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Triassic diapiric structures in the central Dolomites (northern Italy)

By CARLO DOGLIONI[1])

ABSTRACT

Diapiric structures, emplaced during the Middle Triassic, occur in the central Dolomites. They are formed by the Late Permian evaporitic Bellerophon Formation and are elongated along a N70E axis, parallel to the Ladinian carbonate platform of the Costabella massif. The overlying sequences were uplifted, eroded and truncated by penecontemporaneous or only slightly younger thrusts. The diapiric highs were also the source areas of the submarine mass-flow deposits of the Caotico eterogeneo, the basal unit of the Ladinian volcanoclastics in the Dolomites. The diapiric anticlines have been caused by Middle Triassic compressional tectonics, which might have been related to sinistral transpressive movements.

RIASSUNTO

Nel Trias medio, nelle Dolomiti centrali, si sono formate delle strutture diapiriche. Esse hanno al nucleo la facies evaporitica della Formazione a Bellerophon (Permiano superiore). Le strutture sono per lo più disposte lungo un allineamento N70E, parallelamente alla piattaforma carbonatica ladinica del massiccio della Costabella. Le formazioni sovrastanti sono state sollevate dalla risalita diapirica, impostatasi al limite di facies piattaforma carbonatica-bacino. Le aree innalzate sono state erose sempre in epoca ladinica, contribuendo ad alimentare le frane sottomarine del Caotico eterogeneo, livello basale della serie vulcanoclastica ladino-carnica dolomitica. Gli alti diapirici sono stati troncati da coevi sovrascorrimenti, divergenti dal massiccio della Costabella. Le anticlinali diapiriche sono state generate da tettonica compressiva medio-triassica, forse prodotta da fenomeni transpressivi sinistri.

Introduction

The present paper reports on the occurrence of diapirs and diapiric anticlines emplaced during the Middle Triassic in the central Dolomites. The source of these structures that pierce through the overlying sediments, is the Late Permian evaporitic Bellerophon Formation, which is composed of gypsum, dark shales, mudstones, marls, black limestones and vuggy dolomites ("fiammazza facies", Fig. 1). ROSSI (1962) was one of the first to infer a diapiric origin of the peculiar anticline at the upper end of the S. Nicolò Valley, where in the core of the fold no formation older than the Bellerophon Formation occurs. Later ENGELEN (1963) described some diapiric anticlines from the Dolomites which he interpreted as being caused by Pliocene gravity gliding of huge Triassic carbonate masses as a consequence of their lateral erosion and topographic

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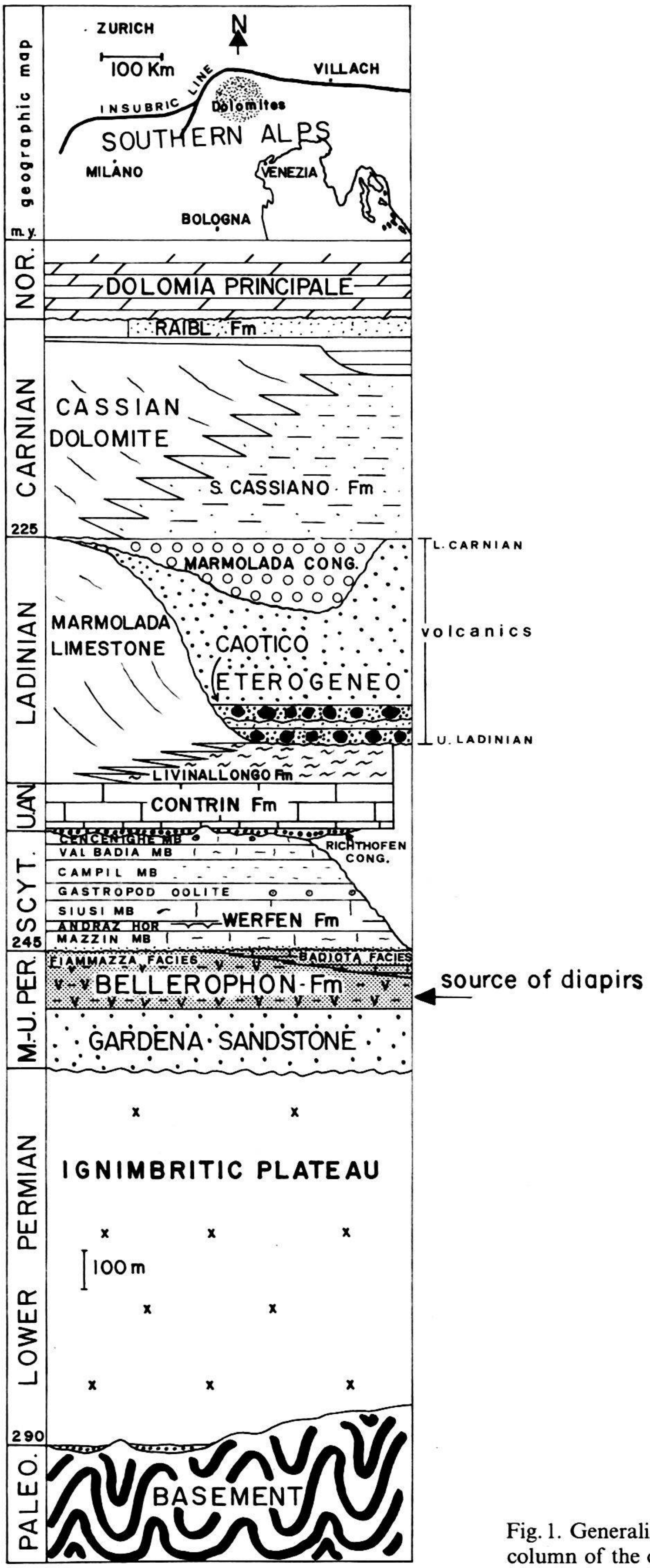


Fig. 1. Generalized Triassic and pre-Triassic stratigraphic column of the central Dolomites.

isolation. LEONARDI (1963, 1967) also accepted the presence of diapiric structures and ROSSI (1977) subsequently noted that the folds of the S. Nicolò anticline are cross-cut by Middle Triassic volcanic dikes. Recently CASTELLARIN et al. (1982) interpreted this structure as a product of the compressional tectonics that affected the Dolomites in Ladinian time. DOGLIONI (1983) mentioned the presence of a series of diapiric structures along an N70E-trending lineament that was probably associated with crustal doming of the central Dolomites during the initial phases of Ladinian volcanism (Fig. 21). Here an attempt is made to reconstruct the formation of these diapiric structures and to interpret their regional geologic significance.

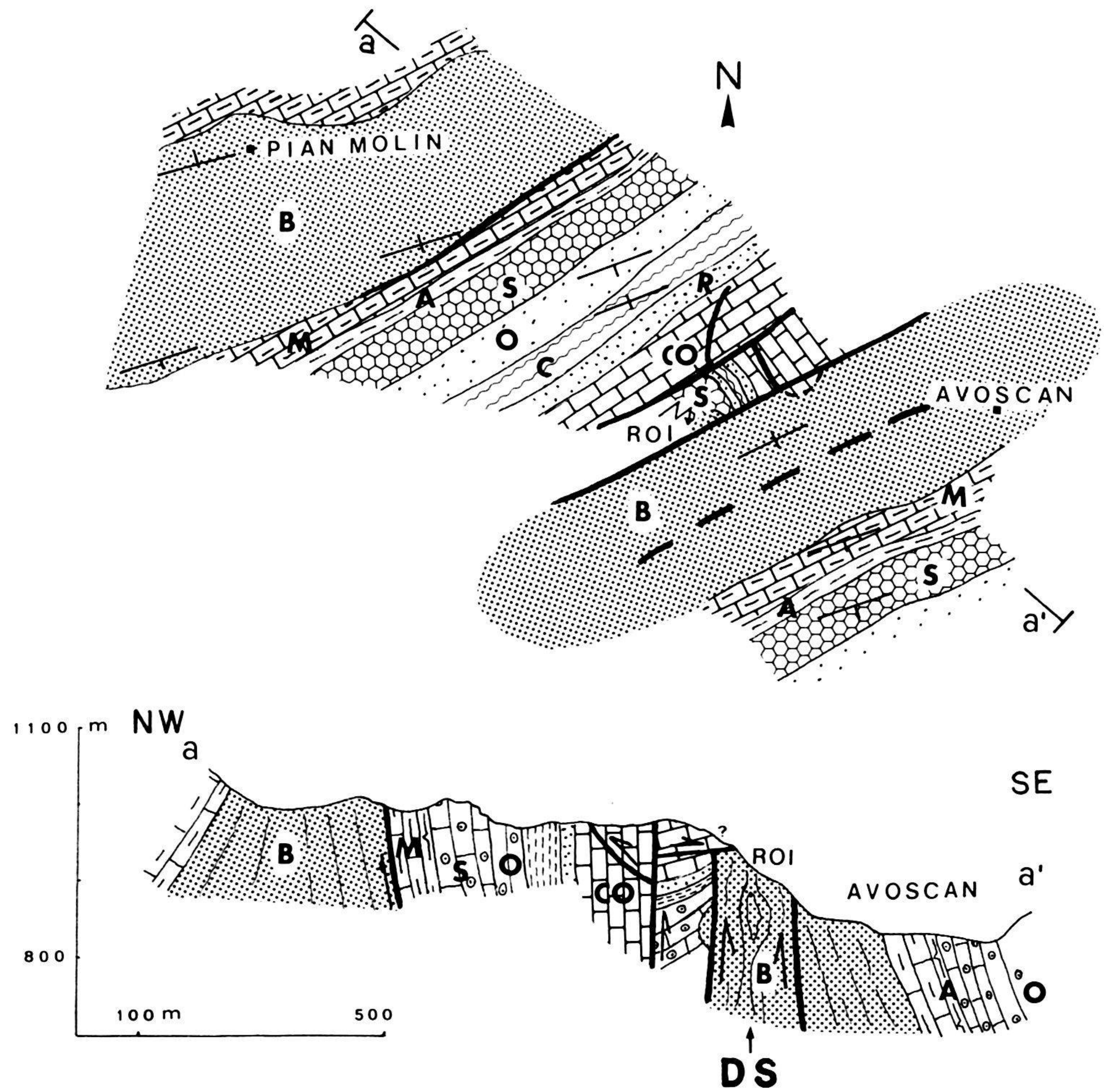


Fig. 2. Geologic map and section of the diapiric anticline of Avoscan. DS: diapiric structure; B: Bellerophon Formation; Werfen Formation: M: Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member; R: Richthofen Conglomerate; CO: Contrin Formation.

