmucker, U. (1959) - Gesteinsmagnetische Untersuchungen an permischen Nahe-eruptiven: Geol. Rdsch., 48, p. 184-195.
Schwinner, R. (1913) - Der Südostrand der Brentagruppe (SW Tirol): Mitt. geol. Ges. Wien, p. 197-223.
——, (1915-a) - Dinariden und Alpen: Geol. Rdsch., VI.
——, (1915-b) - Zur Tektonik des N-Etschbuchtgebirges: Verh. k. k. geol. R. Anst., 7, p. 135-138.
Scott, D. H. (1920) - Studies in fossil botany: Black Ltd, London.
Signorini, R. (1951) - Osservazioni sulla struttura e la morfologia delle dolomiti orientali: Boll. Soc. geol. It., v. LXX, fasc. 3, p. 545-564.
——, (1955) - Discutendo sulle interpretazioni tettoniche delle Dolomiti: Boll. Soc. geol. It., v. LXXIV, fasc. 1, p. 150-157.
Sitter, L. U. de (1939) - Les porphyres luganois et leurs enveloppes. l'Histoire géologique des alpes tessinoises entre Lugano et Varèse: Leidsche geol. med., XI, p. 1-61.
——, (1947) - Antithesis Alpes-Dinarides: Geol. & Mijnb. (Nwe ser) 9e jrg, no. 1.
——, (1954) - Gravitational gliding tectonics, an essay in comparative structural geology.: Am. Journ. Sci., vol. 252.
——, (1956-a) - Structural Geology: Mc Graw-Hill series, New York.
——, (1956-b) - A comparison between the Lombardy Alps and the Dolomites: Geol. & Mijnb. (Nwe Ser.), 18e jrg., p. 70-77.
Sitter, L. U. de, and de Sitter-Koomans, C. M. (1949) The Geology of the Bergamasc Alps, Lombardia, Italy: Leidsche geol. med., Deel XIV B.
Sonder, R. A. (1956) - Mechanik der Erde: Stuttgart.
Spitz, A. (1919-a) - Eine Querstörung bei Meran: Verh. k. k. geol. R. Anst., Wien, p. 62-66.
——, (1919-b) - Die Nonsberger Störungsbündel: Jhrb. geol. R. Anst., Wien, Bnd 69, p. 205-220.
Staub, R. (1926) - Südalpen und Dinariden: Ecl. geol. Helv. vol. XIX.
——, (1949) - Betrachtungen über den Bau der Südalpen: Ecl. geol. Helv., vol. 42, p. 215-408.
Tedesco, C. (1958) - Studio petrografico comparativo delle differenti facies di arenarie permiane delle Alpi Orientali: Studi e ricerche d. div. geomin. d. CNRN, vol. 1, 52 p.
Teichmüller, R. (1929) - Zur Frage des Alters der tektonische Bewegungen in den südlichen Kalkalpen: Zeitschr. Deut. geol. Ges., Berlin, 81, p. 381-410.
Trener, G. B. (1933) - Note illustrative della carta geologica delle Tre Venezie, foglio Trento: Uff. Idrogr., Padova.
Trevisan, L. (1936) - Nota preventiva sui risultati di un nuovo studio geologico del Gruppo di Brenta (Trentino occidentale) con particolare riguardo alla tettonica: Stud. Trent. di Sci. Nat., vol. XVII, fasc. 2.
——, (1939-a) - Il Gruppo di Brenta: Mem. Ist. geol. Univ. Padova.
——, (1939-b) - A Proposito di una recente monografia e carta geologica sul Gruppo di Brenta di J. Wiebols: Stud. Trent. Sci. Nat., vol. XX, Trento.
——, (1955) - Il Trias della Toscana e il problema del Verrucano triassico: Atti d. Soc. Tosc. di Sci. Nat., ser. A, vol. LXII, fasc. 1, Pisa.
Trümpy, R. (1955) - Wechselbeziehungen zwischen Palaeogeographie und Deckenbau: Vierteljschr. natf. Ges. Zürich, Jhrg. 100, p. 217-231.
——, (1958) - Remarks on the preorogenic history of the Alps: Geol. & Mijnb. (nwe Ser.), 20e jrg., p. 340-352.
Vacek, M. (1882) - Vorlage der geologischen Karte des Nonsberges: Verh. k. k. geol. R. Anst., Wien.
——, (1903) - Exkursion durch die Etschbucht: Führer IX. Int. geol. Kongresz, VI.
——, (1915) - Einige Bemerkungen zu Folgner's "Paganella-linie": Verh. k. k. geol. R. Anst., Wien, p. 138-139.
Vacek, M. und Hammer, W. (1911) - Erläuterungen zur geologischen Karte, Cles, nr. 79: K. k. geol. R. Anst., Wien.
Vardabasso, S. (1926) - Sulla tettonica della piattaforma porfirica atesina fra Bolzano e Trento: Atti d. Acc. Ven.-Trent.-Istr., vol. XVI, Padova, p. 51-60.
Vecchia, O. (1957) - Significato del fascio tettonico Giudicario-Atesino: Boll. Soc. geol. It., vol. LXXVI, fasc. 1, p. 81-135.
Vialli, V., (1938) - Note geologiche sul Monte Peller: Boll. Soc. geol. It., vol. LVII, fasc. 3, p. 293-330.

