GEOLOGIE EN MIJNBOUW© VOLUME 58 (2), p. 145-152 1979

NAPPES OF THE ALTA ROMAGNA

E. TEN HAAF[1] & W. A. VAN WAMEL[1]

ABSTRACT

Ten Haaf, E. & W. A. van Wamel 1979 Nappes of the Alta Romagna. *In:* W. J. M. van der Linden (ed.): Fixism, mobilism or relativism: Van Bemmelen's search for harmony – Geol. Mijnbouw 58: 145-152.

The structure of the Romagna Apennines is less simple than has been supposed. Between the Ligurid allochthon and the true autochthon of the Romagna there are several superposed thrust sheets. each with a distinctive stratigraphy. Their emplacement in the Romagnan flysch basin was a submarine and synsedimentary process, driven by gravity.

INTRODUCTION

During the summers of 1970-1978, the authors worked in the Toscana-Romagna Apennines, training geology students. The mapping efforts made us familiar with the terrain, and showed up the admirable factual correctness of the new 'Carta Geologica d'Italia 1 : 100 000' (1969). But a few questions kept obtruding themselves.

(1) The tectonic contact between the two great arenaceous flysch complexes, the Tuscan 'macigno' and the 'formazione marnoso-arenacea' ('marly-arenaceous formation', abbreviated *mar)* of Romagna, is commonly depicted as a cross-cutting reverse fault. If so, why is its outcrop line so sinuous and clearly determined by topography; and why is it, across the Marecchia and Tevere (Tiber) valleys, exactly parallel to the base of the Ligurid allochthon – which is recognized unanimously as an overthrust?

(2) Outcrops of macigno and *mar,* away from the Toscana-Romagna divide, look distinctive enough; but along this divide there is an intermediate zone where the rocks cannot be decently assigned to either complex. Should this strip be mapped separately?

(3) Do the 'Verghereto marls' really belong to the Romagnan autochthon? They resemble the Tuscan 'Vicchio marls' much more than any marly member of the Romagna series, from which they are set off by tectonic contacts.

These questions have led us towards a new structural interpretation, involving extensive overthrusting between units underlying the Ligurid allochthon.

STRUCTURAL UNITS BETWEEN BOCCA TRABARIA AND PASSO DEI MANDRIOLI

Systematic field work in this region has resulted in a tectonic map and sections (Figs. 1 and 2). The major elements can be followed much farther to the NW, as shall be shown later.

[1] Geological Institute, Oude Gracht 320, UTRECHT, The Netherlands.