Local description of the structures

1. *The Avoscan diapiric structure*

The geologic map (Fig. 2) illustrates that tight N70E-trending folds with approximately vertical axial planes dominate the structural framework of this zone. The Bellerophon Formation, which is here predominantly composed of dark shales and marls, constitutes the cores of the anticlines. The underlying Val Gardena Sandstone is not involved in the folding. At Roi, near Avoscan, the Bellerophon Formation pierces through the overlying sedimentary sequence and propagates upward through the nucleus of the anticline. The outcrop of the Bellerophon Formation illustrated in Figure 3, shows to the left (N) a subvertical, disconformable contact with various members of the Werfen Formation and with the Contrin Formation. In the centre, blocks of limestones and vuggy dolomites are present which have been folded and disrupted by the diapiric transport (Fig. 4); the strata are subvertical with a steep (80°) inclination to the left (N) and the right (S). The southern sector of the diapir presents a less sharp intraformational contact with the adjacent non evaporitic part of the Bellerophon Formation ("badiota facies"). Gypsum occurs here only rarely, but it is unclear whether this is due to a primary lack or to tectonic removal. The diapiric contact to the left (Fig. 5) consists of a distinct, undulate N70E-trending plane with vertical striations on N70E-trending planes. The central part of the diapiric anticline exhibits horizonal striations an N70E-trending planes. The shales involved in the folding display cleavage. Folds and minor faults with a prevailing orientation around N70E are present in the Werfen Formation to the south, where considerable tectonic complications can be noted, which are probably related to strike-slip movements. The age of the diapiric

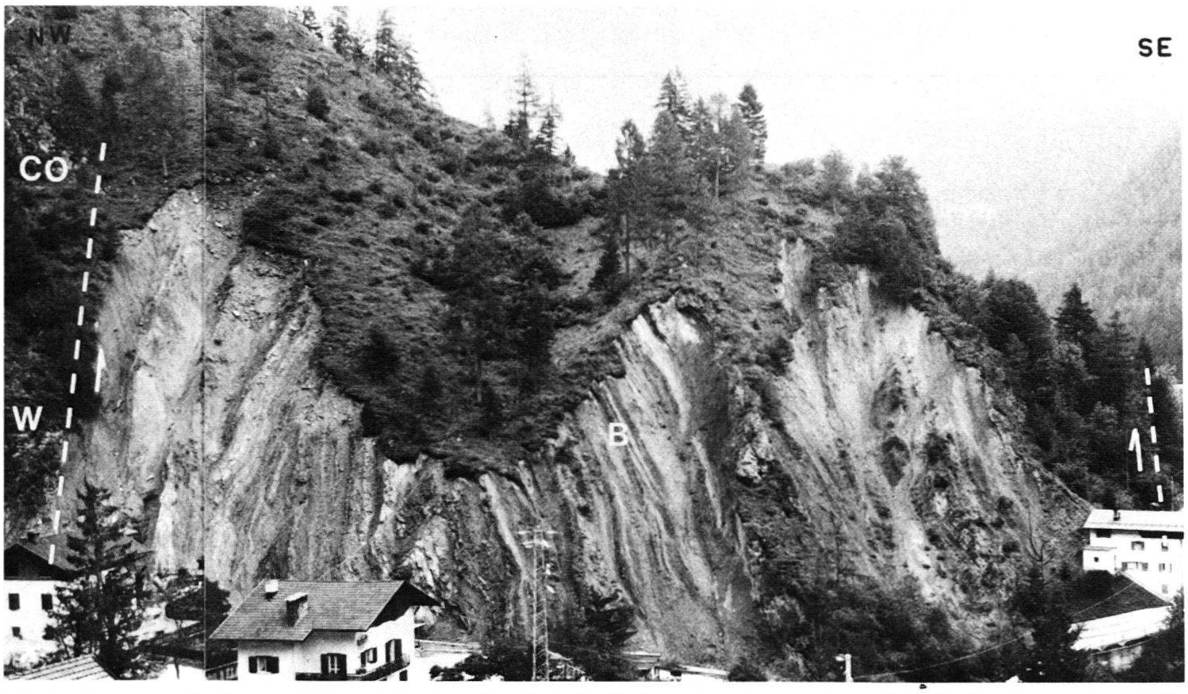


Fig. 3. Avoscan diapiric anticline at the locality Roi. B: Bellerophon Formation; W: Werfen Formation; CO: Contrin Formation. For description see text.

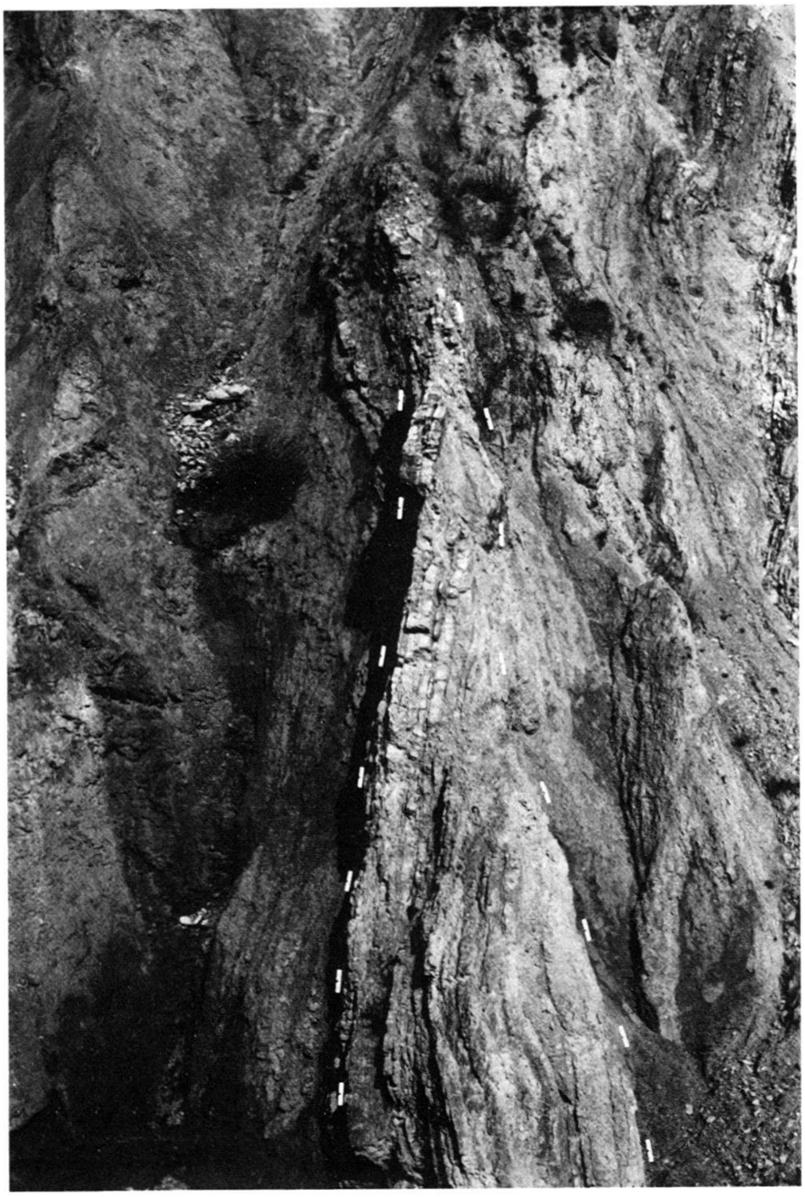


Fig. 4. Block of disrupted limestones and marls within the shale and mudstones of the Bellerophon Formation. Avoscan diapiric structure, Roi.

structure cannot be determined reliably. It could be Middle Triassic in view of analogies with adjacent diapiric structures, whose description follows and which are certainly of Middle Triassic age.

2. *The Col Becher diapiric structure*

It is clearly visible from Pizzo Forca (Fig. 6) that the Col Becher presents one of the most outstanding structures of the Dolomites. The exposure allows to distinguish at least three Middle Triassic tectonic phases:

1. An Anisian phase: a normal fault displaces the Werfen Formation which has been subsequently eroded and covered unconformably by the Upper Anisian Richthofen Conglomerate.

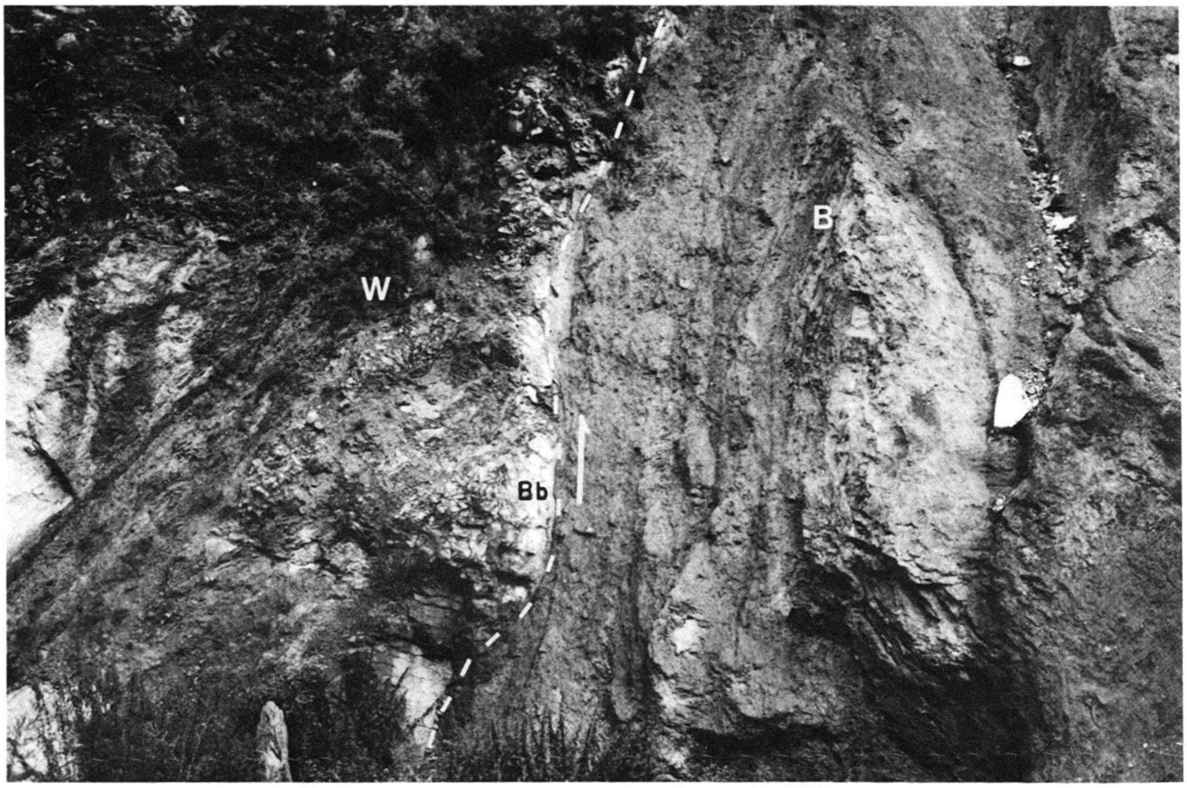
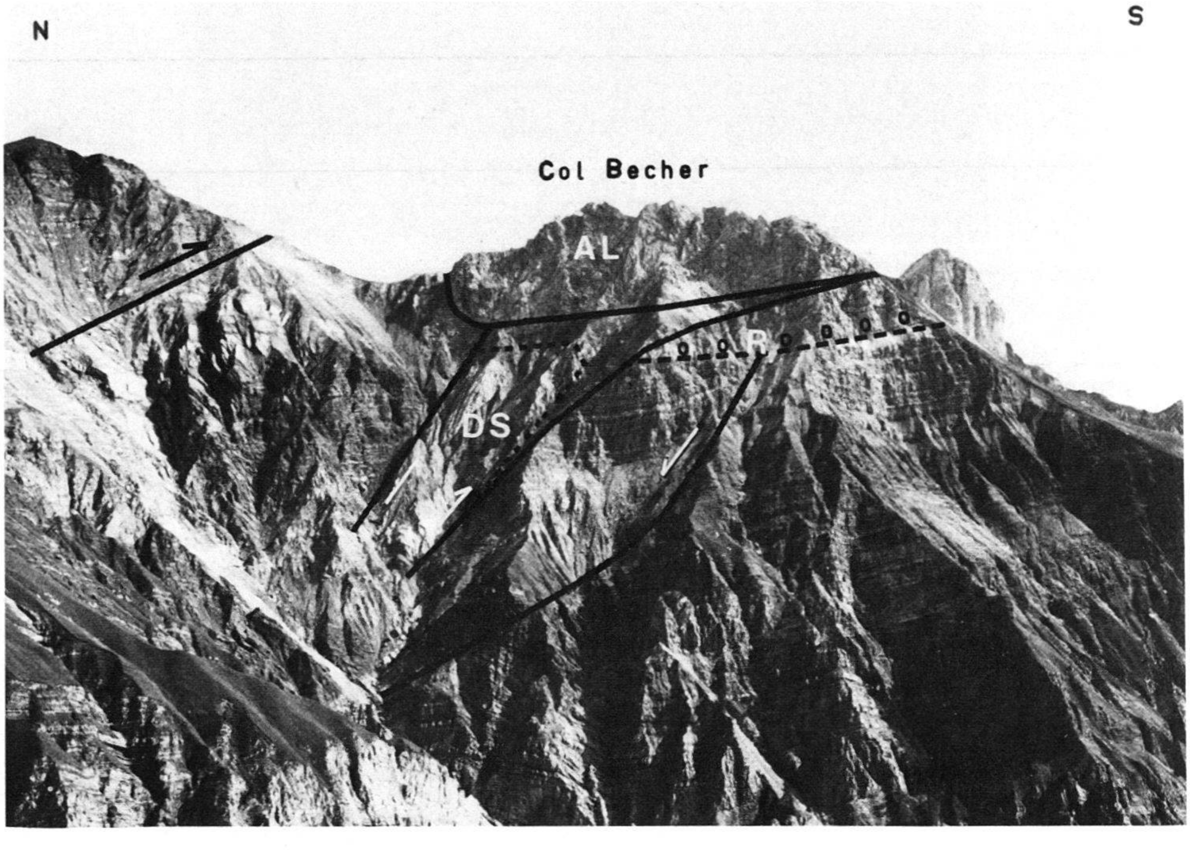


Fig. 5. Diapiric contact of the Avoscan diapiric structure at the locality Roi. Block of the "badiota" facies of the Bellerophon Formation Bb, which was tectonically emplaced between the Werfen Formation W and the evaporitic Bellerophon Formation B.



