N. 25 • 2001

MONOGRAFIE DI «NATURA BRESCIANA»

MUSEO CIVICO
DI SCIENZE NATURALI
DI BRESCIA

PERMIAN CONTINENTAL DEPOSITS OF EUROPE AND OTHER AREAS. REGIONAL REPORTS AND CORRELATIONS

Giuseppe CASSINIS (*Editor*)

PERMIAN CONTINENTAL DEPOSITS OF EUROPE AND OTHER AREAS.
REGIONAL REPORTS AND CORRELATIONS

MONOGRAFIE DI «NATURA BRESCIANA»

MUSEO CIVICO DI SCIENZE NATURALI DI BRESCIA
via Ozanam, 4 - 25128 Brescia (Italia)

«NATURA BRESCIANA»
Direttore responsabile: MASSIMO TEDESCHI
Autorizzazione del Tribunale di Brescia N. 33 del 3-VI-1998
Realizzazione editoriale: GRAFO edizioni - Brescia
Stampa: STA.G.ED. - San Zeno Naviglio (Brescia)

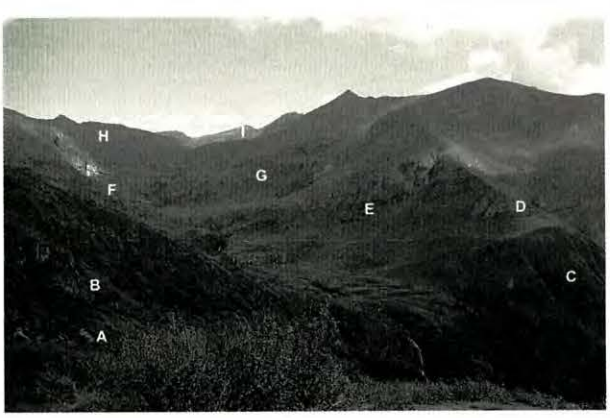
MONOGRAFIE DI
«NATURA BRESCIANA»

MUSEO CIVICO
DI SCIENZE NATURALI
DI BRESCIA

N. 25 • 2001

PERMIAN CONTINENTAL DEPOSITS OF EUROPE AND OTHER AREAS. REGIONAL REPORTS AND CORRELATIONS

Giuseppe CASSINIS (*Editor*)



Front Cover Explanation

The Permian continental succession in the Val Trompia Basin (Central Southern Alps, Italy). It consists of calcalkaline acidic to intermediate volcanics (A, B, D, H) and alluvial to lacustrine (C, E, F, G) deposits, which are unconformably overlain by the Upper Permian fluvial redbeds of the Verrucano Lombardo (I).
Above, one of the first tetrapod footprints (interpreted as *Amphisauropus latus* by Ceoloni *et al.*, 1987), together with a tail drag. These were probably found in the upper part of member "C" near Malga Cuta (now called "Stabul Maggiore"), approximately two kilometres west of the basin. The discovery was made by curate Giovanni Bruni (1816-1880) (see photograph) on 23 September 1873.

CONTENTS

1.2. OTHER REGIONS

2. NON-EUROPEAN TERRITORIES AND GLOBAL MATTERS

LIST OF CONTRIBUTORS

1. S.A. Afonin, Paleontological Institute, 123 Profsoyusnaya Street, 117647 Moscow, Russia.
2. M. Aldinucci, Dipartimento di Scienze della Terra dell'Università, 8 Via Laterina , 53100 Siena, Italy. E-mail: <aldinuccimau@unisi.it>; Fax: +39 0577 233938; Tel. +39 0577 233971.
3. E. Arranz Yagüe, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 12 Pedro Cerbuna, 50009 Zaragoza, Spain. E-mail: <earranz@posta.unizar.es>; Fax: +34 (0)976 761088; Tel.: +34 (0)976 761072.
4. M. Avanzini, Museo Tridentino di Scienze Naturali, 14 Via Calepina, 38100 Trento, Italy. E-mail: <avanzini@mtsn.tn.it>; Fax: +39 0461 233830; Tel.: +39 0461 270312.
5. L. Benciolini, Dipartimento di Georisorse e Territorio dell'Università, 114 Via Cotonificio, 33100 Udine, Italy.
6. C. Beretta, Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, 26 Corso Europa, 16132 Genova, Italy. E-mail: <beretta@dister.unige.it>; Fax: +39 010 352169; Tel.: +39 010 3538137.
7. B. Bonin, Université de Paris-Sud, Département des Sciences de la Terre, 91405 Orsay cedex, France. E-mail: <bbonin@geol.u-psud.fr>; Fax: +33 (0)1 69156772; Tél.: +33 (0)1 69156766.
8. C. Breitkreuz, Institut für Geologie, Lehrstuhl für Allgemeine und Historische Geologie, TU Bergakadamie Freiberg, 2 Bernhard-von-Cotta Str., 09596 Freiberg, Germany. E-mail: <cbreit@geo.tu-freiberg.de>, Fax: +49 (0)3731 393599; Tel.: +49 (0)3731 393126.
9. J. Broutin, Université Pierre et Marie Curie, Paris 6, Lab. de Paléobotanique et Paléoécologie, 12 rue Cuvier, 75005 Paris, France. E-mail: <jean.broutin@snv.jussieu.fr>; Fax: +33 (0)1 44376513; Tél.: +33 (0)1 44274865.
10. B.V. Burov, Geological Faculty of Kazan State University, 18 Kremlevskay Str., 420008 Kazan, Russia. E-mail: <boris.burov@ksu.ru>.
11. F. Bussy, Institut de Minéralogie et Pétrographie, Université de Lausanne, BFSH 2, 1015 Lausanne, Switzerland. E-mail: <francois.bussy@imp.unil.ch>.
12. B. Cabanis, Université Pierre et Marie Curie, Paris 6, Géochimie, 75005 Paris, France. E-mail: <cabanis@ipgp.jussieu.fr>.
13. N. Capuzzo, Geologisch-Paläontologisches Institut, Universität Basel, 32 Bernoullistr., 4056 Basel, Switzerland. E-mail: <nicola.capuzzo@unibas.ch>; Fax: +41 (0)61 2673613; Tel.: +41 (0)61 2673607.
14. G. Cassinis, Dipartimento di Scienze della Terra dell'Università, 1 Via Ferrata, 27100 Pavia, Italy. E-mail: <cassinis@unipv.it>; Fax: +39 0382 505890; Tel.: +39 0382 505834.
15. P. Ceoloni, 24 Via Pestalozzi, 00168 Roma, Italy.
16. J.J. Châteauneuf, 8 Quai du Châtelet, 45000 Orléans, France. E-mail: <chateauboy@wanadoo.fr>; Tél/Fax: +33 (0)238 627299.
17. C. Checchia, 18 Fürstenstr., 14163 Berlin, Germany.
18. J.A. Clement-Westerhof, Lab. Palaeob. Palyn., Utrecht Univ., 4 Budapestlaan, 3584 CD Utrecht, The Netherlands
19. M.A. Conti, Dipartimento di Scienze della Terra, Università "La Sapienza", 5 P.le A. Moro, 00185 Roma, Italy. E-mail: <sandra.conti@uniroma1.it>; Fax:+39 06 4454729; Tel.: +39 06 49914801.
20. L. Cortesogno, Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, 26 Corso Europa, 16132 Genova, Italy. E-mail: <cortez@dister.unige.it>; Fax: +39 010 352169, Tel.: +39 010 3538304.
21. R. Damotte, Université Pierre et Marie Curie, Paris 6, Lab. de Micropaléontologie, 4 Place Jussieu, 75005 Paris, France. Fax: +33 (0)1 44273831.
22. J.P. Deroin, Université Michel de Montaigne, EGID Bordeaux III, 33607 Pessac cedex, France. E-mail: <deroin@egid.u-bordeaux.fr>; Fax: +33 (0)5 56848073.
23. M.T. Dunn, Department of Environmental and Plant Biology, Ohio University, Athens, Ohio 45701, USA.
24. M. Durand, Université Henri Poincaré, Nancy I, Sciences de la Terre et UMR G2R, 54506 Vandoeuvre cedex, France. E-mail: <marc.durand@g2r.uhp-nancy.fr>; Fax: +33 (0)383 912589 ou 3831; Tél.: +33 (0)383 912488.
25. N.K. Esaulova, Geological Faculty of Kazan State University, 18 Kremlevskay Str., 420008 Kazan, Russia. E-mail: <nataly.esaulova@ksu.ru>; Fax: +7 (0)8432 928577.
26. D. Fontana, Dipartimento di Scienze della Terra dell'Università, 19 Largo S. Eufemia, 41100 Modena, Italy. E-mail: <dfont@unimo.it>; Fax: +39 059 417399; Tel.: +39 059 2055844.
27. F. Forcella, Dipartimento di Scienze Geologiche e Geotecnologie, Università degli Studi di Milano-Bicocca, 14 Via Emanuele, 20126 Milano, Italy. E-mail: <franco.forcella@unimib.it>; Tel.: +39 02 64484233.
28. L. Gaggero, Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, 26 Corso Europa, 16132 Genova, Italy. E-mail: <gaggero@hpe35.dip-