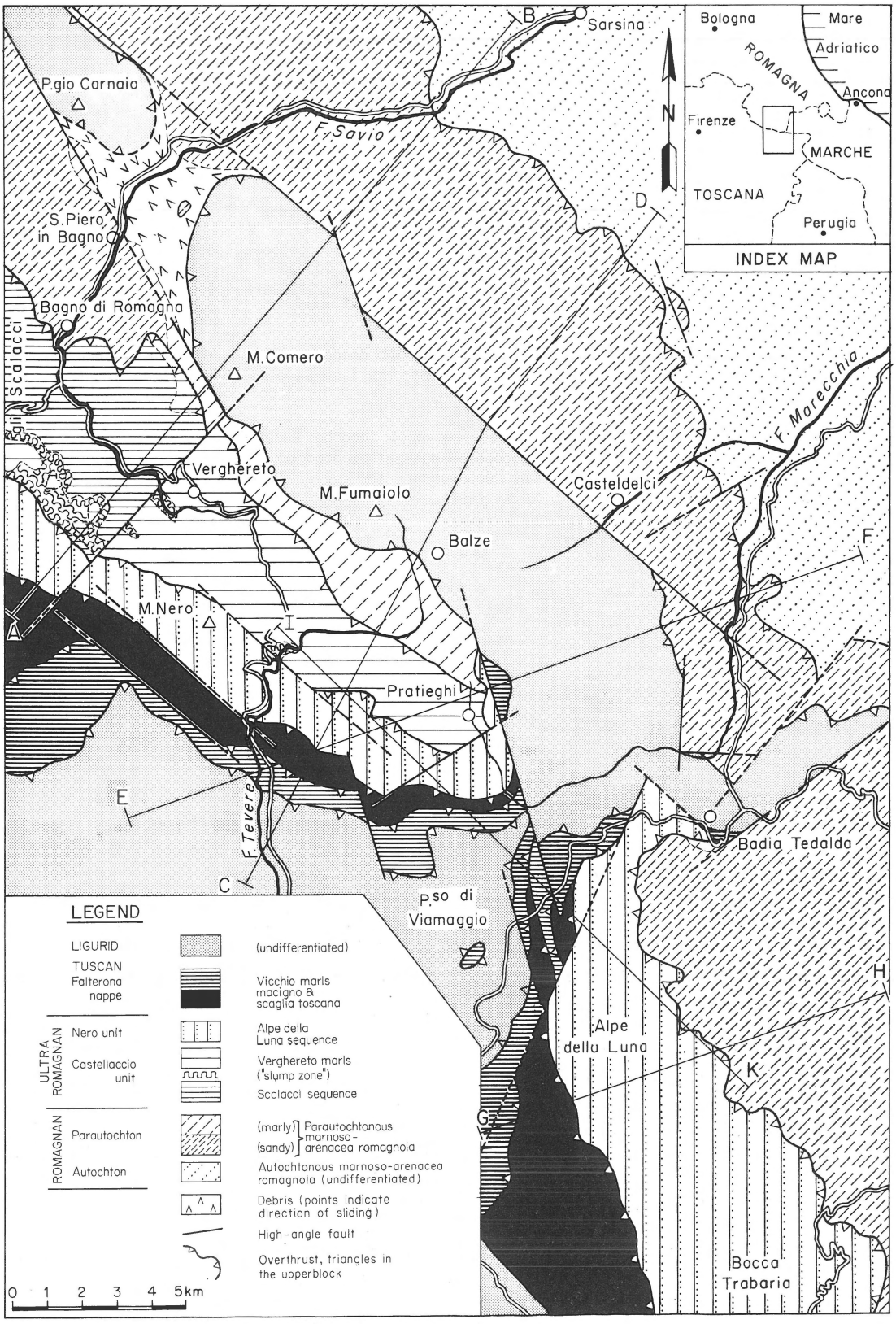

Fig. 1
Tectonic map of the upper Savio, Tiber and Marecchia valleys.