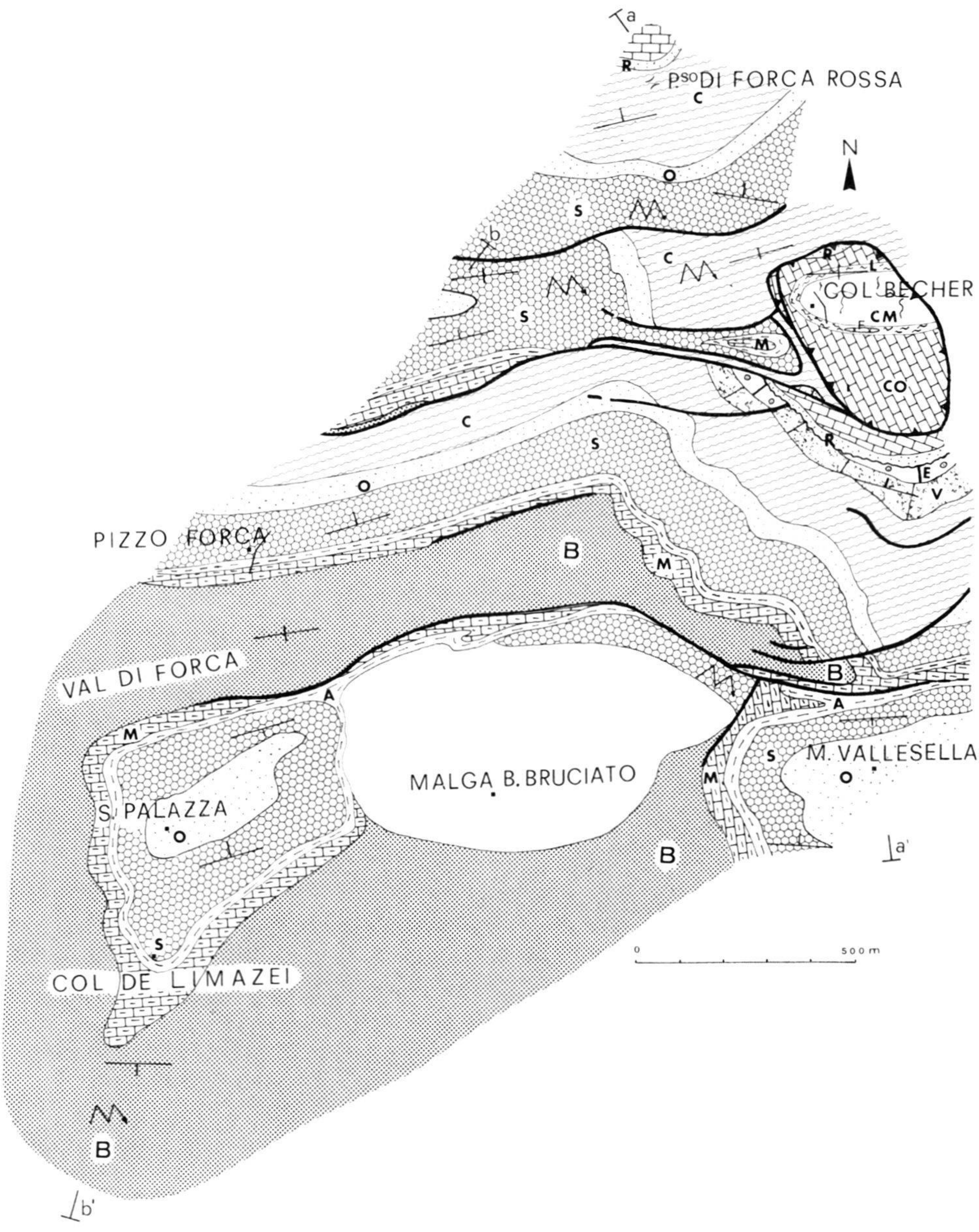


Fig. 7. Geologic map of the diapiric structures of Col Becher, Vallesella, Val di Forca and Col de Limazei. B: Bellerophon Formation; Werfen Formation: M: Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member, V: Val Badia Member, E: Cencenighe Member; R: Richthofen Conglomerate; CO: Contrin Formation; L: Livinallongo Formation; CM: Marmolada Limestone; F: latitic-basaltic dike.

Fig. 6. Col Becher seen from Pizzo Forca. The late diapiric structure (DS) has been truncated by an allochthonous carbonate block (AL). The Upper Anisian Richthofen Conglomerate (R) fossilizes an extensional Anisian fault. For a detailed illustration see geologic section of Figure 8.

2. A first Ladinian phase: a thrust which evolves into a diapiric structure, piercing through the Lower Triassic and Anisian series and dragging upward fragments of the Werfen Formation like a "cap rock".
3. A second Ladinian phase: the diapiric structure, whose top had been eroded, has been overthrusted by an allochthonous block of Anisian–Ladinian limestones and dolomites (Contrin Formation, Livinallongo Formation, Marmolada Limestone) forming the summit of the Col Becher.

In contrast to other diapiric structures, the Bellerophon Formation does not constitute the visible core of the piercing structure (Fig. 7–8). This formation here must be presumed to lie below the exposed Mazzin Member, the basal member of the Werfen Formation. The Andraz Horizon has been severly deformed in the core of the diapiric anticline. The allochthonous carbonate block on the summit of the Col Becher is

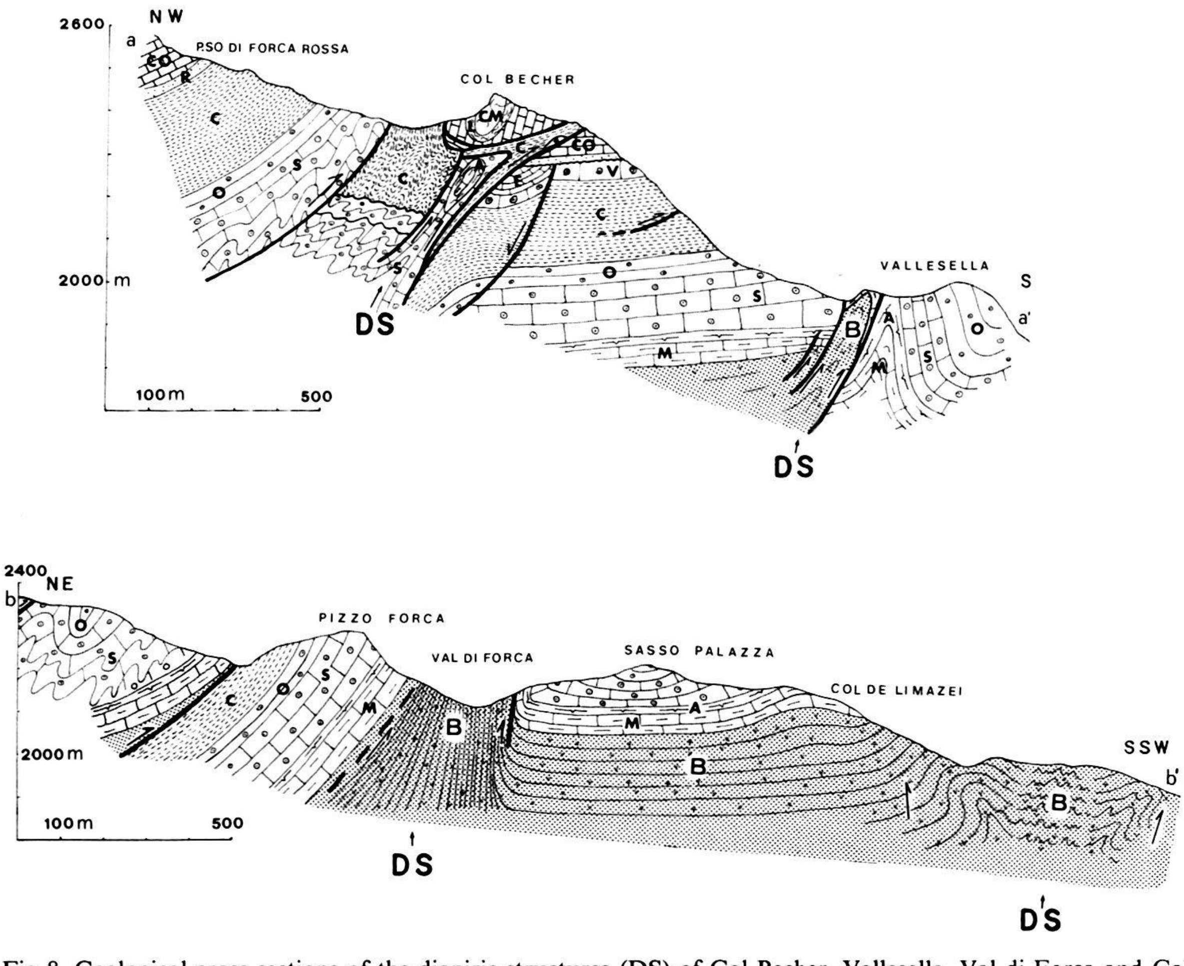


Fig. 8. Geological cross sections of the diapiric structures (DS) of Col Becher, Vallesella, Val di Forca and Col de Limazei. In the Col Becher structure there is more than one tectonic phase observable: 1. An Anisian extensional fault is sutured by the Richthofen Conglomerate. 2. A Ladinian piercement of the not outcropping Bellerophon Formation (which, however, is presumed to occur little below) has been truncated 3, by the penecontemporaneous thrust of the carbonate block of the summit of Col Becher. A subsequent thrust (to the left) deformed this thrust. B: Bellerophon Formation; Werfen Formation: M: Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member, V: Val Badia Member, E: Cencenighe Member; R: Richthofen Conglomerate; CO: Contrin Formation; L: Livinallongo Formation; CM: Marmolada Limestone

strongly fractured and forms a syncline with a truncated base that disconformably rests upon the tectonized Werfen Formation. It is visible that the associated thrust cuts through an older fault related to the emplacement of the diapir (Fig. 7–8). The carbonate block was cut by a volcanic dike which perhaps cuts the underlying thrust as well. The diapiric structure, the associated folds as well as those in the allochthonous carbonate block have axial trends ranging between N70E to N100E. The Late Anisian and Early Ladinian sequence of the Col Becher shows close similarities to that of the Cima dell'Auta immediately east of it. This massif might also have been moderately detached from its original position and could represent an allochthonous mass above a tectonized Werfen Formation. The thrust to the extreme left (N) of Figure 8 is probably of a later age and has deformed the basal tectonic contact of the Col Becher allochthon along its northern sector. Along the southern flanc of the exposure, a minor thrust affects the Campil Member which here has a considerable thickness. Aerial photographs reveal that this structure tends to accentuate to the east, where it cuts the Middle Triassic volcanics of the Piz Zorlet. This fault could thus be of latest Middle Triassic or of Alpine age, it must, however, be younger than the Middle Triassic volcanics which in turn unconformably cover strongly tectonized and eroded terranes. The orientation of the Col Becher diapir, which lies in the continuation of the structure of Passo delle Selle and which is parallel to the coeval structure of S. Nicolò, suggests a Middle Triassic age also for this structure. Its similarities with other structures, e.g. the truncation by allochthonous thrust masses, seems to confirm this interpretation. The faults limiting the diapir confine blocks with different Anisian erosion, and might therefore be Anisian faults which were reactivated during the Ladinian.

3. *The Vallesella diapiric structure*

Similar to the diapiric structure of the Col Becher, the Vallesella diapir is genetically connected with a thrust (Fig. 7–8). Here it is clearly visible that the Bellerophon Formation pierces through the overlying strata and has dragged upward a block of the Werfen Formation (Fig. 9). This structure is situated on the general N70E alignment of diapirs.