Wiebols, J. (1938) - Geologie der Brentagruppe: Jhrb. geol. B. Anst. Bnd 88, p. 261-350.

Wolff, F. von (1909) - Beiträge zur Petrographie und Geologie des Bozener Quarzporphyrs: N. Jhrb. Min., Beil. Bnd 27, p. 72-156.

Wunderlich, H. G. (1957-a) - Grenzfragen der saxonischen Tektonik Südniedersachsens: Zeitschr. Deut. geol. Ges., Bnd 109, p. 159-168.

——, (1957-b) - Brüche und Gräben im tektonischen Experiment: N. Jhrb. Geol. Pal. Min., 11, p. 477-498.

STELLINGEN

I

De midden-tertiaire tektonische bewegingen in het Val-di-Non gebied vormen de gravitatieve reactie op het opstijgen van een centraal-alpine geanticlinaal.

II

De knik die de Judicariënbreuk in de peri-adriatische sutuur vormt, moet worden opgevat als een aanpassing van deze sutuur aan een oude zwaktezone in de korst.
De opvatting van Kraus, de Sitter, Staub en Trevisan, die een sinistrale zijschuiving ('sinistral strike-slip faulting') langs de Judicariën- en Foianabreuken aannemen, wordt weersproken door de veldgegevens.

KRAUS, E., (1951) – Die Baugeschichte der Alpen: Akademie-Verlag, Berlin.
SITTER, L. U. de, (1956) – A comparison between the Lombardy Alps and the Dolomites: Geol. & Mijnb. (Nwe Ser.), 18e jrg., p. 70–77.
STAUB, R., (1949) – Betrachtungen über den Bau der Südalpen: Ecl. geol. Helv., vol 42, p. 215–408.
TREVISAN, L., (1939) – Il gruppo di Brenta: Mem. Ist. geol. R. Univ., Padova.

III

Het diaklaaspatroon in de permische formaties van de Dôme de Barrot (SE. Frankrijk) vertoont een symmetrie t.o.v. de plooiingsrichting van de sub-alpine ketens daar ter plaatse. Het bestaan van tangentiële en radiale systemen t.o.v. het centrum van de Dôme, zoals voorgestaan door Schuiling, wordt niet bevestigd door diens diaklaasdiagrammen.

SCHUILING, R. D., (1956) – Jointing in the Permian Dôme de Barrot, S. France: Geol. & Mijnb. (Nwe Ser.), 18e jrg, p. 227–234.
—— (1958) – Jointing in the Permian Dôme de Barrot; a reply: Geol. & Mijnb. (Nwe Ser.), 20e jrg., p. 353.
HILTEN, D. VAN, (1958) – Jointing in the Permian Dôme de Barrot, S. France; a discussion: Geol. & Mijnb. (Nwe Ser.) 20e jrg., p. 266–268.

IV

De samenstelling der boven-permische 'Val Gardena' zandstenen duidt erop dat zij de vulkano-tektonische depressie opvulden, die ontstond tijdens de afzetting van de onder-permische vulkanische serie.

TEDESCO, C., (1958) – Studio petrografico comparativo delle differenti facies di arenarie permiane delle Alpi orientali: Studie ricerche Div. geomin. d. CNRN, Roma, vol. I, 52 p.

V

Veldgeologische criteria zijn van doorslaggevende betekenis bij het vaststellen van het ignimbritische karakter van een effusieve serie.