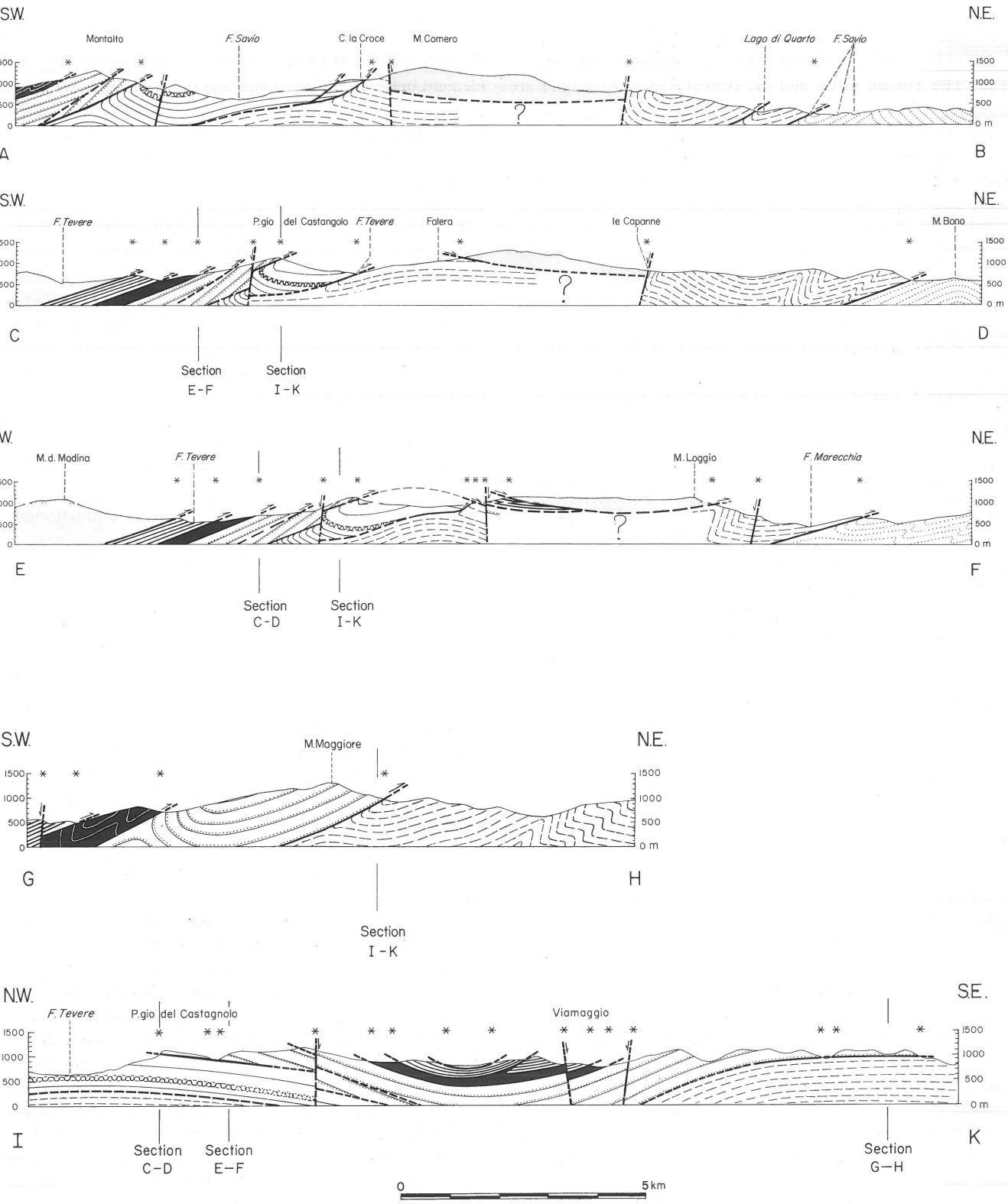

Fig. 2
Sections to figure 1. Note: scale is different from the map, and more detail is shown; asterisks denote tectonic contacts also figured on the map. Legend as in figure 1, but hatching patterns follow the general attitude of the bedding.

Our map implies that:
(1) The tectonic contact bordering the Tuscan series on the NE side is not a high-angle fault but a basal overthrust.
(2) The Tuscan series and the typical *mar* of Romagna are not in direct contact. They are separated by one or several thrust slices possessing their own stratigraphic identity.
(3) The Verghereto marls of the type locality do not belong to the Romagnan autochthon but to a higher tectonic unit.
(4) The complete thrust pile has been gently folded and tilted.

As these statements contradict prevalent ideas, they deserve some amplification.

(1) Rocks of the Tuscan series (scaglia toscana, macigno or 'Cervarola sandstone', Vicchio marls) along and beyond the Toscana-Romagna divide are superposed tectonically, as a composite thrust sheet, on more external and partly younger formations. By giving this sheet the local name 'Falterona nappe' we evade the more general question whether it still belongs to the Tuscan nappe proper, to a more external 'Cervarola unit' (GIANNINI ET AL., 1962; SESTINI, 1970) or constitutes a separate tectonic entity.

The basal overthrust plane of this nappe is marked all along its outcrop line by discontinuous remnants of heavily tectonized scaglia toscana. In addition to this main thrust there has been a partial *décollement* and sliding ahead of the Vicchio marls. In the most external part of the Falterona nappe (i.e. the Badia Tedalda-Passo di Viamaggio region) the macigno sandstones are much reduced; often they are only represented by disconnected shreds scattered through the tectonized scaglia, sheared out under a rigid slab of Vicchio marls.

(2) The Falterona nappe rests on another tectonic unit that crops out as a strip, a few kilometres wide, along the front. We shall call it the 'Nero unit', after the Monte Nero. Its lower contact is an overthrust generally parallel to the Falterona overthrust above. Thus the Nero unit comprises an asymmetrically folded, or even imbricated slice of an isolated and distinctive arenaceous flysch sequence, which we call the 'Alpe della Luna sequence'. The Carta Geologica d'Italia does not distinguish this sequence and assigns its outcrop area mostly to the *mar,* but partly also to the macigno[2].

Where the Nero overthrust plane is parallel to the bedding in the footwall, tectonic disturbance is slight; but where the thrust cuts across the bedding, it is accompanied by an abrupt overturning of the underlying beds. Such 'footwall synclines' can also be seen beneath the more external thrusts: they are characteristic of the tectonic style of the Romagna (Fig. 2).

(3) NW of the Val Marecchia, there is yet another tectonic element between the Nero unit and the Romagnan sequence proper. This 'Castellaccio unit' (named after the Poggio Castellaccio near Verghereto) comprises the Verghereto marls and the underlying thin-bedded turbidite sequence so magnificently exposed in Gli Scalacci (between Bagno di Romagna and Passo dei Mandrioli).

The name 'Verghereto marls' should be restricted to the well bedded, calcareous and silty marls of the type area. The outcrops of clayey marls around Poggio Carnaio and Monte Comero, W and S of Monte Fumaiolo, and S of Badia Tedalda (also figured as Verghereto marls by the C.G.I.) belong to the top of the parautochthonous Romagna sequence; the calcareous marls east of Passo di Viamaggio are Vicchio marls of the Falterone nappe (Fig. 1).

Finally, the remaining outcrop are of the 'marnoso-arenacea romagnola' proper is divided by another, still more external thrust front. The southwestern part is therefore not really autochthonous but 'parautochthonous'; the rocks of the Castellaccio and Nero units should be qualified as 'Ultra-Romagnan'.

(4) This whole thrust pile – autochthon and parautochthon. Castellaccio and Nero units, Falterona nappe, and the Ligurid allochthon on top – has subsequently been tilted and gently folded. Along the Toscana-Romagna divide, uplift of the Romagna relative to the Tiber, Casentino and Mugello depressions has caused a prevalence of southwesterly dips. Farther out, the thrust sheets have been broadly folded around axes that plunge toward the transverse Marecchia depression from both sides (Fig. 2, section I-K). The combination of plunging axes, low dips, and rugged terrain determines the meandering map pattern of the thrusts.