4. *The Val di Forca diapiric structure*

This structure constitutes the western continuation of the Vallesella structure (Fig. 7–8) and is associated with the same thrust (Fig. 10). On the saddle, to the south of Pizzo Forca, the Bellerophon Formation pierces through the adjacent series. Striations indicate upward-directed diapiric movements. This structure is located on the N70E alignment of diapirs and displays bulges perhaps generated by a greater diapiric accumulation.

5. *The Col de Limazei diapiric structure*

Some hundreds of meters to the south of Sasso Palazza, to the east of Rifugio Flora Alpina, there is a diapiric anticline with a double vergence (Fig. 8). The Bellerophon Formation is rich in gypsum here and exhibits N70E-trending folds with amplitudes

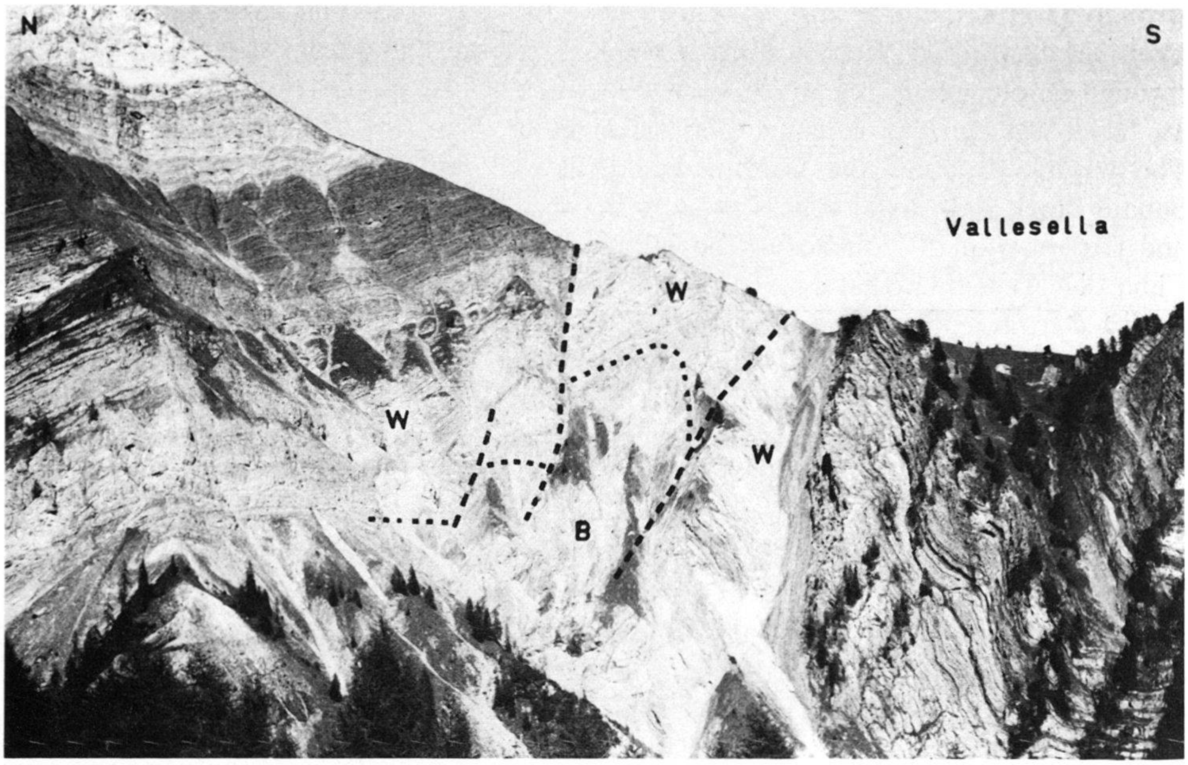


Fig. 9. The diapiric structure of Vallesella seen from Malga Bosco Bruciato. B: Bellerophon Formation; W: Werfen Formation.

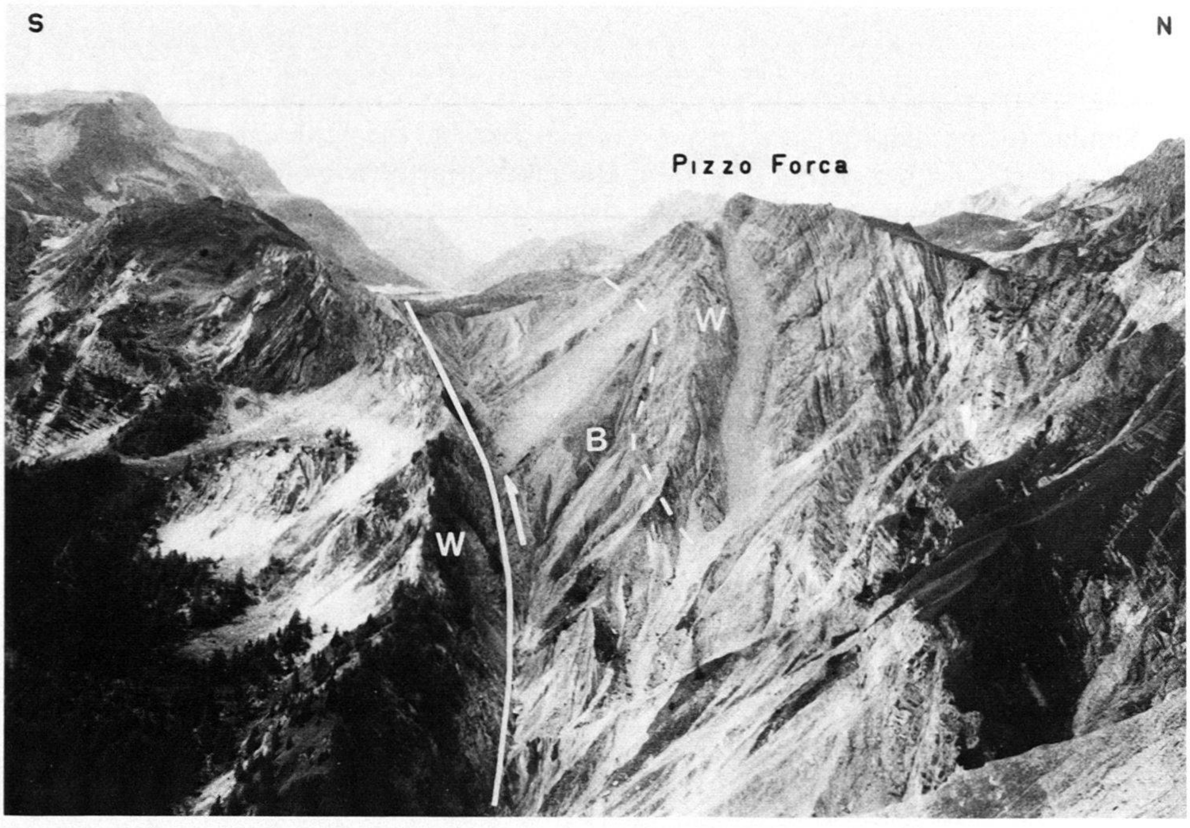


Fig. 10. The diapiric anticline of Val di Forca, seen from Col Becher.
Note the thickness of the Bellerophon Formation (B). Werfen Formation (W).

Fig. 11. Nothern part of the Col the Limazei structure seen from the vicinity of Malga Bosco Bruciato. Note the folds at the center of the figure contrasting with the disorganized structure to the left. White strata are gypsum-rich.

around 20–30 m. Along the margin of the structure, their axial planes dip at the angle of 35° toward the core of the structure. The core displays a chaotic structure with innumerous folds with amplitudes of about 1 m (Fig. 11). Outside the core, e.g. below Sasso Palazza, the Bellerophon Formation has a very regular strike and dip. The Col de Limazei structure is of particular importance because it is situated along the continuation of the structural depression which occurs in the centre of the Triassic Cima Bocche anticline at the San Pellegrino Pass, and which has also a N70E-orientation. This relationship with the Cima Bocche anticline in which also pre-Upper Permian rocks are involved indicates in turn a (still poorly understood) connection between the diapirs and basement deformation.

6. *The Passo delle Selle diapiric structure*

The outstanding feature of this structure is its fossilization by contact metamorphism caused by the Middle Triassic Monzoni intrusion (Fig. 12). As a result of the metamorphic alteration, the formations are difficult to distinguish, but contact metamorphism proves the Middle Triassic age of the structure. It is located on the western continuation (along the N70E-axis) of the above mentioned diapirs and immediately to the north of the Cima Bocche anticline. After extensive erosion, all we can see today is what probably was the northern sector of a structure, whose nature, either a diapir or a diapiric anticline (no piercement of the overlying strata is visible), cannot be deter-

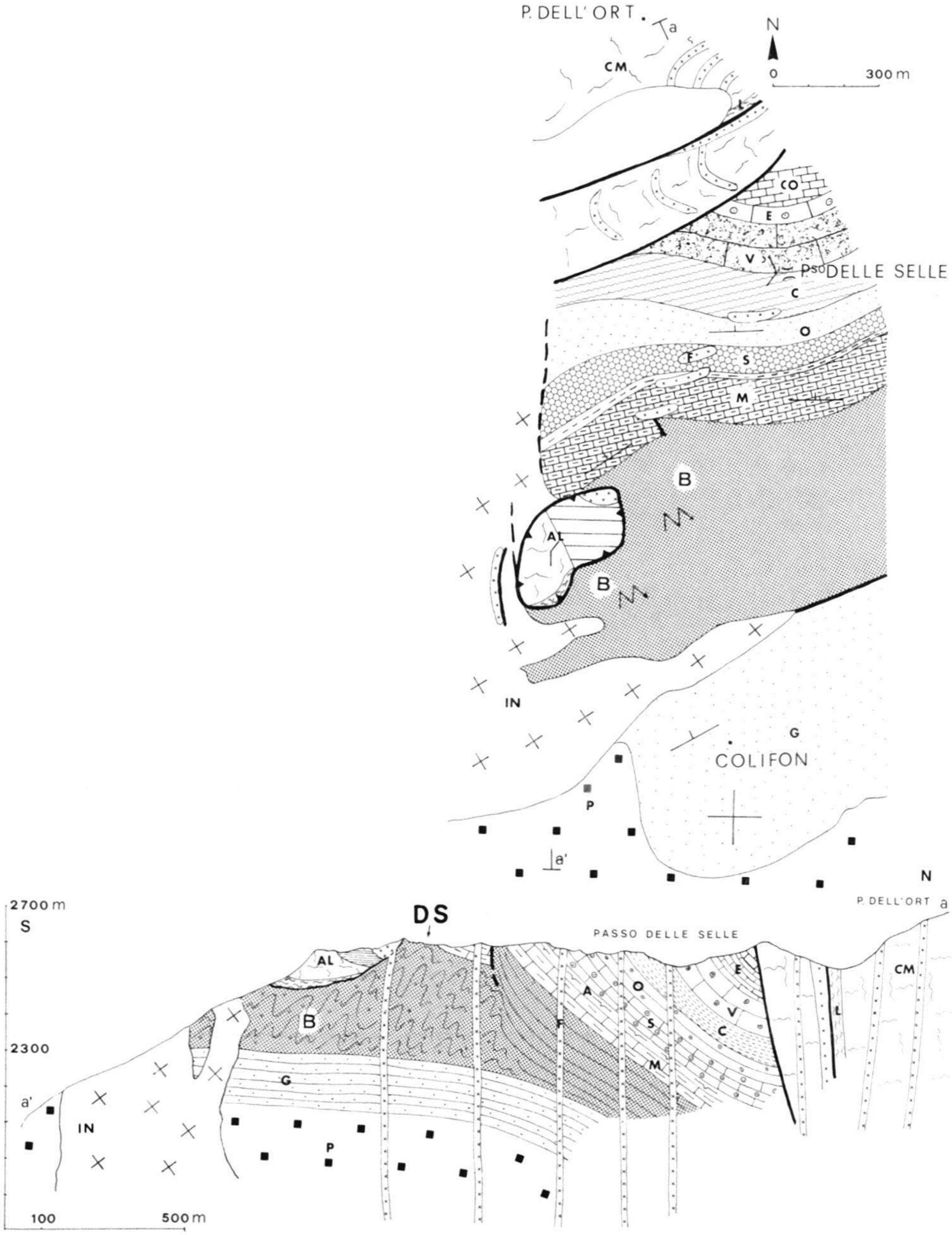


Fig. 12. Geologic map and cross section of the Passo delle Selle diapiric anticline. P: Permian volcanics; G: Val Gardena Sandstone; B: Bellerophon Formation; Werfen Formation: M: Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member, V: Val Badia Member, E: Cencenighe Member; CO: Contrin Formation; L: Livinallongo Formation; CM: Marmolada Limestone; AL: allochthonous Ladinian(?) limestones and dolomites; F: latitic-basaltic dikes; IN: Monzonitic intrusion; DS: diapiric structure.

mined. In any case we can observe an abnormal accumulation of gypsum and greyish-black mudstones outcropping with numerous folds. This accumulation seems to have caused a monocline and small-scale folds and faults in the overlying Werfen Formation, which subsequently became metamorphosed by the intrusion. The Middle Triassic volcanic dikes of Passo delle Selle cut these preexistent structures.