teris.unige.it>; Fax: +39 010 352169; Tel.: +39 010 3538317.

29. C. Galé Bornao, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 12 Pedro Cerbuna, 50009 Zaragoza, Spain. E-mail: <carlosgb@posta.unizar.es>; Fax: +34 (0)976 761088; Tel.: +34 (0)976 762474.
30. G. Gand, Université de Dijon, UMR 5561, du CNRS, Centre des Sciences de la Terre, 6 boulevard Gabriel, 21000 Dijon, France. E-mail: <georges.gand@wanadoo.fr>; Tél./Fax: +33 (0)3 85554218.
31. A. Gandin, Dipartimento di Scienze della Terra dell'Università, 8 Via Laterina, 53100 Siena, Italy, E-mail: <gandin@unisi.it>; Fax: +39 0577 233938; Tel. +39 0577 233805.
32. A. Gil Imaz, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 12 Pedro Cerbuna, 50009 Zaragoza, Spain. E-mail: <agil@posta.unizar.es>; Fax: +34 976 761088.
33. V.I. Gubareva, Geological Faculty of Kazan State University, 18 Kremlevskay Str., 420008 Kazan, Russia.
34. H. Haubold, Martin-Luther-Universität, Institute of Geological Sciences and Geiseltalmuseum, 5 Domstrasse, 06108 Halle, Germany. E-mail: <haubold@geologie.unihalle.de>; Fax: +49 (0)345 5527179; Tel.: +49 (0)345 5526100.
35. H. Kerp, Westf. Wilh.-Univ., Abt. Paläob. am Geol.-Paläont., Institut u. Museum, 57-59 Hindenburgplatz, 4400 Münster, Germany. E-mail: <kerp@uni-muenster.de>; Fax: +49 (0)251 834831; Tel.: +49 (0)251 833933.
36. V.A. Krassilov, Paleontological Institute, 123 Profsoyusnaya Street, 117647 Moscow, Russia.
37. B. Krstic, Geoinstitut, 12 Rovinjska, Beograd-22 11050, Yugoslavia. E-mail: <n krstic @ptt.yu>.
38. M. Lago San José, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 12 Pedro Cerbuna, 50009 Zaragoza, Spain. E-mail: <mlago@posta.unizar.es>; Fax: +34 (0)976 761088; Tel.: +34 (0)976 761069.
39. E. Lasheras Adot, Facultad de Ciencias Biológicas, Departamento de Química y Edafología, Universidad de Navarra, C/ Irunlarrea s/n, 31080 Pamplona, Spain. E-mail: elasheras@unav.es; Fax: +34 (0)948 425649; Tel.: +34 (0)948 426326.
40. G. Leonardi, 2 Via A. Modigliani, 80078 Monterusciello, Pozzuoli, Italy.
41. Zhuoting Liao, Nanjing Institute of Geology and Palaeontology, Academia Sinica, 39 East Beijing Road, 210008 Nanjing, China. E-mail: <paleobot@public1.ptt.js.cn>; Fax: +86 (0)25 3357026; Tel.: +86 (0)25 6637526.
42. Lujun Liu, Nanjing Institute of Geology and Palaeontology, Academia Sinica, 39 East Beijing Road, 210008 Nanjing, China.
43. C.V. Looy, Lab. Palaeob. Palyn., Utrecht Univ., 4 Budapestlaan, 3584 CD Utrecht, The Netherlands.
44. V.R. Lozovsky, Moscow Geological Prospecting Academy, 23 Miklucho-Maklay Str., 117873 Moscow, Russia. E-mail: <vlozovsky@mtu-net.ru>; Fax: +7 (0)95 1622621; Tel.: +7 (0)4389058.
45. S.G. Lucas, New Mexico Museum of Natural History & Science, 1801 Mountain Road NW, Albuquerque, NM 87104, USA. E-mail: <lucas@darwin.nmmnh-abq.mus.nm.us>; Fax: +1 (0)505 8412866; Tel.: +1 (0)505 8412873.
46. E.O. Malysheva, Institute of Geology Komi Science Center, Russian Academy of Sciences, 54 Pervomayskaya st., 167610 Syktyvkar, Russia. E-mail: <malysheva@geo.komisc.ru>; Fax: +7 (0)8212 425346; Tel.: +7 (0)8212 425181.
47. R. Manni, Dipartimento di Scienze della Terra, Università "La Sapienza", 5 P.le A. Moro, 00185 Roma, Italy. E-mail: <riccardo.manni@uniroma1.it>; Fax: +39 06 4454729; Tel.: +39 06 49914315.
48. N. Mariotti, Dipartimento di Scienze della Terra, Università "La Sapienza", 5 P.le A: Moro, 00185 Roma, Italy. E-mail: <nino.mariotti@uniroma1.it>; Fax: +39 06 4454729; Tel.: +39 06 49914799.
49. L. Maslarevic, 96 Strumicka, 11000 Beograd, Serbia.
50. M. Menning, GeoForschungsZentrum Potsdam, C128 Telegrafenberg, 14473 Potsdam, Germany. E-mail: <menne@gfz-potsdam.de>; Fax: +49 (0)331 2881302; Tel.: +49 (0)331 2881333.
51. P. Mietto, Dipartimento di Geologia, Paleontologia e Geofisica dell'Università, 1 Via Giotto, 35127 Padova, Italy. E-mail: <paolo.mietto@unipd.it>; Fax: +39 049 8272070; +39 049 8272079.
52. C. Muraro, 15 Via Ninfa, 04100 Latina, Italy.
53. C. Neri, Dipartimento di Scienze Geologiche e Paleontologiche dell'Università, 32 Corso Ercole I d'Este, 44100 Ferrara, Italy. Fax: +39 0532 206468; Tel.: +39 0532 293715.
54. I. Nicolae, Geological Institute of Romania, 1 Caransebes Str., 79678 Bucharest, Romania
55. U. Nicosia, Dipartimento di Scienze della Terra, Università "La Sapienza", 5 P.le A. Moro, 00185 Roma, Italy. E-mail: <unicosia@uniroma1.it>; Fax:+39 06 4454729; Tel.: +39 06 49914800.
56. G. Oaie, National Institute of Marine Geology and Geoecology, Geoecomar, 23-25 D. Onciul Str., 78318 Bucharest, Romania. E-mail: <goaie@roliuk.iiruc.ro>; Fax: +40 (0)1 2522594; Tel.: +40 (0)1 2525512.
57. E. Pandeli, Dipartimento di Scienze della Terra dell'Università, 1 Via La Pira, 50121 Firenze, Italy. E-mail: <pandeli@geo.unifi.it>; Fax: +39 055 218628; Tel.: +39 055 2757530.
58. P. Pittau, Dipartimento di Scienze della Terra dell'Università, 51 Via Trentino, 09100 Cagliari, Italy. E-mail: <pittaup@unica.it>; Fax: +39 070 282236; Tel.: +39 070 6757742.
59. B.A. Pocoví Juan, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, 12 Pedro Cerbuna, 50009 Zaragoza, Spain. E-mail: <apocovi@posta.unizar.es>; Fax: +34 976 761088.
60. M.E. Poli, Dipartimento di Georisorse e Territorio dell'Università, 114 Via Cotonificio, 33100 Udine, Italy. E-mail: <poli@dgt.uniud.it>; Fax: +39 0432 558700; Tel. +39 0432 358747.
61. M. Popa, University of Bucharest, Faculty of Geology and