Of the numerous high-angle faults, our map shows only those that cause an appreciable offset of the main outcrop lines.

To facilitate comparison, we have drawn one section (C-D) to coincide with an important section on the C.G.I. 1: 100 000 (F. 108 Mercato Saraceno, section II). It will be seen that the difference is mostly a matter of interpretation.

Note that, in section C-D, the Ligurid allochthon NE of Falera directly overthrusts the parautochthon; while in section E-F near Pratieghi, Falterona and Nero elements are still interposed between. The original front of both of these units is thus fixed at about 2 km beyond the line Pratieghi-Badia Tedalda. The double tectonic half-window around Pratieghi discloses, by its width, a minimum amplitude for two overthrusts: 6 km for the Falterona nappe, 3 km for the Nero unit with respect to the parautochthon. The thrust of the parautochthon over the autochthon cannot be inconsiderable either, because of the length and continuity of its sinuous outcrop line: another 2 km at the very least. These figures add up to an irreducible minimum of 11 km for the

[2] FREY (1969) does distinguish his 'Mandrioli sandstone' as a separate formation and tectonic unit, corresponding to part of our Nero unit.

total translation of the Falterona nappe, 5 km for the Nero unit.

However, from the whole configuration and from the lithostratigraphical distinctiveness of successive tectonic units, it seems likely that the real amounts of slip are much larger.

REMARKS ON THE STRATIGRAPHY

An extensive description of lithostratigraphic units is beyond the scope of this paper. We shall use a provisional and informal classification, retaining as many well-established terms as possible. A summary is provided by the legend to figure 1. The Ligurid complex (undifferentiated) and the Tuscan sequence of the Falterona nappe need no comment here; but our new lithostratigraphic distinctions within the Romagnan and Ultra-Romagnan tectonic units must be presented briefly, as most of these rocks were formerly lumped together in a single autochthonous 'formazione marnoso-arenacea'. In order of superposition we recognize:

(1) The autochthonous marnoso-arenacea romagnola, an alternation of marls and turbiditic sandstones. The latter contain only few dark minerals and rock fragments. The calcareous cement is sparse toward the top of some sandstone beds, and causes rapid weathering. Flute casts indicate a NW origin of most turbidites. Going upward in the sequence, the sandstone intercalations diminish and the marls become more clayey, finally grading into clays of the Tortonian. The autochthonous *mar* is at least 2.5 km thick in the Savio section. The lack of calcarenites distinguishes it from the parautochthonous *mar*.

(2) The parautochthonous marnoso-arenacea romagnola also consists of a sandy basal part and a marly top. The sandy part is rather similar to the sandy autochthonous sequence, except that the sandstone beds tend to be more closely spaced and better cemented. Most of them are relatively pure quartz-arenites with a NW origin. In outcrop they often stick out with a distinctive saw-toothed appearance, due to widely-spaced transversal jointing. Some of the beds, however, are true calcarenites: these all are supplied from the opposite, SE, direction. Compared to the quartz-arenites, the calcarenite beds are denser, more brightly coloured, more resistant to weathering and more closely jointed. About 1% of all beds are calcarenites, but in the uppermost 350 m of the sandy sequence they have not been found.

A conspicuous very calcareous quartz-arenite, approximately 4 m thick with very deep flute casts indicating a SE origin, has been traced from SE to NW across the area illustrated in figure 1. Below this key bed at least 600 m, and above it certainly 1000 m of parautochthonous *mar* with calcarenites has been established.

Upward, sandstone beds gradually disappear and the sequence grades into the marly upper part of the parautochthonous *mar*. The marls become more clayey upward, and locally contain contorted limestone beds with *Lucina*. These beds are characteristic of the marly parautochthon which, between Balze and Pratieghi, attains a minimum thickness of 300 m.

(3) The Scalacci sequence is beautifully exposed in its type area, E of Passo dei Mandrioli: it is a thin-bedded, very regular alternation of marls and turbiditic quartz-arenites. The latter have a calcareous cement, contain few dark minerals and rock-fragments and mostly have a NW origin.

Calcarenites with SE supply, similar to those of the parautochthonous *mar*, do occur in the Scalacci sequence but much less frequently. Here, too, a useful key bed is constituted by a very calcareous quartz-arenite with supply from the SE, about 4 m thick; the Scalacci sequence extends about 625 m above, and at least 225 m below this bed.

South and west of Verghereto a huge slump zone, which seems to be lacking farther north, separates the Scalacci sequence from the overlying Verghereto marls. As mentioned before, the latter name should be restricted to the calcareous and silty marls directly around Verghereto, where they have a minimum thickness of 500 m.