VI

Metamorfe differentiatie speelt een voorname rol bij de vorming van anorthosieten en charnockieten.

VII

De afwijkende magnetisatierichting der permische gesteenten in de Zuid-Alpen maakt het waarschijnlijk dat dit deel van het orogeen grote translatieve en roterende bewegingen heeft meegemaakt.

VIII

Voor de theoretische verklaring van diaklaaspatronen verdient het aanbeveling na te gaan welke spanningsvelden zullen optreden in een sedimentair pakket dat, gravitatief afglijdend, geplooid wordt.

IX

Bij het ontstaan van submarine canyons wordt een belangrijke rol gespeeld door het plastisch vervloeien van de rand van het continentale 'basement' in de richting van de oceaan.

EVISON, F. F., (1960) – On the growth of continents by plastic flow under gravity: Geoph. Journ. roy. Astr. Soc., vol. 3/2, p. 155–190.

X

Het is nuttig de gesteentemonsters van instituutsverzamelingen met de Geiger-Müller teller te onderzoeken op hun gehalte aan radioactieve bestanddelen.

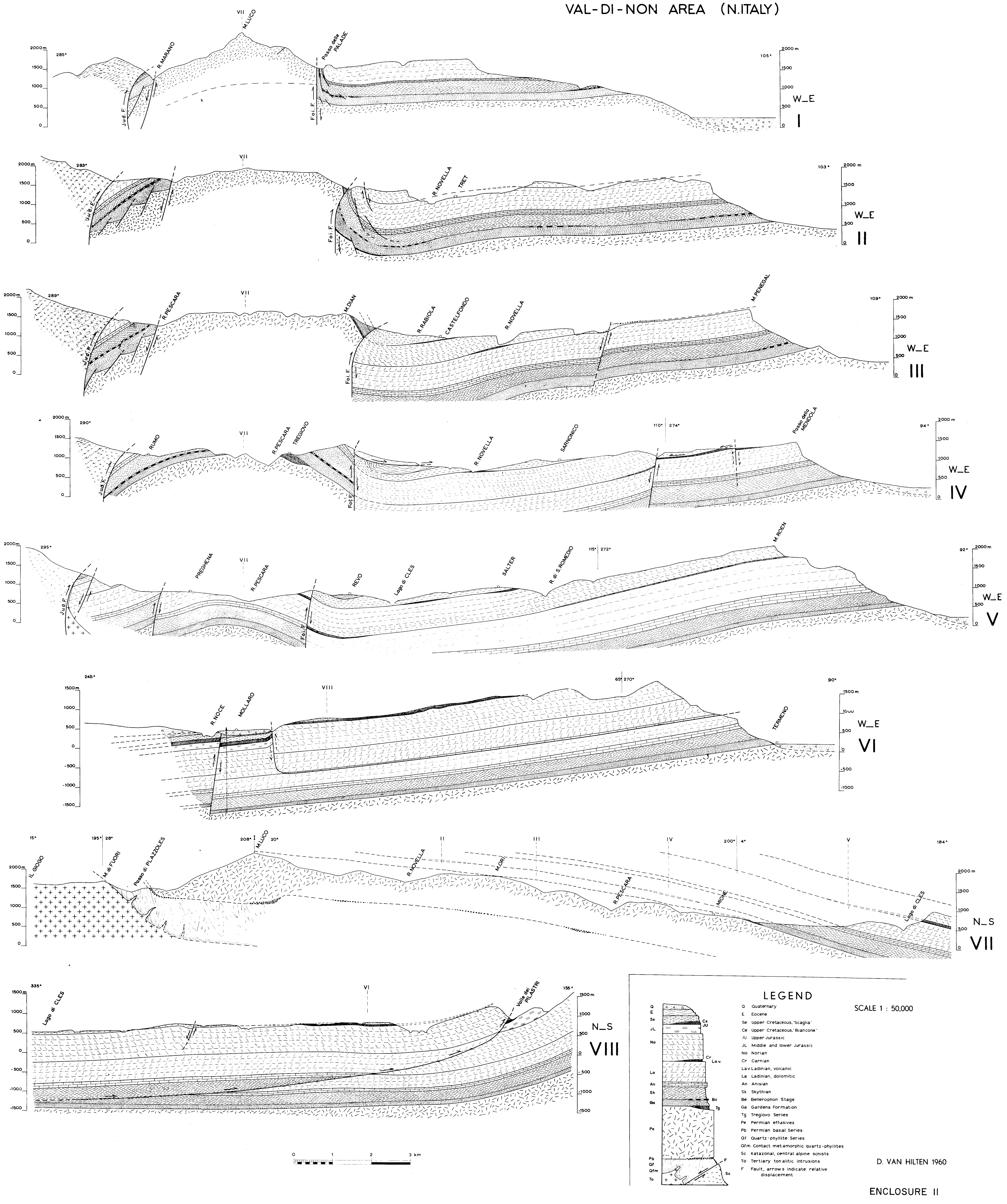
XI

Het feit dat de radio-ontvangst invloed ondervindt van structurele onregelmatigheden in de ondergrond, verdient grotere belangstelling van geophysische zijde.

CLOOS, E., (1934) – Auto radio – an aid in geologic mapping: Am. Journ. Sci., vol. XXVIII, p. 255–268.

D. van Hilten
21 november 1960

GEOLOGICAL SECTIONS I-VIII of the VAL-DI-NON AREA (N.ITALY)



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ENCLOSURE II


GEOLOGICAL MAP OF THE
VAL-DI-NON AREA (N. ITALY)
SCALE 1 : 50,000
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GEOLOGICAL SKETCH MAP OF THE JUDICARIA REGION
Scale 1 : 1,000,000
Main fault lines
Tertiary tonalitic intrusions
Mesozoic and younger sediments
Permian effusives
Crystalline schists (epizonal)
Crystalline schists (mesozonal)
Crystalline schists (katazonal)
OUTLINE MAP OF N. ITALY
Scale 1 : 4,360,000