Another important feature is the presence of an outlier of limestones resting on the top of the truncated diapir, very similar to the structures of Col Becher, Pecol and Passo San Nicolò. This limestone block (which is probably a block of Marmolada Limestone, because of the occurrence of nodular limestones similar to those of the Livinallongo Formation at its base) is considerably altered by metamorphism and rests unconformably on the upward sqeezed Permian evaporites of the Bellerophon Formation. The emplacement of this outlier seems to be of Ladinian age because it has been metamorphosed by the monzonite intrusion. The structure seems to be limited by N70E-trending faults, which were intruded by the monzonites and associated subvolcanic dikes. Along the Selle line (VARDABASSO 1930) a dike intruded parallel to the vertical Livinallongo Formation and suggests a prevolcanic strike-slip fault.

7. *The Forno diapiric structure*

This structure, some tens of meters wide, is formed by a diapiric core of Bellerophon Formation, which pierces through Ladinian volcanic resediments along the northeastern margin of the structure and through latitic-basaltic lavas along the southern margin (Fig. 13). The northeastern flanc of the diapir seems to be cut by a

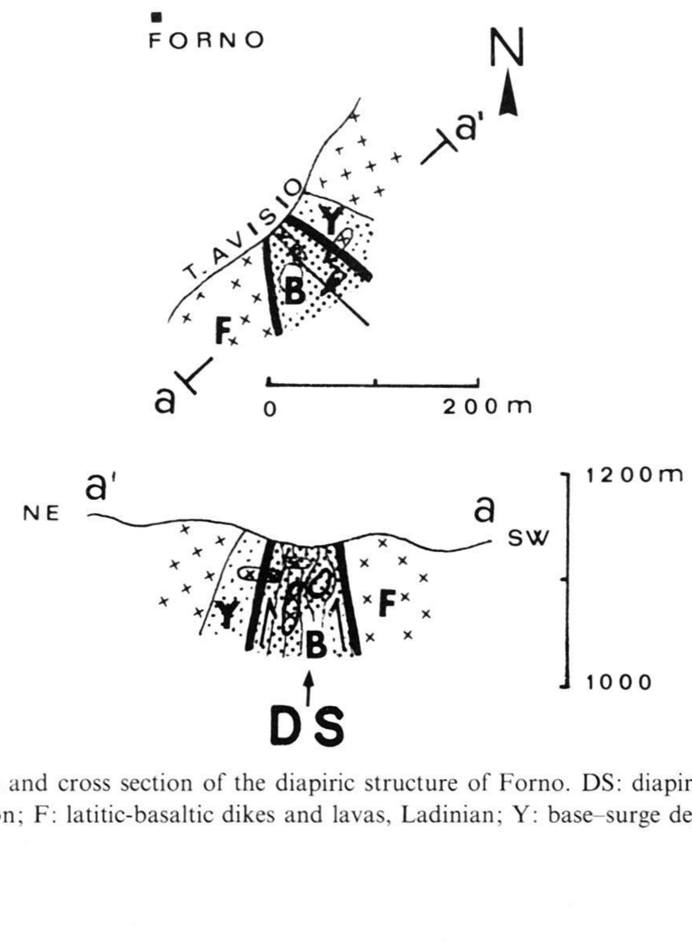


Fig. 13. Geologic map and cross section of the diapiric structure of Forno. DS: diapiric structure, B: Bellerophon Formation; F: latitic-basaltic dikes and lavas, Ladinian; Y: base–surge deposits, Ladinian.

dike which subsequently has been displaced towards the interior of the diapir indicating several phases of diapiric rise. A disrupted and strongly tectonized block of limestones is included in the mudstones and marls of the Bellerophon Formation at its southwestern flanc. Gypsum occurs here only rarely. The southwestern contact is particularly tectonized. The only fold which is visible within the Bellerophon Formation has a N100E-trending axis. This structure is again situated along the N70E alignment of diapiric structures and parallels the eastern continuation of the Stava line. The faults confining the structure, however, have a different orientation (N60W and N5W). My attention has been drawn on this tructure by A. Castellarin and P. L. Rossi.

8. *The Pecol diapiric structure*

Already Vardabasso (1930) and Rossi (1962) have mapped this structure, which is situated on the southern flanc of the S. Nicolò Valley (Fig. 14). A particularity of this structure is its truncated top, caused by the northward thrust of the Ladinian carbonates of the Costabella. The vertical core of the Permian evaporites, confined by N70E-trending faults, pierces through the overlying Werfen Formation. Here, the Bellerophon Formation is poor in gypsum. Volcanic dikes parallel to the flancs of the diapir suggest deep-seated tectonic fractures in the basement causing magma extrusion and triggering the rise of the diapir.

9. *The S. Nicolò diapiric structure*

This spectacular, complicated structure is certainly one of the most crucial outcrops as far as the Middle Triassic stratigraphy and tectonics of the Dolomites are concerned. As mentioned above, this structure has been the aim of various studies. The recent one of Castellarin et al. (1982) analyzed it in detail. For this reason only some field data are added here. The diapiric structure is situated on the N70E-alignment of diapiric structures and shows two separate zones of Bellerophon Formation divided by a central zone of Werfen Formation (Fig. 19). The two outer margins of the structure display opposite vergences. At various localities the structure pierces through the overlying sequence (Fig. 15). The "fiammazza facies", which is here composed of abundant gypsum, pierces also through the "badiota facies" of the same formation. The diapiric extrusion of material to the north is very pronounced. In the associated folds the mudstones exhibit fracture cleavage and schistosity by plastic flow of gypsum with local accumulations in the hinge zone (Fig. 16). Axial planes have trends between N50E and N70E and are inclined at angles of 40–60° to the south (Fig. 17). Below the Varos, the northern limb of the diapiric anticline overrides the Werfen Formation (Fig. 18). The southern margin shows a nearly vertical contact with the adjacent sequences. Folds with N70E-axes and axial planes dipping at an angle of 50° to the north are exposed at 300 m to the south of Passo di San Nicolò. The southern margin of the S. Nicolò structure joins with the complicated Vernadais structure to the northeast (Fig. 15), where also the two separated zones of evaporites of the diapiric anticline meet. An essential feature of the diapir is its distinct Ladinian erosional surface in the top (Sasso di Rocca, Varos) which cuts through the different members of the Werfen Formation, the Richthofen Conglomerate and the Contrin Formation, and which is

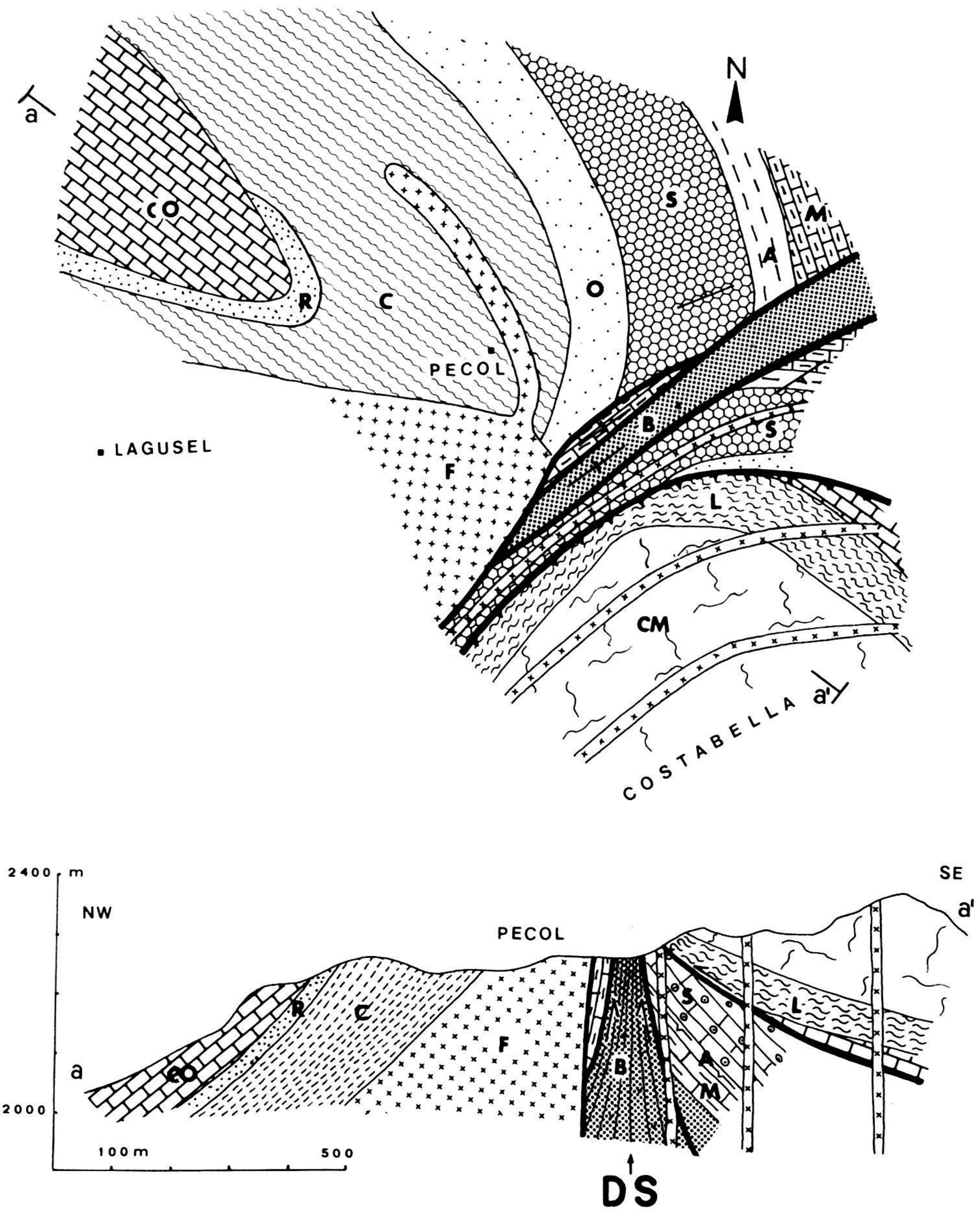


Fig. 14. Geologic map and cross section of the diapiric structure of Pecol. DS: diapiric structure; B: Bellerophon Formation; Werfen Formation: M. Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member; R: Richthofen Conglomerate; CO: Contrin Formation and Morbiac Limestone; L: Livinallongo Formation; CM: Marmolada Limestone; F: latitic-basaltic dikes and sill.