The Verghereto marls are very similar to the Vicchio marls of the Tuscan sequence; this resemblance, and the tectonized state of the marls and the 'slump zone', will be discussed in a later section.

(4) The Alpe della Luna sequence is markedly different from the others. Its turbidites, instead of relatively 'clean' quartz-arenites, are full of varicoloured mineral and rock fragments especially in the coarse parts. The matrix is more clayey, which causes outcropping beds to weather into rounded shapes.

The basal 700 m of the Alpe della Luna sequence is an alternation of these sandstones, supplied from the NW, with marls and calcarenites. The latter have, as usual, been supplied from the SE; but they are also characterized by the admixture of various mineral and rock fragments together with organoclastics. Occasionally, entire pelecypods and bryozoans are found reworked at the base of both the quartz- and calcarenites.

Above this basal part, in the next 450 m, the sandstone beds are very thick and often densely piled, almost without marl intercalations; their base is often distinctly erosive.

Upward the thick beds gradually disappear and the next 300 m of the Alpe della Luna sequence is an alternation of marls and quartz-arenites. The uppermost 200 m are built up of alternating beds of calcareous marl and clayey marl. Distinct bedding, and the lack of *Lucina* limestone distinguish these marls from the marly parautochthon.

(5) From the familiar Tuscan sequence, the macigno (or 'Cervarola sandstone') and the scaglia toscana are much reduced in our area: the more external, the thinner and more

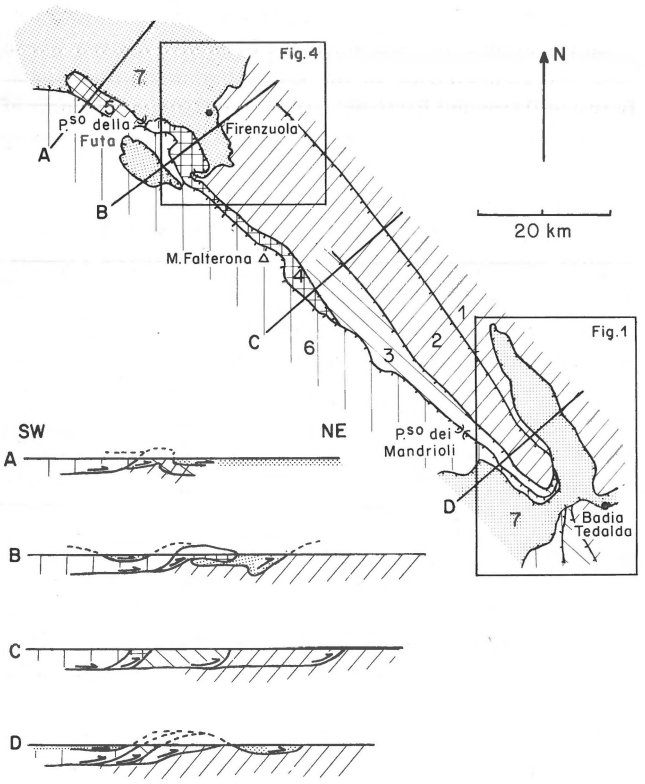

Fig. 3
Structural elements of the Romagna (after De Jager, 1979). 1: parautochthon: 2: Castelaccio unit: 3: Nero unit; 4-5: Castel Guerrino-Castiglione unit; 6: Falterona nappe; 7: Ligurid allochthon.

tectonized. This reduction is probably not wholly tectonic but also due to a primary wedging-out of the turbidite facies towards the former rim of the Tuscan flysch basin.

The varicoloured shales of the scaglia toscana, the graywacke composition of the macigno sandstones, and the high carbonate content of the Vicchio marls are distinctive of the Tuscan sequence.

FROM PASSO DEI MANDRIOLI TO PASSO DELLA FUTA (Figs. 3, 4)

This part of the Romagna, NW of the area depicted in figure 1, has a comparable structure: most of our tectonic units can be followed along the strike for considerable distances. Beyond the Senio valley, axes begin to plunge NW until the entire Romagna flysch disappears under the Ligurid allochthon along the 'Sillaro line'. The structural development of this region has recently been studied by DE JAGER (1979), to whom we are indebted for much preliminiary information.