Geophysics, Lab. of Palaeontology, 1 N. Balcescu Ave., 70111 Bucharest, Romania. E-mail: <mihaip@ns.geo.edu.ro>; Fax: +40 (0)1 2113120; Tel.: +40 (0)1 3143128.

62. S. Radrizzani, 28 Via Europa, 20097 San Donato Milanese (MI), Italy. Tel.: +39 02 5274369.
63. A. Ronchi, Dipartimento di Scienze della Terra dell'Università, 1 Via Ferrata, 27100 Pavia, Italy. E-mail: <geoars@unipv.it>; Fax: +39 0382 505890; Tel.: +39 0382 505843.
64. E. Sacchi , 163 Via Trevi, 05100 Terni, Italy.
65. F. Sandrelli , Dipartimento di Scienze della Terra dell'Università, 8 Via Laterina, 53100 Siena, Italy. E-mail: <sandrelli@unisi.it>; Fax: +39 0577 233938; Tel.: +39 0577 233935.
66. G. Santi, Dipartimento di Scienze della Terra dell'Università, 1 Via Ferrata, 27100 Pavia, Italy. E-mail: <gsanti@unipv.it>; Fax: +39 0382 505890; Tel: +39 0382 505895.
67. A. Schäfer, Institute of Geology, University of Bonn, 8 Nassallee, 53115 Bonn, Germany. E-mail: <schaefer@uni-bonn.de>; Fax: +49 (0)228 739037; Tel.: +49 (0)228 732461.
68. T.A. Schiappa, Permian Research Institute, Geosciences Department, Boise State University, Boise, ID 83725, USA. E-mail: <tschiapp@boisestate.edu>; Fax: +1 (0)208 4264061; Tel.: +1 (0)208 3851397.
69. P. Schirolli, Museo Civico di Scienze Naturali, 4 Via Ozanam, 25128 Brescia. E-mail: <pschirolli@comune.brescia.it>; Fax: +39 030 3701048; Tel.: +39 030 2978668.
70. D. Sciunnach, Struttura Analisi e Informazioni territoriali, D.G. Territorio e urbanistica, Regione Lombardia, 4 Piazza Duca d'Aosta, 20124 Milano, Italy. E-mail: <dario_sciunnach@regione.lombardia.it>; Fax: +39 02 67654620; Tel.: +39 02 67656706.
71. A. Seghedi, Geological Institute of Romania, 1 Caransebes Str., 78344 Bucharest, Romania. E-mail: <antoneta@ns.igr.ro>; Fax: +40 (0)1 2240404, Tel.: +40 (0)1 6657530.
72. G.B. Siletto, Struttura Analisi e Informazioni territoriali, D.G. Territorio e urbanistica, Regione Lombardia, 4 Piazza Duca d'Aosta, 20124 Milano, Italy. E-mail: <gian_bartolomeo_siletto@regione.lombardia.it>; Tel. +39 02 67656712; +39 011 6296023.
73. M. Spezzamonte, 2018 San Polo, 30125 Venezia, Italy.
74. C. Spinosa, Permian Research Institute, Department of Geosciences, Boise State University, Boise Idaho, 83725, USA. E-mail: <cspinosa@boisestate.edu>; Fax: +1 (0)208 4264061; Tel.: +1 (0)208 4261581.
75. G.M. Stampfli, Institut de Géologie et Paléontologie, Université de Lausanne, BFSH 2 Dorigny, 1015 Lausanne, Switzerland. E-mail: <gerard.stampfli@igp.unil.ch>; Fax: +41 (0)21 6924305;Tel.: +41 (0)21 6924342.
76. C. Stefani, Dipartimento di Geologia, Paleontologia e Geofisica dell'Università, 1 Via Giotto, 35127 Padova, Italy. E-mail: <cristina.stefani@unipd.it>; Fax: +39.049.8272070; Tel.: +39.049.8272058.
77. J. Utting, Geological Survey of Canada (Calgary), 3303-33rd Str., NW, Calgary, Alberta, T2L 2A7, Canada. E-mail: <jutting@nrcan.gc.ca>; Fax: (403) 292-6014, Tel.: (404) 202-7093
78. D. Visonà, Dipartimento di Mineralogia e Petrologia dell'Università, 37 Corso Garibaldi, 35137 Padova, Italy.
79. H. Visscher, Lab. of Palaeob. and Palyn., Utrecht Universiteit, 4 Budapestlaan, 3584 CD Utrecht, The Netherlands. E-mail: <h.visscher@bio.uu.nl>; Fax: +31 (0)30 531357 or +31 (0)30 2535096; Tel.: +31 (0)31 532634 or +31 (0)30 2532629.
80. S. Voigt, Martin-Luther University, Institute of Geological Sciences, 5 Domstrasse, 06108 Halle, Germany. E-mail: <voigt@geologie.uni-halle.de>; Fax: +49 (0)345 5527179.
81. A. Vozárová, Comenius University, Faculty of Natural Sciences, Department of Mineralogy and Petrology, Mlynská dolina pav. G, 84215 Bratislava, Slovak Republic. E-mail: <vozarova@nic.fns.uniba.sk>; Fax: +42 1760 296293; Tel.: +42 1760 29660681.
82. B. R. Wardlaw, U.S. Geological Survey, 926A National Center, Reston, VA 22092-0001, USA. E-mail: <bwardlaw@usgs.gov>; Fax: +1 (0)703 6485420; Tel.: +1 (0)703 6485288.
83. S. Yanev, Geological Institute of the Bulgarian Academy of Sciences, "Acad. G. Bonchev" Str., Bl. 24, 1113 Sofia, Bulgaria. E-mail: <snyanev@router.geology.bas.bg>; Fax: +359 (0)2 724638; Tel.: +359 (0)2 9792280.
84. O.P. Yaroshenko, Geological Institute, 7 Pyzhevski, 109017 Moscow, Russia.
85. A. Zanferrari, Dipartimento di Georisorse e Territorio dell'Università, 114 Via Cotonificio, 33100 Udine, Italy. E-mail: <zanferrari@dgt.uniud.it>; Fax: +39 0432 558700; Tel. +39 0432 558740.
86. P.A. Ziegler., Geological-Palaeontological Institute, University of Basel, 32 Bernoullistr., 4065 Basel, Switzerland; home: Kirchweg 41, Binningen 4102, Tel. & Fax +41 (0)61 4215535.