Area covered by geological map
Area covered by geological sketchmap of the Judicaria region
LEGEND
a) Town, village
b) Road
c) River
d) Lake
e) Drilling well
f) Elevation in M's
Area covered by detail map A
Section I
Dip and strike symbols of strata or schistosity
0° - 3°
4° - 9°
10° - 29°
30° - 49°
50° - 69°
70° - 89°
90°
Overturned
Formational boundary
a) known
b) uncertain; covered by quaternary deposits
FAULTS
Fault, dipping 80°, barbs on downthrown side
Fault with mainly horizontal relative displacement
Overthrust, reverse fault with direction of relative displacement of upper block
Fault, concealed
Sub-recent collapse structure
Quaternary; alluvial and morainic deposits
Tertiary tonalite of the M. Croce and along the Judicaria fault
Eocene
Upper Cretaceous, Scaglia
Upper Cretaceous, Biancone
Upper Jurassic, Ammonitico rosso
Middle and Lower Jurassic
Rhaetian
Norian
Carnian
Ladinian volcanic dolomitic
Anisian
Skythian
Bellerophon stage
Gardena formation
Tregiovo series
Effusive system
Basal series
Epizonal quartz-phyllites
Contact metamorphic quartz-phyllites
Mesozonal schists
Katazonal schists
Long. E. of Greenwich
S. Pancrazio
VAL D'ULTIMO
Plazzoles
Tésimo
Prisciano
Nalles
TERLANO
Senale
Tret
Castelfondo
Lauregno
Proves
Rumo
Tregiovo
Mione
FONDO
Bréz
Cloz
Sarnonico
Ruffré
Preghena
Bévia
Cagno
Romallo
Romeno
REVO
Banco
Sanzéno
CLES
LAGO DI CLES
COREDO
Rallo
Dermulo
Sfruz
Taio
Trés
Vervo
Mollaro
Prio
Vigo
Caldaro
S. Paolo
Termeno
Corona
Cortaccia
Magrè
Passo della Mendola
M. Penegal
M. Macaión
Monte Roèn
Corno di Tres
M. d'Arza
M. Pietro
Monte Vicale
M. di Fuori
Monte Ori
M. Dian
M. Ori
M. Ozol
Monte Pin
M. Cornicolo
Vedetta Alta
MONTE LUCO
Passo del Palade
Passo di Castrin
ALLUVIAL PLAIN OF THE ADIGE RIVER
ADIGE
Lago di Caldaro
Rio Novella
Rio di S. Romedio
Rio di Verdes
Rio Noce
Rio Pescara
Rio Barnes
Rio di Lavazze
Rio Campo
Valle dei Pilastri

ENCLOSURE I