The thrust front of our Castellaccio unit, attended part of the way by a footwall syncline, can be traced for 60 km to Palazzuolo sul Senio; beyond, the structure gradually degenerates into an anticline (Fig. 4). As to whether the overthrust really dies out along the strike, or the axial plunge

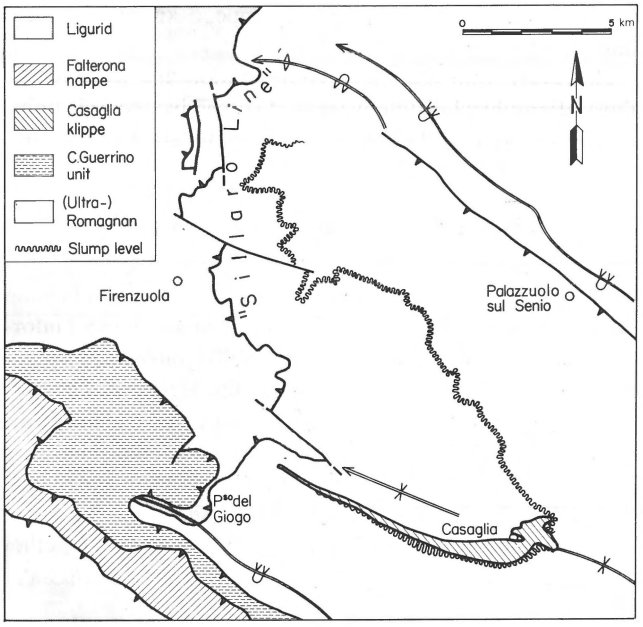

Fig. 4
Tectonic map of the Passo del Giogo – Casaglia area (adapted from De Jager 1979).

merely exposes a higher part of the structure where the thrust has been 'smothered' by progressively younger syntectonic sediments, is hard to decide. Anyway it still separates two different flysch sequences, an external one corresponding to the *mar* in our restricted sense (parautochthonous and autochthonous), and an internal one that is an extension of our Scalacci and Alpe della Luna sequences.

Likewise, the overthrust of parautochthon over autochthon seems to persist as a more or less continuous structure, as far as the Senio valley where it also begins to plunge and fade out.

The Nero overthrust, on the other hand, dies out in the neighbourhood of Monte Falterona, where the Nero and Castellaccio units gradually coalesce. Here it can be seen that the Alpe della Luna sequence is stratigraphically lower than the Scalacci sequence – an order that, along the Savio and Tiber valleys, has been reversed by overthrusting.

Toward the NW, the Nero overthrust is relayed by another thrust front that appears from under the Falterona nappe and delimits a new tectonic and lithostratigraphic unit: the Castel Guerrino sandstone (GROSSCURTH, 1971) and Castiglione sandstone (HEMMER, 1966). For structural details, see DE JAGER (1979).

PROVENANCE OF THE CASAGLIA AND VERGHERETO MARLS

Near Casaglia in the upper Lamone valley, there is a large lenticular outcrop of peculiar marls on top of an extended slump zone (fig. 4). The marls are calcareous and