PREFACE

The papers assembled in this special volume by the Museum of Natural Sciences of Brescia represent the preliminary research on the subject "Late Palaeozoic stratigraphic and structural evolution in Alpine and Apennine sectors. Comparison with Sardinia and other areas of the western Mediterranean", which was co-financed by the Ministry of University and Scientific and Technological Research (MURST) in 1998. In addition to the aforementioned project, other regions, both in Europe and outside, have been included.

The present volume generally focuses only on the continental domains, contrary to the Brescia "Abstracts" which consist of a larger number of papers (60) that also cover marine areas and other topics.

These preliminary results will certainly be followed by others at the second meeting of the above research project, which will be held in Siena, in April/May 2001, when new ideas about the Permian evolution will be highlighted on a wider scale. Consequently, we want to encourage further investigations, *i.e.* related to the continental geology, which is still scarcely known. Moreover, the interpretations arising could indirectly stimulate the research activity of the "Continental Permian Working Group", founded some years ago by the executive board of the IUGS Subcommission on Permian Stratigraphy (SPS).

This foreword is now followed by the transcription of some speeches given by Prof. Paolo Corsini, the Mayor of Brescia, and Prof. Mario Vanossi, Director of the Earth Science Department and Head of the CNR "Alps Group" in Pavia, and Member of the Italian Geological Society Council.

OPENING SPEECHES

Ladies and Gentlemen,

As Mayor of Brescia, I have great pleasure in welcoming you to the Civic Museum of Natural Sciences with the aim of participating in this Congress on the "Continental Permian". As people say, this meeting deals with a research field which stimulates considerable interest among geologists, as that period lies between the Hercynian orogeny and the Alpine cycle, accompanied by paleontological, stratigraphical, petrographical, paleogeographical and geodynamic changes of worldwide importance.

From the first half of the 1900s, the Permian of the Brescian Pre-Alps already attracted the attention of Italian and foreign researchers, and Brescia was also the site of an unforgettable field trip throughout the Permian and the Permian-Triassic boundary of the central-eastern Southern Alps, in July 1986. As a consequence, Brescia and the Town Council are very pleased to receive you again in this Museum, so that your research can be debated, new evidence possibly discovered, and excellent results achieved.

Furthermore, I fully support the activity of this didactic and scientific centre, and the work carried out and still to be developed in other research sectors, along with a number of other organisations. In addition to make your stay in Brescia easier, in agreement with the Director of the Museum, Dr. Marco Tonon, the Curator of Earth Sciences of the Museum, Dr. Paolo Schirolli, and the Organising Committee of this meeting, we have also agreed to publish the proceedings in a special volume, of monographic type, in the local review «Natura Bresciana». I hope that this decision can be interpreted as a sign of our sincerity and sense of collaboration.

Finally, I want to thank everyone who has contributed to the organisation of this meeting, and all who wish to take part in this scientific initiative.

Buon lavoro a tutti!

Prof. Paolo Corsini
Mayor of Brescia

Good morning and welcome to everybody

The research group that I represent is currently known as the "Alps Group", although its complete definition would be "Research Group on the Geodynamics of the Alpine-Apennine System". Founded in the late 1950s, it is one of the oldest groups of the National Council of Research, uniting researchers from ten different universities of northern Italy, in order to share specific competencies and knowledge applied to some main projects: from the pre-Alpine setting, up to the present-day evolution of the chain and its foredeeps.

One of the principal projects is to investigate the Permian-Upper Carboniferous covers of the basements, and to acquire further knowledge about processes (magmatism, sedimentation, tectonics) during the post-collisional Variscan history, as well as timing and mutual relationships. This topic is not only very interesting, but also allows us to verify how and to what extent the pre-Alpine setting influenced location, geometries and evolution of the subsequent Mesozoic continental margins. Moreover, knowledge of the post-collisional evolution of the Variscan chain might provide models that can be used when comparing the younger Alpine chain.

Research on Late Paleozoic history has been carried out for more than 30 years by some of the universities in the Group, particularly the University of Pavia. So, when Prof. Giuseppe Cassinis submitted his programme for this meeting which involved not only the Southern Alps, but also the Sardinia sector, the proposal was greatly appreciated by the "Alps Group".

This Group is much indebted to the organisers of this meeting for the scientific coordination and the realisation of the two field-excursions in Sardinia and the Southern Alps, respectively.

We also wish to thank all the participants, and especially those who will present their work at this Conference. The collaboration of the Museum of Natural Sciences of Brescia is also gratefully acknowledged.

As to my wishes: discuss, fight – if necessary – and, above all, enjoy yourselves.

Don't worry if, sometimes, confusion seems to arise from discussions. As Friedrich Nietzsche, the German philosopher, stated, "one must have chaos inside himself to generate a dancing star". If so, may each one of you have his own brilliant dancing star!

Long life to Permian times and to everyone here. Thank you.

Mario Vanossi
Director of
the Earth Science Dept.,
University of Pavia

1. EUROPE

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 17-34

LATE PALAEOZOIC-EARLY MESOZOIC PLATE BOUNDARY REORGANIZATION: COLLAPSE OF THE VARISCAN OROGEN AND OPENING OF NEOTETHYS

PETER A. ZIEGLER [1] and GÉRARD M. STAMPFLI [2]

Key words – Variscan orogen; Pangea; Apulia; plate reorganization; wrench tectonics; rifting; back-arc extension; Palaeotethys; Neotethys; Cimmerian orogeny; Carboniferous; Permian; Triassic sedimentation.

Abstract – Late Palaeozoic suturing of Laurussia and Gondwana was accompanied and followed by a major plate boundary reorganization that involved subduction progradation from the Hercynian suture in the interior of Pangea to its peripheries and detachment of the Cimmerian composite terrane from the non-collisional northern margin of Gondwana, entailing Permo-Triassic opening of Neotethys.

During the latest Carboniferous-Early Permian Alleghanian orogeny, a dextral translation of Africa relative to Europe gave rise to the development of a conjugate shear system that transected the Variscan fold belt and its northern foreland. Collapse of the Variscan orogen was accompanied by regional uplift, the subsidence of an array of transtensional and pull-apart basins and widespread magmatism that can be related to the detachment of subduction slabs and possibly mild plume activity. With the Mid-Permian consolidation of the Alleghanian orogen, tectonic and magmatic activity abated in the Variscan domain. Its Late Permian and Triassic evolution was dominated by thermal relaxation of the lithosphere, southward propagation of the Arctic-North Atlantic and westward propagation of the Tethys rift systems.