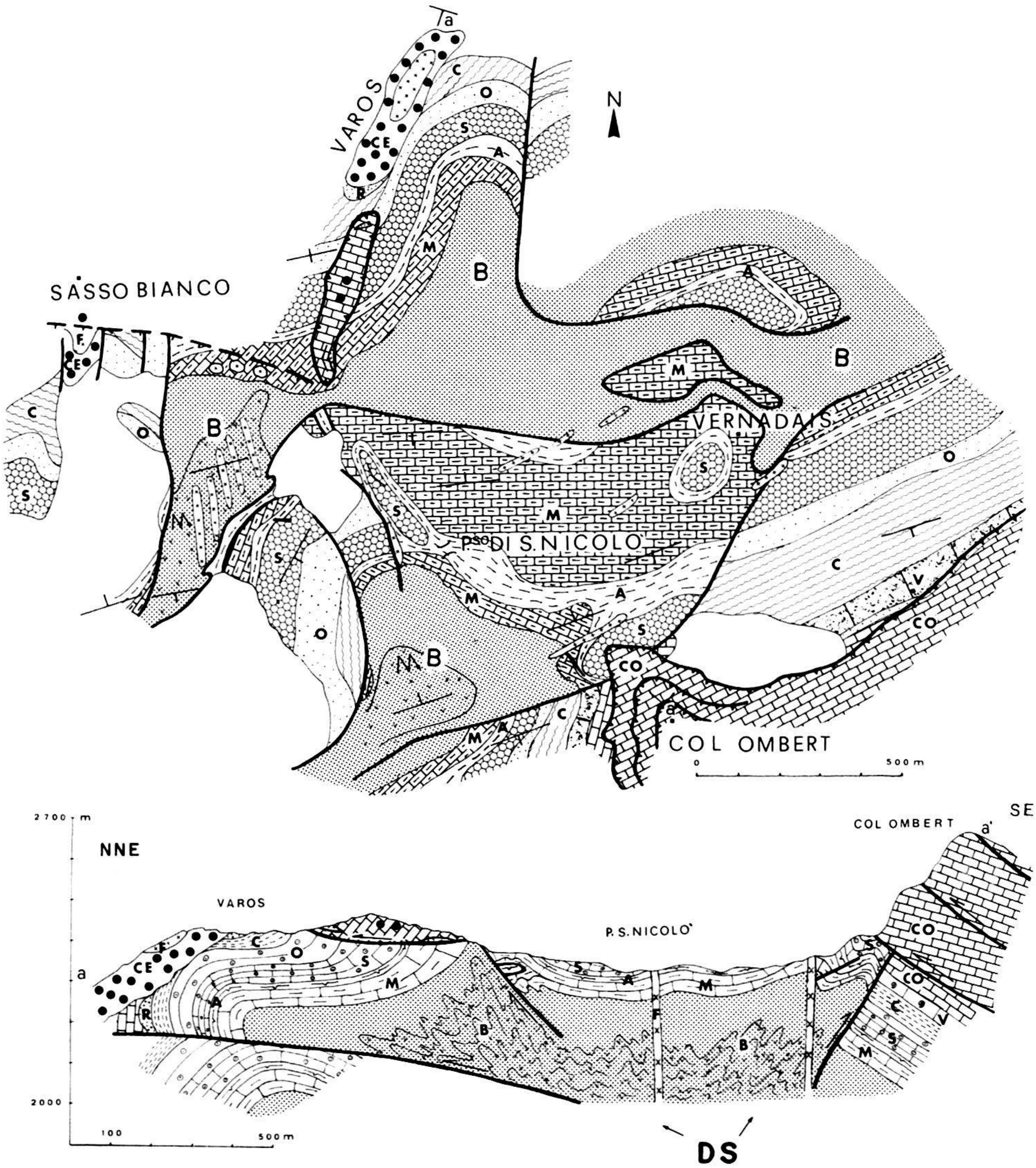


Fig. 15. Geologic map and cross section of the diapiric anticline of S. Nicolò. B: Bellerophon Formation; Werfen Formation: M: Mazzin Member, A: Andraz Horizon, S: Siusi Member, O: Gastropod Oolite, C: Campil Member, V: Val Badia Member; R: Richthofen Conglomerate; CO: Contrin Formation, Moena Formation, Morbiac Limestone; F: latitic-basaltic dikes, diatremes and subvolcanic bodies; CE: Caotico eterogeneo; DS: diapiric structure.

covered by mass-flow sediments of the so-called "Caotico eterogeneo" (Fig. 1 and 18). These Ladinian debris-flow deposits are composed of pebbles derived from formations ranging in age from Late Permian (Bellerophon Formation) to Ladinian (Marmolada Limestone and its coeval basinal equivalent, the Livinallongo Formation) and arenitic volcanic material. In the case of the S. Nicolò structure it can be proved that the emplacement of the diapir preceded the deposition of the Caotico eterogeneo. At Passo

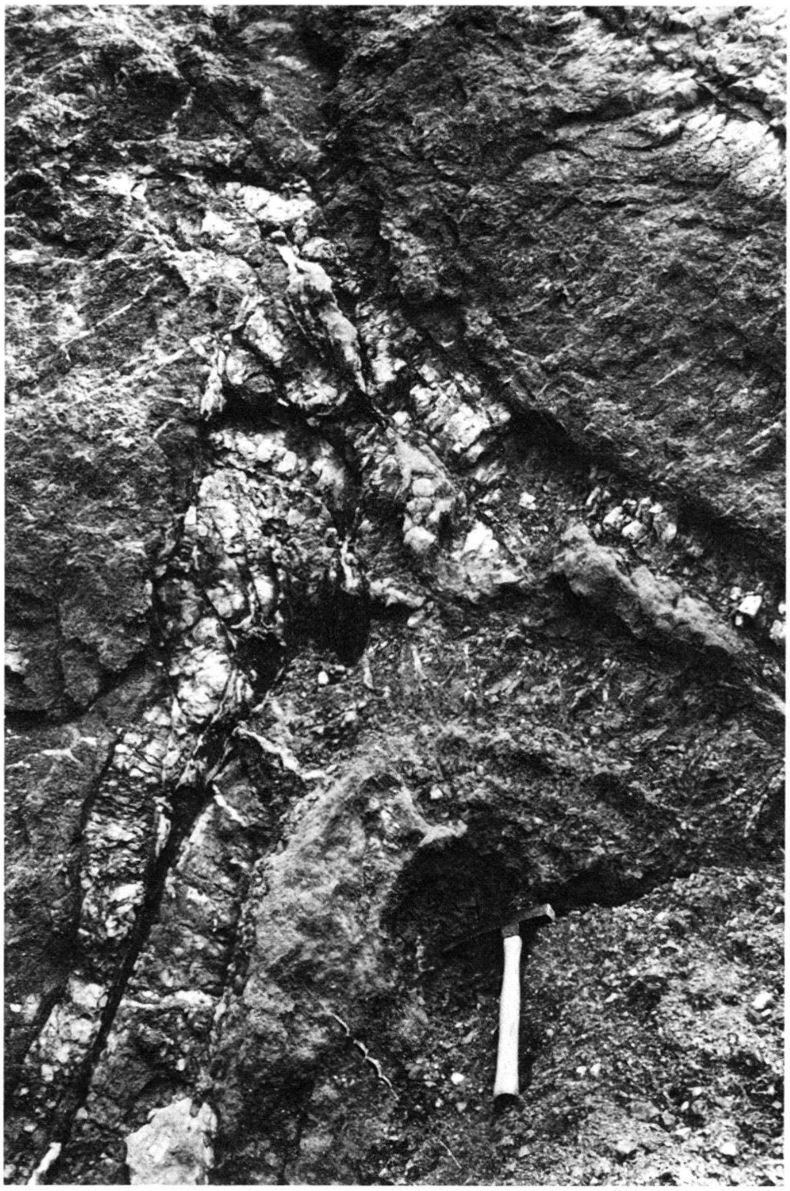


Fig. 16. Fold within the Bellerophon Formation with accumulation of gypsum and mudstones in the hinge.

Pasche, south of Col Ombert (Rossi 1962), a synsedimentary syncline of the Contrin Formation has been filled by the Livinallongo Formation, also suggesting a Triassic age for the deformation. Another spectacular feature is the southern fault limiting the diapiric anticline, which subsequently has been cut by the northward directed thrusts of the Col Ombert (Fig. 19). These thrusts, which displace the Late Anisian Contrin Formation, trend N70E, and are therefore penecontemporaneous or younger than the diapiric anticline and seem to have caused the tectonic denudation observed along the top of the diapiric structure. In fact, south of the Varos, the Contrin Formation covers with a tectonic unconformity older rocks of the Werfen Formation. Additionally, patches of Caotico eterogeneo are attached to one of the thrust blocks of Contrin Limestone, which according to the orientation of extensional Riedel shears at its base has been transported from S20E. This direction is very similar to that recorded in

Fig. 17. Upper end of the S. Nicolò Valley. The photograph shows the northern margin of the diapiric anticline. Note the unconformities caused by the flow of material within the Bellerophon Formation.

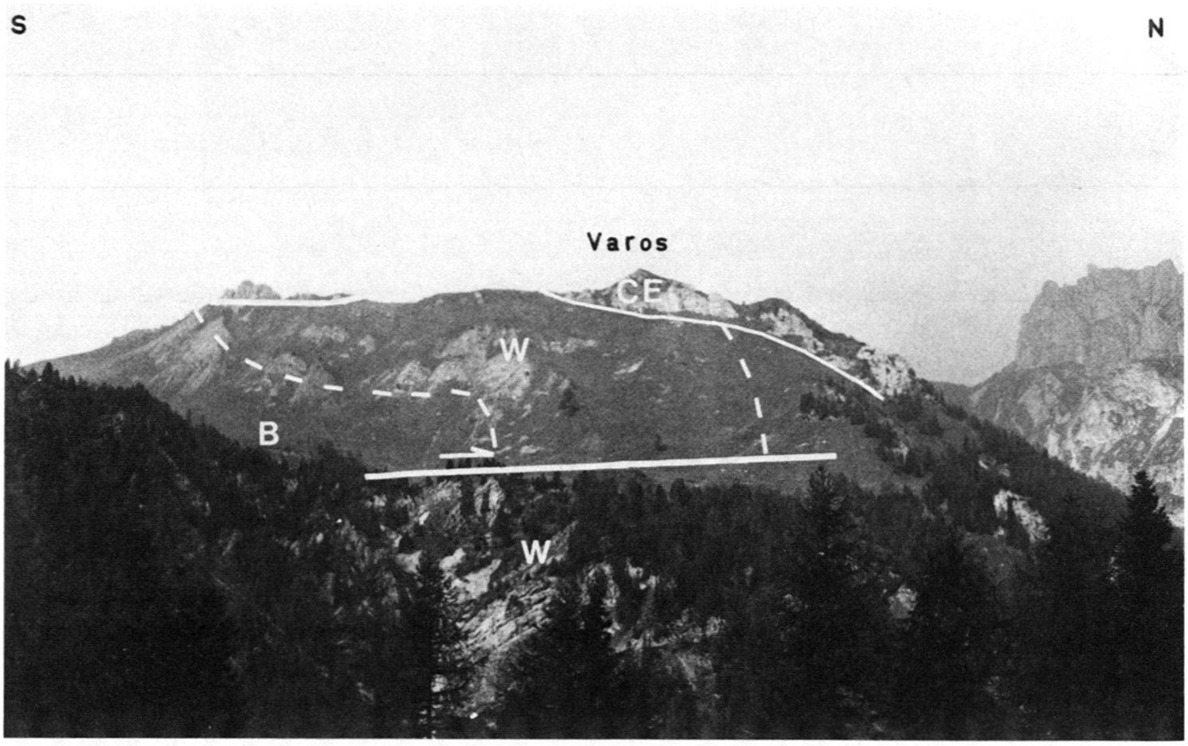


Fig. 18. S. Nicolò diapiric anticline. The Varos seen from Rifugio Contrin. The diapiric fold has been eroded and subsequently unconformably covered by the Ladinian Caotico eterogeneo (CE). Bellerophon Formation (B); Werfen Formation (W).