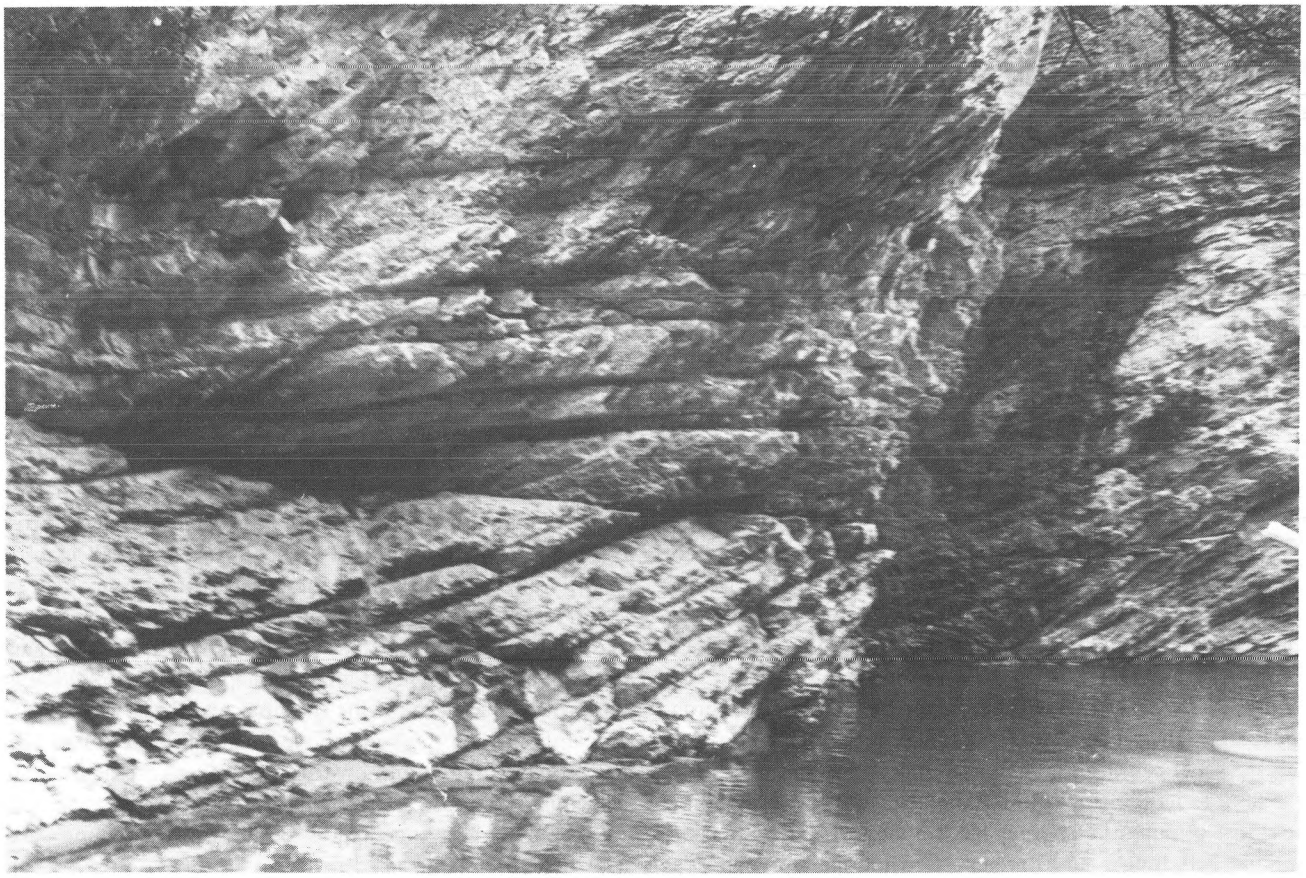

Fig. 5
Thrust imbrication and various cleavages in the basal part of the Verghereto marls. Tiber gorge, 2 km north of Valsavignone.

rather severely tectonized, with several cleavages. The lens is overlain, with a sedimentary contact, by some 30 m of ordinary Romagna-type marls that are hardly tectonized at all, before turbiditic sandstone beds come in again.

The most likely interpretation is that the cleaved marly lens constitutes a large olistolith or 'sedimentary klippe', already lithified and tectonized before it came sliding into the flysch basin[3]; apparently it stood up high enough at first (150 m) to prevent turbidity currents from overflowing it. Lithologically, there is a great similarity to the Vicchio marls of the Tuscan series; a similarity enhanced by chaotic shaly remnants generally referred to the sub-ligurid 'Canètolo complex'. Even though the front of the Falterona nappe has been cut back by erosion, it is still only 4 km distant; Vicchio marls as well as Canètolo complex crop out beyond. So the Casaglia klippe may well be a truly foreign, Tuscan element contributed by the approaching Falterona nappe.

It is tempting to postulate a similar origin for the Verghereto marls, which exhibit many points of analogy. In an extensive area S. and W. of Verghereto (Fig. 1), the base of the marls is underlain by a magnificent slump zone. While the Scalacci flysch below is remarkably undisturbed and untectonized, the Verghereto marls are internally sheared and thrust-sliced; toward the base, several systems of fracture cleavage appear (Fig. 5). The likeness to the Vicchio marls that crop out near by as a part - already more or less detached - of the Falterona nappe is such that our search for a diagnostic difference mostly turned up new lithologic similarities. All these phenomena would be explained by the hypothesis that the Verghereto marls were not originally sedimented on top of the Scalacci sequence, but have been emplaced there as an already lithified slab -a *diverticule,* to borrow a term from Alpine geology- slid ahead from the Falterona nappe.

On the other hand, it can be argued that the lithology immediately above and below the slump zone is rather similar, suggesting a normal sedimentary transition from Scalacci flysch to Verghereto marls, locally obscured by intraformational slumping.

Either way, one curious problem remains: the strong cleavage of the lower Verghereto marls affects the underlying slump as well. How, then, did the Scalacci flysch below it escape from being tectonized? An interesting pos-

[3] Cf. Signorini (1937) who interpreted the entire Casaglia 'slump' as an overthrust phenomenon – an opinion not favoured by most later authors.

sibility is that the 'slump' is not a true sedimentary slump at all, but a tectonic, syndiagenetic phenomenon: a zone of concentrated shear at the transition from an upper sequence of calcareous marls, lithified early, to the still unconsolidated turbidite deposits below. If the numerous turbidite interbeds were not yet cemented, they probably could take up a lot of shearing strain without visible trace.

Otherwise we must fall back on the *diverticule* hypothesis, by supposing that the slump zone was always an integral part of the Verghereto marls and that the whole slab was tectonized before its emplacement -without much disturbance- on top of the Scalacci sequence. The matter deserves further study.