Back-arc rifting, controlled by roll-back of the Palaeotethys subduction zone, caused Permo-Triassic opening of the oceanic Meliata-Maliak and the Svanetia-Küre-Karakaya system of basins. Late Permian and Triassic opening of the East-Mediterranean branch of Neotethys was accompanied by progressive closure of the western parts of Palaeotethys, culminating in Middle and Late Triassic collision of the Greater Apulia terrane with the Pelagonia block that had been detached from Europe in conjunction with opening of the Meliata-Maliak basin. Similarly, Late Triassic collision of Cimmerian terranes with the eastern, Pontides parts of the Palaeotethys arc-trench system was accompanied by closure of the Svanetia-Küre-Karakaya back-arc basins during the Early Cimmerian orogeny.

In the Variscan domain, Late Palaeozoic-Early Mesozoic continental series can be grossly subdivided into a latest Carboniferous-Early Permian syn-tectonic and a Late Permian-Early Triassic post-tectonic cycle. The latter was diachronously interrupted by the onset of rifting and the Early Cimmerian orogeny. The Tethys rift system provided avenues for Late Permian and Triassic transgressions of the Tethys seas. The Norwegian-Greenland Sea rift system paved the way for the Late Permian Zechstein Sea transgression into Western and Central Europe. The Illawarra magnetic reversal and the end-Permian isotope anomalies provide a-biotic chronostratigraphic markers that take priority over biostratigraphic correlations.

Parole chiave – Orogene Varisico; Pangea; Apulia; riorganizzazione di zolle; tettonica trascorrente; *rifting*; Paleotetide; Neotetide; Orogenesi Cimmerica; Carbonifero; Permiano; sedimentazione triassica.

Riassunto – La formazione e la chiusura della sutura tardo-paleozoica tra Laurussia e Gondwana fu accompagnata e seguita da una riorganizzazione d'ordine maggiore dei limiti delle zolle, che coinvolse la progradazione della subduzione dalla sutura ercinica, posta all'interno della Pangea, verso le sue zone periferiche, nonché il distacco del *terrane* composito cimmerico dal margine settentrionale non collisionale del Gondwana, che comportò l'apertura permo-triassica della Neotetide.

Durante l'Orogenesi Appalachiana, tra la fine del Carbonifero e il Permiano inferiore, una traslazione sinistra dell'Africa rispetto all'Europa generò lo sviluppo di un sistema coniugato di tagli che segmentò la catena a pieghe varisica ed il suo avampaese settentrionale. Il collasso dell'Orogene Varisico fu accompagnato da un sollevamento regionale, dalla subsidenza di un insieme di bacini transtensivi e di *pull-apart*, e da un esteso magmatismo che può essere riferito al distacco di *slab* di subduzione e possibilmente a un'attività di pennacchi a temperatura moderata (*mild plumes*). Con il consolidamento nel Permiano medio dell'Orogenesi Appalachiana, l'attività tettonica e magmatica si affievolì nel dominio varisico. La sua evoluzione tardo-permiana e triassica fu dominata da un rilassamento termico della litosfera, una propagazione verso sud della zona artica-nord atlantica e una propagazione verso ovest dei sistemi di rift tetidei.

Un *rifting* di retro-arco, controllato dall'arretramento (*roll-back*) della zona di subduzione della Paleotetide, determinò l'apertura permo-triassica del sistema di bacini oceanici di Meliata-Maliak e di Svanetia-Küre-Karakaya.

L'apertura tardo-permiana e triassica del ramo mediterraneo orientale della Neotetide fu accompagnata da una progressiva chiusura dei settori occidentali della Paleotetide, culminante nella collisione medio- e tardo-triassica del *terrane* della *"Greater Apulia"* con il blocco della Pelagonia, che iniziò a distaccarsi dall'Europa in concomitanza con l'apertura del bacino di Meliata-Maliak. Analogamente, la collisione tardo-triassica dei *terranes* cimmerici con i settori della Pontide occidentale appartenenti al sistema arco-fossa della Paleotetide fu accompagnato,

[1] Geological-Palaeontological Institute, University of Basel, Bernoullistr. 32, 4065 Basel, Switzerland.
[2] Geological-Palaeontological Institute, University of Lausanne, BFSH 2 Dorigny, 1015 Lausanne, Switzerland.

durante le fasi iniziali dell'orogenesi cimmerica, dalla chiusura dei bacini di retro-arco di Svanetia-Küre-Karakaya.
Nel dominio varisico, le serie continentali tardo-paleozoiche e mesozoiche inferiori possono essere grossolanamente suddivise in un ciclo sin-tettonico, intercorrente tra la fine del Carbonifero e il Permiano inferiore, e un ciclo post-tettonico, sviluppatosi tra il Permiano superiore e il Triassico inferiore. Quest'ultimo fu diacronicamente interrotto dall'inizio del *rifting* e dalle fasi iniziali dell'orogenesi cimmerica. Il sistema di *rift* della Tetide aprì vie alle trasgressioni tardo-permiane e triassiche dei mari della Tetide. Così, il sistema di *rift* dei Mari di Norvegia e della Groenlandia portò alla trasgressione tardo-permiana del Mare dello Zechstein nell'Europa occidentale e centrale. L'inversione magnetica nota come Illawarra e le anomalie isotopiche registrate alla fine del Permiano sono indicatori cronostratigrafici abiologici d'importanza prioritaria rispetto alle correlazioni biostratigrafiche.

INTRODUCTION

Late Carboniferous-Early Mesozoic times correspond to a period of global plate boundary reorganization that was presumably also accompanied by a reorganization of the deep mantle convection systems (Ziegler, 1993 a, b; Ziegler *et al.*, in press).

With the Late Carboniferous and Early Permian consolidation of the Variscan and Appalachian-Mauretanides-Ouachita-Marathon orogens, respectively, the Hercynian suturing process of Laurussia and Gondwana came to an end (Ziegler, 1989, 1990). However, during the Permian and Triassic, orogenic activity persisted in the Uralian system, along which Kazakhstan and Siberia were welded to the eastern margin of Laurussia (Zonenshain *et al.*, 1990; Matte, 1995; Nikishin *et al.*, 1996), as well as along the southern margin of Eurasia that was associated with the Palaeotethys subduction zone (Sengör *et al.*, 1984; Ricou, 1995). Locking of the Hercynian sutures in the centre of Pangea was accompanied and followed by accelerated orogenic activity along the American, Antarctic and Australian Panthalassa margins of Pangea (Proto-Cordillera: St. John, 1986; Ziegler, 1989, 1993 a; Visser & Praekelt, 1998). This reflects a first-order subduction progradation from the interior of Pangea to its peripheries. This important plate boundary reorganization was accompanied by a counterclockwise rotation of Pangea, amounting to 20° during the Permian and a further 17° during the Triassic around a pole located in the Gulf of Mexico (Ziegler, 1993 a).