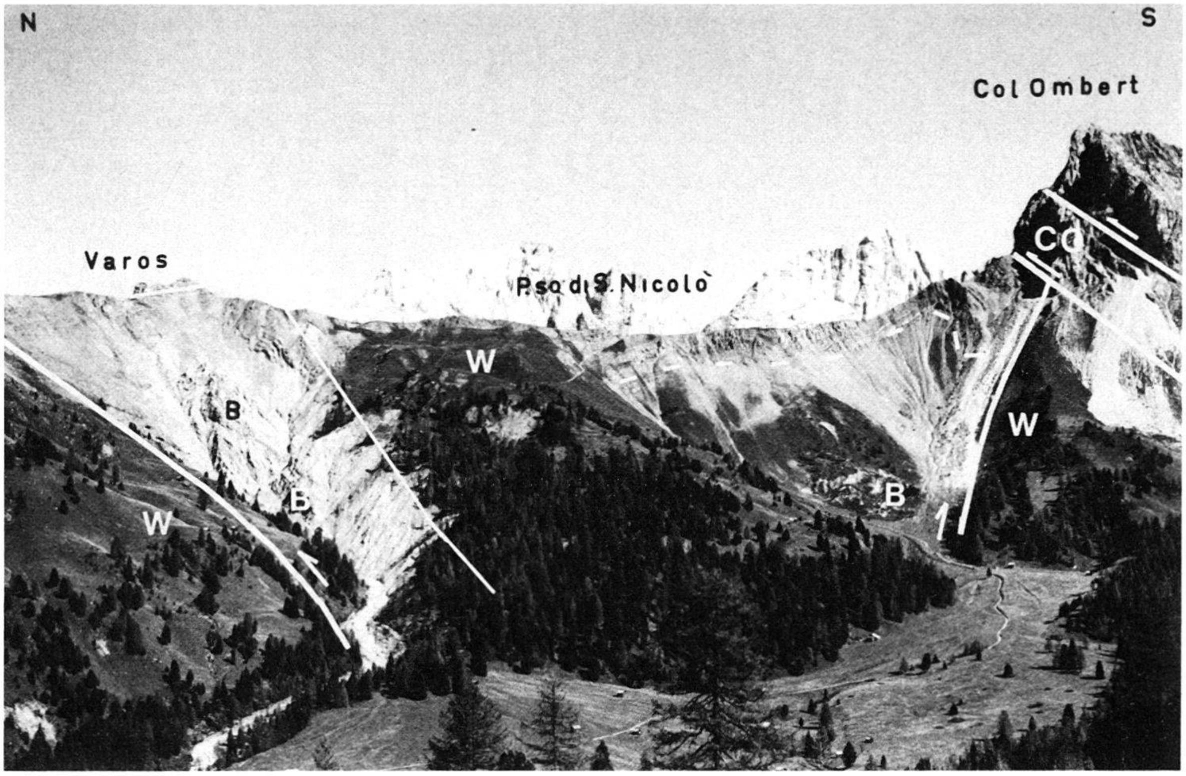


Fig. 19. The diapiric anticline of the S. Nicolò seen from M. Pecol. Note the two flancs with opposite vergences and the fault limiting the diapir to the right. This fault has been truncated by the northward thrusts of the Col Ombert thrust mass. B: Bellerophon Formation; W: Werfen Formation; CO: Contrin Formation.

striations of the Col Ombert Thrusts. Therefore a chronological relationship between the thrusts in the south and the deposition of the Caotico eterogeneo along their front to the north seems probable (cf. the reconstruction for the area between Varos and Col Ombert in Fig. 22). Similar relationships have been described from the surroundings of Arabba (Soura Sass) by Bosellini et al. (1982). We can conclude that the diapiric anticline has been a zone of tectonic and gravitational denudation in Ladinian times and thus could have alimentated the debris flows of the Caotico eterogeneo. Volcanic dikes and diatremes abundantly occur in the marginal zones of the diapir and seem to be related to deep-seated fractures, whose reconstruction, however, remains speculative.

10. *The Campo di Selva diapiric structure*

It is situated on the eastward continuation of the N70E lineament which can be traced from the Monzoni Valley to Pecol, S. Nicolò and Vernadais until it disappears below the Marmolada massif. The Bellerophon Formation, which here as usual forms the diapiric structure, is composed of dark, bituminous limestones ("badiota facies"). Gypsum and dark mudstones are lacking (Fig. 20). The marginal faults have a N70E orientation and exhibit vertical striations. The structure is some tens of meters wide and perhaps forms the top of a larger subsurface structure. Very similar to other diapiric structures, its top has been eroded and covered by the Caotico eterogeneo

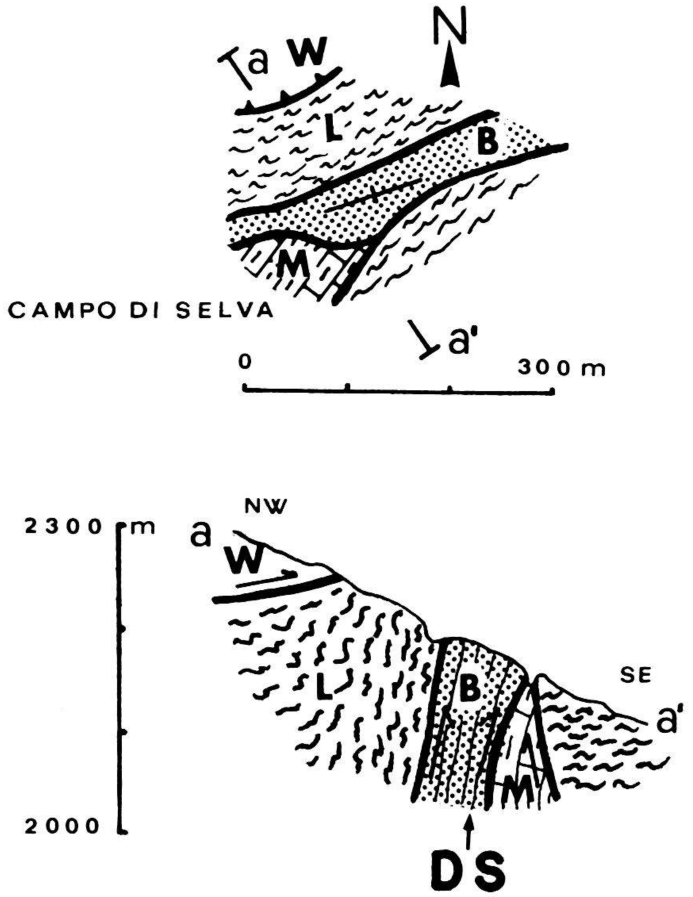


Fig. 20. Geologic map and cross section of the diapiric structure of Campo di Selva. B: Bellerophon Formation; W: Werfen Formation, M: Mazzin Member; L: Livinallongo Formation; DS: Diapiric structure.

(W. Blendinger, pers. comm.). This complicated structure has been truncated by one of the southwest-verging thrusts of the Marmolada massif, which are of Middle Triassic age (CASTELLARIN et al. 1982) as they are cut by Ladinian volcanic dikes (W. Blendinger, pers. comm.)

11. *Alleghe 1 Well*

In 1967 SNIA Viscosa has drilled a well in the core of the Cordevole anticline near Vallazza (Alleghe 1, about 2.5 km to the northwest of Pieve di Livinallongo, SNIA Viscosa 1967). 500 m of gypsum, mudstone and dark limestone of the "fiammazza facies" of the Bellerophon Formation were transversed. The base of this sequence has not been reached. Dip measurements revealed, below an upper disturbed zone, an almost constant 5°-inclination to the northeast. These data could suggest isoclinal folding, which was probably caused by the plastic flow of evaporitic material. The abnormal thickness of the Bellerophon Formation, which in this area usually has a thickness of 150–200 m, is connected with the Cordevole anticline, of which it is the core. Refraction seismics suggest a subhorizontal acoustic basement (Val Gardena Sandstone?, Bolzano Quartz porphyries?, Paleozoic basement?) which was not involved in the folding at some hundreds of meters below total depth. Decollement and tectonic accumulation of the Bellerophon Formation may thus be due to northward directed gravity thrusts of Triassic age (Bosellini 1984), Alpine thrusts with a southern vergence or Triassic shear or compression.

12. *Intraformational folds*

Intraformational folds occur in various parts of the Dolomites. They are well exposed near San Martino di Castrozza and Passo Valles. These folds are confined to the Bellerophon Formation and affect the sequences rich in gypsum and dark shales. Within these folds the gypsum frequently exhibits schistosity caused by plastic flow and accumulation in the hinge zones of the folds. Strike and dip of axial planes of folds vary considerably and refolded folds are frequent. This "plastic" style of deformation characterizes the "fiammazza facies" of the Bellerophon Formation. The intraformational folds seem to be associated with different types of faults and thrusts of Triassic or Alpine age. Their dimensions are of several meters and can, therefore, not be related to the generally smaller enterolithic folds caused by early diagenesis of evaporites as observed in modern sabkhas or in the Mediterranean Messinian evaporites (Garrison et al. 1978). Other similar structures in the Bellerophon Formation which are probably of diapiric origin are present to the east of Agordo, some kilometers to the north of Trento and near Auronzo. Near S. Martino in Badia and S. Vigilio di Marebbe they were also described by Engelen (1963).

The regional significance of the diapiric structures

a) The general features of the diapiric folds and the associated structures

The diapiric structures of the central Dolomites have a general N70E-trend and, with the exception of the Forno diapir, are limited by faults with the same orientation. They are composed of rocks of the evaporitic "fiammazza facies" of the Late Permian Bellerophon Formation. Diapiric rise with respect to the enclosing formations may amount to more than 500 m. At the described localities the width varies from some tens to several hundreds of meters. The pierced formations were dragged along by the diapiric masses and were affected by minor faults which are parallel to the margins of the diapirs. The roof of the diapirs was truncated by later thrusts or eroded during Ladinian time. Other diapiric structures, not exposed or largely eroded, may be present along the axial continuation of those structures described above.

Doglioni (1983) has hypothesized the existence of an elongated crustal dome of Ladinian age in the central Dolomites, associated with the emplacement of coeval magmatism. The major axis (N70E, Stava line, Cima Bocche anticline, Selle line) of this crustal dome was perhaps a zone of weakness, inherited by precedent sinistral transcurrent movements. Diapirs extend along this axis, in the eastern part of the subsequent dome, for about 30 km more or less parallel to a zone of only slightly younger Middle Triassic magmatism (Fig. 21) and to the Costabella thrusts (see below). In this area, three structural levels may be distinguished:

1. A lower level with brittle deformation (Val Gardena Sandstone, Permian quartz porphyries, Variscan basement).
2. A middle level with ductile deformation resulting in folds and diapirs (Bellerophon Formation, Werfen Formation).
3. An upper level with brittle deformation, particularly thrusts which truncate the tops of the diapirs (Contrin Formation and Marmolada Limestone, Upper Anisian and Ladinian carbonate platform).

b) The age of deformation

The diapirs are essentially of Middle Triassic (Intra-Ladinian) age as Ladinian rocks are involved in their formation and because they are cross-cut by late Ladinian volcanic dikes. Furthermore, the top of these structures has been truncated and buried below the debris-flow deposits of the Ladinian Caotico eterogeneo or below thrust sheets of Anisian and Ladinian limestones and dolomites. The thrusts in turn are of Middle Triassic age as they are also cut by the late Ladinian volcanic dikes; they seem to be coeval with the debris-flow deposits of the Caotico eterogeneo (basal level of the Ladinian volcanoclastic sequence, with fragments of all the formations affected by