MECHANICAL CONSIDERATIONS

For an understanding of the Ligurid overthrusting, the approach by ELLIOTT (1976) seems especially suitable. He has adapted, to the gravitational motion of a thrust sheet, equilibrium equations that had been found useful in glaciology. On condition that a nappe can be deformed, it is not the slope of the base (overthrust plane) that determines progress: it is the slope of the top. Like a glacier, a non-rigid thrust sheet can surmount even counterslopes of the footwall as long as its top slopes in the direction of flow, providing a net loss of potential energy. This implies, of course, that the nappe gets longer and thinner: 'gravitational spreading' as distinct from uniform downslope sliding.

The spreading model is attractive on two points. It explains gravitational overthrusting on a horizontal surface. And the ragged map pattern of the Ligurid cover in our region, with its disjointed slabs of competent rocks –allochthonous and semi-allochthonous– is very suggestive of such spreading. The intercalation of huge slump zones and olistoliths in the Ultra-Romagnan sequence shows that synsedimentary tilting and gravitational sliding have occurred as well.

The lower thrust sheets apparently advanced more or less simultaneously with the allochthonous cover. In two places at least, some Ligurid material has been overridden by lower thrust fronts: at Passo del Giogo by the Castel Guerrino unit (Fig. 4) and near Badia Tedalda by the Nero unit (tectonized slices too small for our map).

The rocks involved in the overthrusting were probably only partly lithified. Apart from disconnected competent slabs riding with the Ligurid allochthon, only the calcareous Vicchio and Verghereto marls were apparently quite rigid. Lithified early, and not weakened by pronounced interbeds, they have behaved as competent units susceptible to tectonic cleavage.

Now consider the frontal part or 'toe' of a nappe, where the basal thrust cuts up to the surface. Even though the sheet as a whole is driven by gravity, the wedge-shaped toe is subject to a *vis a tergo* pushing it up to the counterslope of the thrust plane, and capable of generating a footwall syncline. The toe gains potential energy at the expense of the main body of the sheet, and will rise above its surroundings unless material is removed. Thus contemporaneous erosion, as invoked by Elliott, or submarine resedimentation and the shedding of olistostromes and klippes, as in our case, would be helpful factors. Compaction of the fresh footwall sediment, under the weight of the advancing nappe, would do much to keep down a frontal bulge – and to reduce friction according to the 'fluid pressure principle' (HUBBERT & RUBEY, 1959). Even a more rapid turbidite sedimentation along, but not on top of an active thrust front might suffice to compensate for the rising of the toe. In that case, slip would decrease upward as the thrust became gradually smothered in syntectonic sediments (a possible example -Palazzuolo thrust near the Sillaro line- has been mentioned).

Otherwise, the gravitational potential of a rising frontal bulge should ultimately favour the formation of a new thrust front farther forward. Thus, a slice of the footwall may be incorporated to constitute a new toe to the original thrust sheet. It is easy to imagine the Castel Guerrino, Nero and Castellaccio units as successive strips of 'Ultra-Romagnan' footwall annexed by the Falterona nappe. And repetition of the process can account for the final overthrust of the parautochthon. Like the beds above them, all these thrust planes probably flatten out towards the back, to merge into one principal overthrust.

Of course, these speculations do not prove anything – except that there is no need to reject *a priori,* on mechanical grounds, the field evidence for synsedimentary overthrusts in the Romagna.

REFERENCES

Carta Geologica d'Italia 1: 100 000, 2nd Ed. (1969), sheets 107, 108, 115.

De Jager, J. 1979 The relation between tectonics and sedimentation along the 'Sillaro line' (Northern Apennines, Italy) – Geol. Ultraiectina 19: 1-98.

Elliott, D. 1976 The motion of thrust sheets – J. Geophys. Res. 81: 949-963.

Frey, W. 1969 Zur Geologie des Grenzgebietes Alta Romagna – Casentino SE des Passo dei Mandrioli – Diss. Freie Univ. Berlin: 182 pp.

Giannini, E., R. Nardi & M. Tongiorgi 1962 Osservazioni sul problema della falda toscana – Boll. Soc Geol. Italia 81: 1-81.

Grosscurth, J. 1971 Zur Geologie der Randgebiete des W-Teils des Mugello-Beckens östlich der Prato-Sillaro 'Linie' – Diss. Freie Univ. Berlin: 215 pp.

Hemmer, C. 1966 Geologische Untersuchungen in einem Gebiet zwischen Treppio und Setta, Bologneser Apennin – Diss. Freie Univ. Berlin: 108 pp.

Hubbert, M. K. & W. W. Rubey 1959 Role of fluid pressure in mechanics of overthrust faulting – Bull. Geol. Soc. Amer. 70: 115-166.

Sestini, G. (ed.) 1970 Development of the Northern Apennines geosyncline – Sedim. Geol. 4: 203-647.

Signorini, R. 1937 Il ricoprimento di Casaglia e del Gruppo del M. Carzolano – Boll. Soc. Geol. Italia 56: 385-401.