Pangea apparently had an insulating effect on the deep mantle convection systems that were active during its Carboniferous and Early Permian suturing phases, causing the decay of old down-welling cells (Guillou & Jaupart, 1995). Moreover, accumulation of large amounts of subducted cool oceanic lithosphere near the core-mantle boundary apparently had a cooling effect on the outer core, causing changes in its convection pattern and the related geomagnetic field, as evident by the Late Carboniferous-Permian Reverse Superchrone (CPRS; "Kiaman Magnetic Interval"; Irving & Parry, 1963; Eide & Torsvik, 1996), that commenced during the Westphalian C (±310 Ma, Menning, 1995; Menning *et al.*, 1997) and terminated with the early Tatarian Illawarra reversal (265 Ma, Menning, 1995; Benek *et al.*, 1996; Menning & Jin, 1998). During the Late Permian and Triassic, the modern bi-polar deep mantle convection system began to develop, one branch of which welled up under the core of Pangea and now lies beneath Africa (Cadek *et al.*, 1995). This is compatible with the lower Tatarian resumption of frequent magnetic field reversals (Permo-Triassic Mixed Superchrone, PTMS, Menning, 1995) that 15 My later was followed by major mantle-plume activity at the Permo-Triassic transition (251 Ma; Courtillot *et al.*, 1999; Nikishin *et al.*, in press a). The mantle that welled up and radially flowed out beneath the core of Pangea exerted drag forces on the base of its lithosphere. Constructive interference of these drag forces with plate-boundary forces presumably contributed materially to the Mesozoic break-up of Pangea along its Panafrican, Caledonian and Hercynian sutures that was punctuated by repeated mantle-plume activity (Ziegler, 1990, 1993; Pavoni, 1993; Janssen *et al.*, 1995; Courtillot *et al.*, 1999; Ziegler *et al.*, in press).

CONSOLIDATION AND DEMISE OF THE VARISCAN OROGEN

Evolution of the Variscan orogen involved the step-wise accretion of Gondwana-derived terranes to the southern margin of Laurussia and ultimately the Late Devonian-Early Carboniferous collision of the northwestern margin of Africa with Iberia (Ziegler, 1989, 1990; Matte, 1991; Stampfli *et al.*, 1991; Stampfli, 1996, 2000; Tait *et al.*, 1997; Unrug *et al.*, 1999). During the Carboniferous main phases of the Variscan orogeny, the collision front between Gondwana and Laurussia propagated eastward and southwestward in conjunction with progressive closure of the Palaeotethys and Protoatlantic oceans. By Westphalian time, Gondwana had collided with the North American craton whereas to the east the Palaeotethys was still open (Fig. 1; Stampfli, 2000; Stampfli *et al.*, in press). Correspondingly, the western parts of the Variscan orogen were characterized by a Himalayan-type setting (continent-continent collision) whereas its eastern parts, that find their prolongation in the Scythian orogen, remained in an Andean-type setting (continent-ocean collision). Subduction of large volumes of oceanic and continental crust and sediments along a system of subduction zones associated with the Palaeotethys arc-trench system, the boundaries between the different Gondwana-derived terranes involved in the Variscan orogen, and Devonian-Early Carboniferous back-arc basins, accounted for a pervasive Late Devonian to Carboniferous syn-orogenic calc-alkaline I- and S-type intrusive magmatism (Ziegler, 1990; Matte, 1991; Neubauer & von Raumer, 1993; Bonin *et al.*, 1993; Dallmeyer *et al.*, 1995; von Raumer, 1998; Vigneresse, 1999).

The late Visean to Westphalian main phases of the Variscan orogeny involved major crustal shortening and subduction of commensurate amounts of crustal and mantle-lithospheric material; this was accompanied by the lateral escape of internal, relatively rigid blocks, such as the Aquitaine-Cantabrian, Armorican and Bohemian terranes, and the development of intramontane transtensional basins in which Namurian and Westphalian continental clastics, partly coal bearing, accumulated (*e.g.* Ancenis, Laval, Saar, Saale, Pilzen basins; Ziegler 1990; Matte, 1991; Dallmeyer *et al.*, 1995; Onken *et al.*, 1999). By end-Westphalian times, crustal shortening ceased in the western parts of the Variscan orogen, but persisted in the Appalachian-Mauretanides-Ouachita-Marathon orogen until mid-Permian times, controlling the Alleghanian orogeny. During the latest Carboniferous and Early Permian, the convergence of Gondwana and Laurussia changed from an oblique collision to a dextral translation, culminating by Mid-Permian times in a Pangea A2 continent assembly (a Pangea B assembly in not compatible with geological data and cannot account for the Permo-Carboniferous development of the Ouachita-Marathon orogen; Ziegler 1989, 1990; Matte, 1991; Stampfli *et al.*, in press).

During the Stephanian and Early Permian, the Palaeotethys spreading axis was obliquely subducted beneath the eastern parts of the Variscan and the Scythian orogens (Fig. 2; Stampfli, 1996, 2000; Stampfli *et al.*, in press). At the same time, a dextral translation of Africa relative to Europe, amounting to some 300 to 400 km, gave rise to the development of a conjugate shear system that transected the Variscan orogen as well as its northern foreland, partly terminating in pull-apart basins (*e.g.* Oslo graben). Main elements of this shear system are the dextral Teisseyre-Tornquist, Bay of Biscay, Gibraltar-Minas and Agadir fracture zones. The Gibraltar-Minas fracture zone marked to northern termination of the Alleghanian (Appalachian) orogen (Arthaud & Matte, 1977; Ziegler, 1988, 1990; Coward, 1993). Areas located between these four principal shear zones were transected by a conjugate system of subsidiary shears. At the same time, the Norwe-

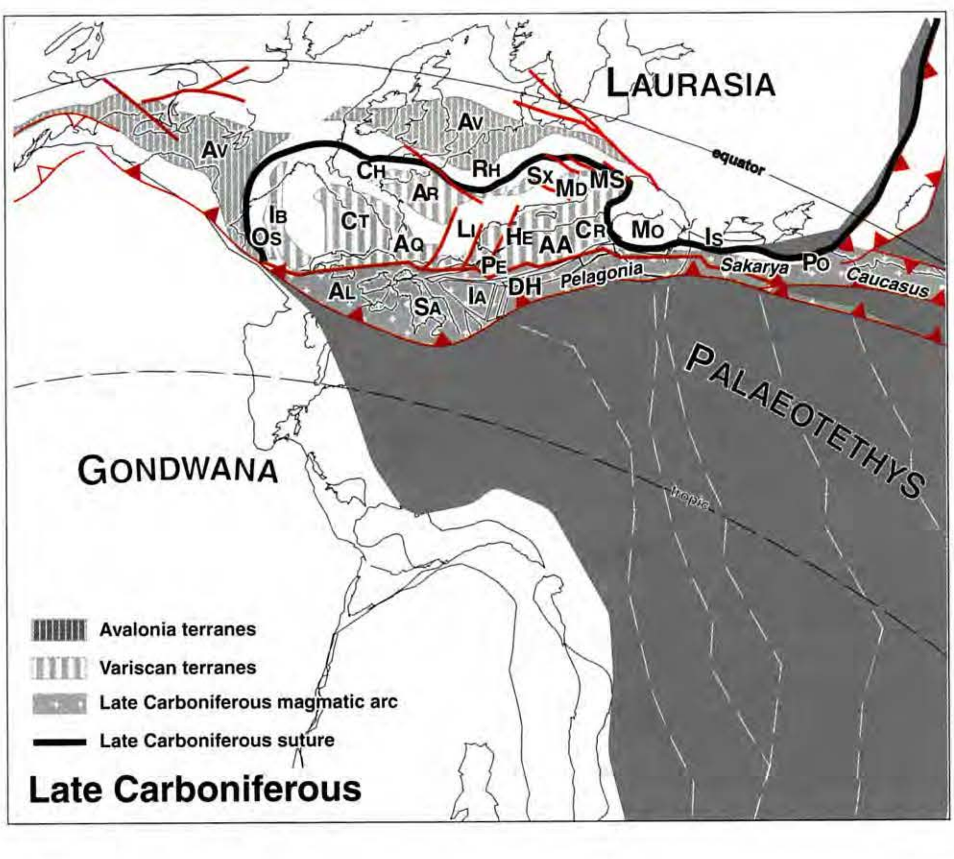


Fig. 1 – Late Carboniferous plate reconstruction, illustrating the Himalayan-type setting of the western parts of the Variscan orogen and the Andean-type setting of its eastern parts. Note subduction of the Palaeotethys sea-floor spreading axis beneath the Scythian orogen (Sakarya-Caucasus domain).