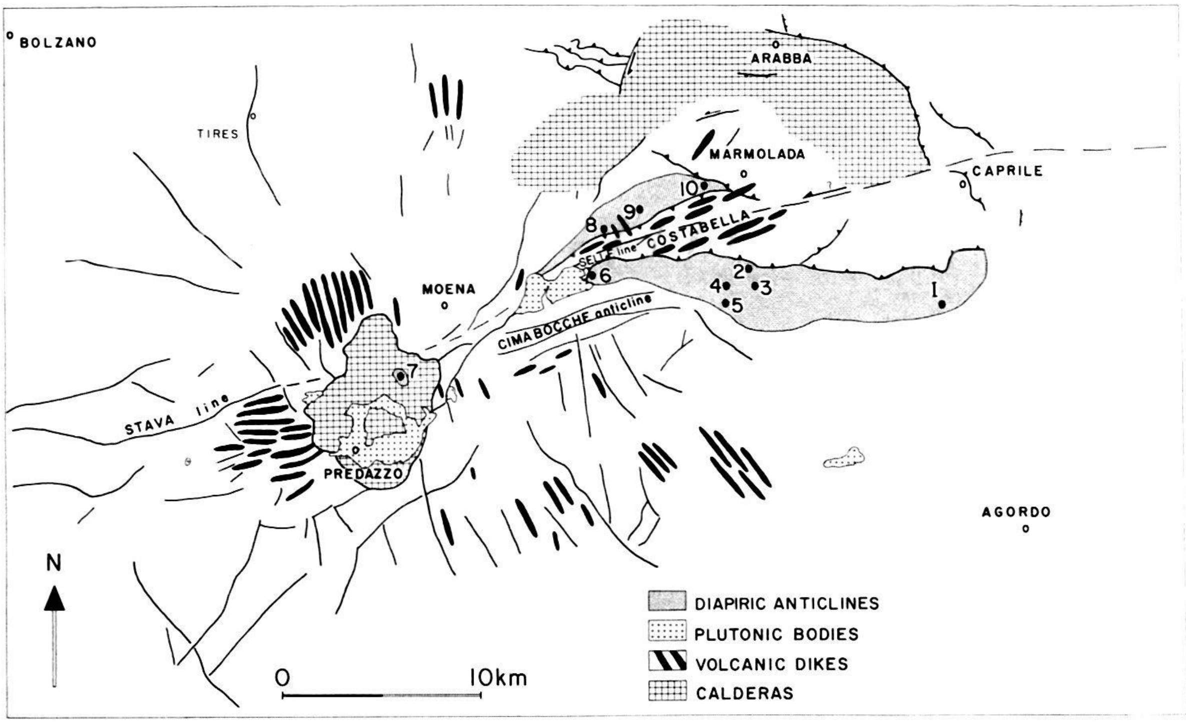


Fig. 21. Structural scheme of the Ladinian tectonics of the central Dolomites. The following phases can be distinguished: a) the development of diapiric anticlines, b) truncation of the diapirs by the Costabella thrusts (flower structure?), c) truncation of the Costabella thrusts by the Marmolada thrusts (en échelon structure?), d) cross cutting of the preexisting structures by volcanic dikes, plutonic bodies and calderas. The numbers refer to the diapiric structures described in the text. Note the radial pattern of volcanic dikes and faults in the central and western part of the area, which can be interpreted as a consequence of magmatic domal uplift (Doglioni 1983). The northern caldera is drawn after Bosellini (1984). The diapiric structures seem to be genetically related to a N70E-trending tectonic element (Stava line, Cima Bocche anticline, Selle line, Costabella). This tectonic lineament has become the preferential sit of Ladinian magmatism.

diapirism from the Bellerophon Formation to the Livinallongo Formation, Fig. 22). Moreover the Passo delle Selle diapiric structure has been metamorphosed by Ladinian monzonitic intrusion. As there is Anisian erosion on top of the diapiric folds (Col Becher, S. Nicolò, Lagusel) the diapirs probably started to rise already during the Anisian.

c) Relation to thrusts and deep-seated tectonics

The surficial thrusts may be the frontal decollement segments, at the base of the Contrin Formation or the Marmolada Limestone (Fig. 21 and 22), of deep-seated structures; being bivergent, they may be parts of a "flower structure" (HARDING & LOWELL 1979; LOWELL 1972). The close age relationship of the emplacement of the diapirs and of the surficial thrust masses could point to a common deep-seated cause. A close relationship between diapirism and thrusts is also suggested by the observed association of higher diapirs with important thrusts (e.g. S. Nicolò, Col Becher, Pecol and Passo delle Selle). The margins of the diapiric structures are the seat of intense volcanism, suggesting deep-seated lines, and the Col the Limazei diapiric anticline is placed above the core of the Cima Bocche anticline, which involves the basement. Gypsum diapirism in general, according to modern authors, cannot be caused by simple lithostatic pressure in an extensional field but requires compression (WALL et al. 1961; DUNNINGTON 1968; VIALLARD 1983). In particular, there is proof that the diapirs of the Dolomites are associated with compressional tectonics as the sedimentary cover is shortened (CASTELLARIN et al. 1982), which is clearly visible at S. Nicolò and Col Becher. Therefore, in the absence of large-scale decollements, the diapirs are valuable

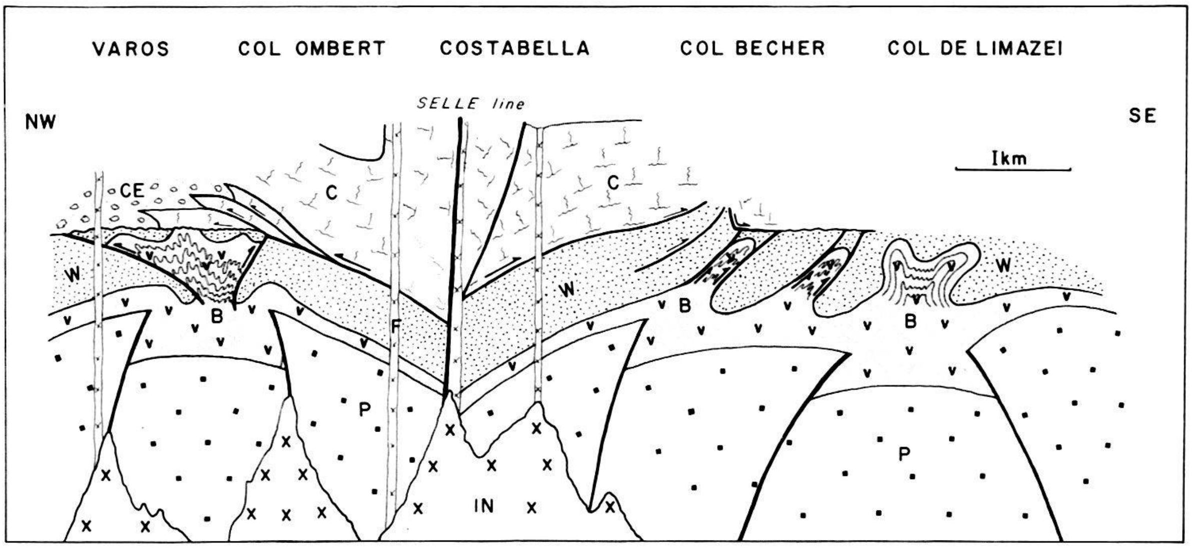


Fig. 22. Interpretative structural section across the Costabella massif, illustrating the presumed deformation of the basement causing diapirism in its sedimentary cover. Note the three different structural levels: a lower level with brittle deformation; an intermediate level with diapiric anticlines; and an upper level with rigid carbonate blocks thrusted over the diapirs. The thrusts diverge from the Selle line, which is perhaps a Triassic transpressive fault. P: crystalline basement, Permian volcanics, Val Gardena Sandstone; B: Bellerophon Formation; W: Werfen Formation; C: Contrin Formation; Livinallongo Formation, Marmolada Limestone; IN: Monzonitic intrusion; F: latitic-basaltic dikes.

indicators of deep-seated Middle Triassic tectonics. Inasmuch as the Costabella thrusts are bivergent they may possibly indicate a deep-seated "flower structure" of which the diapiric folds could be minor associated structures due to the presence of evaporites. This interpretation would appear more plausible than simple compression, as there are also other indications of sinistral transpression. However, this question is still being debated.

Conclusions

Geologic mapping has revealed the presence of Middle Triassic diapiric structures in the central Dolomites. They are formed by the evaporitic member of the Late Permian Bellerophon Formation ("fiammazza facies"). The investigated diapiric folds are elongated and oriented parallel to the N70E direction of the Ladinian Costabella Massif, and are aligned in two rows of the same direction, both north and south of the massif. After having deformed the overlying sequence, including Ladinian sediments, still in Middle Triassic times they were subject to erosion and were the source areas of the submarine mass flow deposits of the Caotico eterogeneo, the basal sequence of the Middle Triassic volcanics. Moreover, they were tectonically truncated during Middle Triassic times by thrusts implying the Anisian and Ladinian carbonate platforms, the thrust masses interfingering with the Caotico eterogeneo (Fig. 22). The direction of the thrusts is normal or oblique to the N70E-trend and suggests a bivergent flower structure (Costabella thrusts) or a sinistrally transpressive en-échelon arrangement (Marmolada thrusts). The formations underlying the Bellerophon formation were not affected by diapirism. Three structural levels may be distinguished:

1. A lower level with brittle deformation.
2. An intermediate level with diapiric anticlines.
3. An upper level with carbonate blocks thrust over the diapirs.

This structural scheme may be traced along the axis N70E along which, at a later stage, large amounts of magma were extruded. The diapiric structures are the result of Middle Triassic compressional, probably transpressional, tectonics.

The elevated temperatures due to Middle Triassic igneous activity, possibly together with the transformation of gypsum to anhydrite plus water, and the Ladinian carbonate platform (Costabella)–basin facies boundary, may have played a role in weakening the evaporites and consequently in favoring the development of diapirism. Regardless of this speculation the diapiric structures and the associated thrusts in the central Dolomites document compression shortly before the magmatic event. During Alpine orogeny Triassic faults were sometimes reactivated, and possibly original strike-slip faults were transformed into thrusts.

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REFERENCES

BOSELLINI, A. (1984): Progradation geometries of carbonate platforms: examples from the Triassic of the Dolomites, Northern Italy. – Sedimentology *31*, 1–24.

BOSELLINI, A., CASTELLARIN, A., DOGLIONI, C., GUY, F., PERRI, M.C., ROSSI, P.L., & SOMMAVILLA, E. (1982): Geologia della Conca di Arabba e dei rilievi circostanti. In: CASTELLARIN, A., & VAI, G.B. (Ed.): Guida alla Geologia del Sudalpino centro-orientale. – Soc. geol. ital.

CASTELLARIN, A., GUY, F., & SELLI, L. (1982): Geologia dei dintorni del Passo di S. Nicolò e della Valle di Contrin (Dolomiti). In: CASTELLARIN, A., & VAI, G.B. (Ed.): Guida alla Geologia del Sudalpino centro-orientale. – Soc. geol. ital.

DOGLIONI, C. (1983): Duomo medio-triassico nelle Dolomiti. – Rend. Soc. geol. ital. (in press).

DUNNINGTON, H.V. (1968): Salt-Tectonics features of Northern Iraq. – Spec. Pap. geol. Soc. Amer. *88*, 183–227.

ENGELEN, G.B. (1963): Gravity tectonics in the Northwestern Dolomites. – Geologica ultraiect. *13*, 1–92.

GARRISON, R., SCHREIBER, B.C., BERNOULLI, D., FABRICIUS, F., KIDD, R.B., & MELIÈRES, F. (1978): Sedimentary petrology and structures of Messinian evaporitic sediments in the Mediterranean Sea. – In: HSÜ, K.J., MONTADERT, L., et al.: Init. Rep. Deep Sea Drill. Proj. *42* A, 571–612; U.S. Govt. Print. Office.

HARDING, T.P., & LOWELL, J.D. (1979): Structural Styles, their Plate Tectonic Habitats, and Hydrocarbon Traps in Petroleum Provinces. – Bull. amer. Assoc. Petroleum Geol. *63*, 1016–1058.

LEONARDI, P. (1963): Gravità, diapirismo e orogenesi nelle Dolomiti. – G. Geol. (2), *31*, 1–13.

– (1967): Le Dolomiti. Geologia dei Monti tra Isarco e Piave. – Ed. Manfrini, Rovereto.

LOWELL, J.D. (1972): Spitsbergen Tertiary orogenic belt and the Spitsbergen fracture zone. – Bull. amer. Assoc. Petroleum Geol. *83*, 3091–3102.

ROSSI, D. (1962): Geologia della parte meridionale del Gruppo della Marmolada. – Mem. Mus. Storia nat. Venetia Tridentina *14*, 1b, 1–189.

– (1977): Un esempio di tettonica preladinica forse diapirica nelle Dolomiti occidentali (Val di S. Nicolò). – Ann. Univ. Ferrara, (4), Sci. geol. paleont. *5*/12, 213–221.

SNIA Viscosa (1967): Rapporto geologico finale del Pozzo Alleghe I. – Unpubl.

VARDABASSO, S. (1930): Carta geologica del territorio eruttivo di Predazzo e Monzoni nelle Dolomiti di Fiemme e di Fassa alla scala 1:25000. – R. Scuola Ing., Padova.

VIALLARD, P. (1983): Le décollement de couverture dans la Chaîne Ibérique méridionale (Espagne): effet de raccourcissements différentiels entre substratum et couverture. – Bull. Soc. géol. France (7), *25*/3, 379–387.

WALL, J.R., MURRAY, G.E., & DIAZ, T.G. (1961): Geologic occurrence of intrusive gypsum and its effect on structural forms in Coahuila marginal folded province of north-eastern Mexico. – Bull. amer. Assoc. Petroleum Geol. *45*, 1504–1522.