Abbreviations: intra-Variscan Gondwana-derived terranes that were accreted to the southern margin of Laurasia during Silurian to Carboniferous times (shown with different signatures). AA Austroalpine, AL Alboran, AQ Aquitaine, AR Armorica, AV Avalonia, CH Channel, CR Carpathian, CT Cantabria, DH Dinaric-Hellenic, HE Helvetic, IA Intra-Alpine, IB Iberian, IS Istanbul, LI Ligerian, MD Moldanubian, MO Moesia, MS Moravo-Silesia, OS Ossa-Morena, PE Penninic, PO Pontides, RH Rheno-Hercynian, SA South Alpine, SX Saxothuringia.

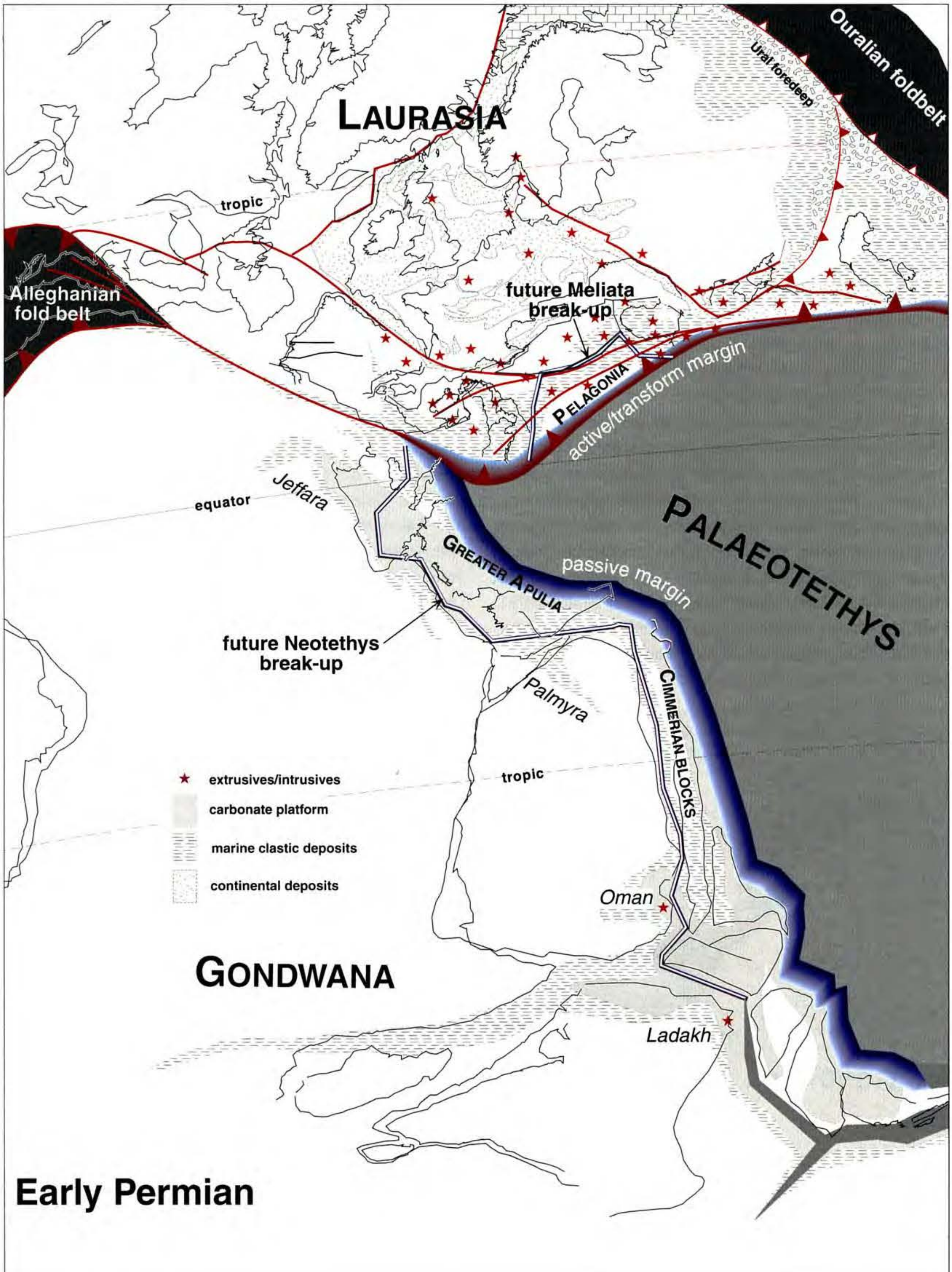


Fig. 2 – Early Permian plate reconstruction, showing trace of Permian rift systems along which the Cimmerian continental terranes were separated from Gondwana and the trace of the Meliata-Maliak back-arc rift system. Palaeogeography shown corresponds to Rotliegend times.

gian-Greenland Sea rift, that had come into evidence already during the Carboniferous main phases of the Variscan orogeny, possibly in response to compressional foreland splitting, was reactivated (Ziegler, 1989, 1990; Smythe *et al.*, 1995). In Western and Central Europe, the Stephanian-Autunian wrench-induced collapse of the rheologically weak, over-thickened crust of the Variscan orogen was accompanied by regional uplift, wide spread extrusive and intrusive magmatic activity that peaked during the Autunian, and the subsidence of an array of multi-directional transtensional trap-door and pull-apart basins in which predominantly continental clastics accumulated (Ziegler, 1990). However, Stephanian marine and transitional marine deposits occur in the wrench-induced basins of Cantabria (Martinez-García & Wagner, 1982) and the South Alpine-Mediterranean domain (Cassinis *et al.*, 1992; Cassinis, 1996). Moreover, also the Stephanian red beds of North Germany contain occasional marine intercalations (Hedemann *et al.*, 1984). On the other hand, throughout the Variscan domain, Early Permian (Autunian) deposits are developed in an entirely continental facies, reflecting its progressive regional uplift. The only exceptions are the South Alpine and Dinaric areas that fringed the evolving Meliata-Maliak back-arc ocean and the Sicilian area that was located on the Palaeotethys shelf (see below; Catalano *et al.*, 1991; Cassinis *et al.*, 1992; Schönlaub, 1993; Cassinis, 1996).

Microtectonic analyses in the Massif Central area indicate for Stephanian-Autunian times a progressive rotation of the principal horizontal compressional stress trajectories from N-S to E-W (Blès *et al.*, 1989). Basins that developed during these times show a complex, polyphase structural evolution, including a late phase of convergent wrench deformation (*e.g.* St. Etienne, Décazeville, Alès basins). Similar stress rotations probably governed the evolution of the wrench-induced Stephanian-Autunian basins in Central Europe and the Alpine domain, development of which generally terminating with a pulse of basin inversion and deep erosion (*e.g.* Saar, Saale and Boscovice basins: see Ziegler, 1990; Aiguilles Rouges basin: Pilloud, 1991; Badertscher & Burkhard, 1998).

Regarding dynamic controls on the post-orogenic collapse of orogens, it must be realized, that deviatoric tensional body forces inherent to the over-thickened lithosphere of an orogen can only come to bear after convergence has ceased and its subducted lithospheric slab(s) has (have) been detached (Fleitout & Froidevaux, 1982; Bott, 1990, 1993). Moreover, post-orogenic thermal re-equilibration of crustal root zones (cooling during rapid subduction of cold foreland lithosphere, followed by post-orogenic heating), involves retrograde metamorphism of eclogites into less dense granulites (Bousquet *et al.*, 1997; Le Pichon *et al.*, 1997). This causes further isostatic uplift of the orogen, thus enhancing its body forces. However, body forces inherent to abandoned orogens are, on their own, unlikely to be sufficiently large to drive apart major cratonic blocks, such as the constituents of a Pangea-type mega-continent (Ziegler, 1993 a). Therefore, it is likely that body forces inherent to the Variscan orogen played only a secondary role during its predominantly wrench-induced Permo-Carboniferous collapse that coincided with the Appalachian suturing phases of Pangea (Ziegler, 1989, 1990; Henk, 1999).

The model of the Cenozoic Basin-and-Range Province has been repeatedly invoked for the Stephanian-Autunian disintegration of the Variscan orogen (Lorenz & Nicholls, 1976, 1984; Jowett & Jarvis, 1984; Ménard & Molenar, 1988; Malavieille, 1993). Despite similarities in the tectonic setting of the Basin-and-Range Province and the Permo-Carboniferous basin system of Europe in terms of subduction of the East Pacific Rise (Verrall, 1989; Parsons, 1995) and the Palaeotethys spreading axis (Stampfli, 1996, 2000), respectively, there are major differences between these two provinces (Ziegler, 1990). The Basin-and-Range Province, which is superimposed on the Andean-type Cordillera, is dominated by a regularly spaced pattern of linear, sub-parallel, partly anastomozing half grabens and intervening horsts; furthermore, it is characterized by frequent core complexes, high strain rates and a large regional extension factor (ß=1.4-1.6; Bally & Snelson, 1980; Eaton, 1982; Coney, 1987; Hamilton, 1987; Oldow *et al.*, 1989; Wernicke, 1992; Parsons, 1995; Westaway, 1999). In contrast, the Permo-Carboniferous basins of Europe are superimposed on the Himalayan-type western parts of the Variscan orogen, as well as on its eastern parts that had remained in an Andean-type setting. These basins are multi-directional, have generally a complex architecture that resulted from syn- and post-depositional transtensional and transpressional deformation, and are closely associated with wrench faults, some of which extend well beyond the northern margin of the Variscan thrust belt (Ziegler, 1990; Bard, 1997; Cassinis *et al.*, 1992, 1997; Cassinis 1996). Moreover, Stephanian and Autunian transtensional and transpressional wrench tectonics gave only locally rise to the development of pull-apart basins and the uplift of core complexes (*e.g.* Massif Central: Malavielle *et al.*, 1990; Burg *et al.*, 1994; Black Forest: Eisbacher *et al.*, 1998). On a regional scale, these wrench tectonics were associated with relatively low crustal stretching factors, as evident, for instance, in the area of the Southern Permian Basin that is mainly located in the Variscan foreland but encroaches in its eastern parts on the Variscan fold-and-thrust belt (van Wees *et al.*, 2000). Nevertheless, and similar to the Basin-and-Range Province (Jones *et al.*, 1992; Parsons, 1995), also the Permo-Carboniferous wrench tectonics of Europe were accompanied by a widespread extrusive and intrusive, mantle-derived alkaline magmatism that shows evidence of strong crustal contamination (Ziegler, 1990; Bonin, 1990; Bonin *et al.*, 1993; Neumann *et al.*, 1995; Marx *et al.*, 1995; Benek *et al.*, 1996; Cortesogno *et al.*, 1998; Breitkreuz & Kennedy, 1999). Melt generation was probably related to localized divergent wrench-induced decompressional partial melting of the uppermost asthenosphere and the lithospheric thermal boundary layer, combined with upwelling of the asthenosphere in response to slab detachment. This was apparently coupled with a rise in the potential temperature of the asthenosphere, possibly related to the impingement of a not very active mantle plume on the base of the lithosphere. Supporting evidence comes from the isotopic signature of the most primitive melts (M. Wilson, pers. comm. 1998). Crustal-scale fractures provided avenues for magma ascent to the surface.

Synorogenic uplift and exhumation of the Variscan internides, up to formerly mid-crustal levels, commenced already during the late Visean and Namurian, partly in conjunction with strike-slip movements related to escape tectonics and the ensuing development of intramontane Namurian (*e.g.* Alpine Zone Houillière: Cortesogno *et al.*, 1993, 1998) and Westphalian neo-autochthonous continental basins (Ziegler, 1990; Henk, 1995, 1999). However, regional uplift of the entire orogen and its foreland began only after crustal shortening had ceased at the end of the Westphalian. Stephanian-Autunian uplift and erosional, as well as tectonic unroofing of the Variscan orogen, in many areas to formerly mid-crustal levels (Burg *et al.*, 1990; Vigneresse, 1999), can be related to a combination of wrench deformation, heating of crustal roots, involving eclogite to granulite transformation (Bousquet *et al.*, 1997; Le Pichon *et al.*, 1997), detachment of subduction slabs, and upwelling and partial melting of the asthenosphere, causing thermal attenuation of the mantle-lithosphere and magmatic inflation of the lithosphere. Mantle derived basic melts that ascended to the base of the crust underplated it, inducing crustal anatexis, fractional crystallisation and the intrusion of granitic to granodioritic-tonalitic melts into the crust (Cortesogno *et al.*, 1998; Breitkreuz & Kennedy, 1999). A unique opportunity to study these processes is offered by the Ivrea Zone where Early Permian mantle-derived (asthenospheric) mafic intrusions caused partial melting of metasediments at basal crustal levels, the ascent of granitic magmas to middle and upper crustal levels, and the development of volcanic activity in contemporaneous wrench-induced basin (Schmid, 1993; P. Brack, pers. comm. 1999). Both retrograde metamorphism of eclogitic roots and the interaction of mantle-derived basic melts with the felsic lower crust contributed to a re-equilibration of the Moho at depth ranges of 30 to 40 km and locally less. By Mid-Permian times, some 40 My after consolidation of the Variscan orogen, its former crustal roots had disappeared.

Permo-Carboniferous wrench tectonics and magmatic activity abated at the transition to the Late Permian, in tandem with the consolidation of the Appalachian orogen (Ziegler, 1989, 1990; Marx *et al.*, 1995).

In view of the above, we feel that kinematics underlying the development of the Cenozoic Basin-and-Range Province in the Cordilleran domain and of the Permo-Carboniferous wrench system transecting the Variscan orogen differ fundamentally to the end that models developed for one of these provinces cannot be indiscriminately extrapolated to the other. Yet, in both cases, ancillary processes inherent to the post-orogenic evolution of an orogen, such as gravitational instability of its over-thickened lithosphere (Dewey, 1988; Braun & Beaumont, 1989), steepening and detachment of subduction slabs, followed by upwelling of the asthenosphere and a mantle derived magmatism, causing thermal thinning of the lithosphere, an increase in heat flow and a commensurate lowering of crustal viscosities, probably contributed to the rapid disintegration of both mountain systems (Coney, 1987; Dilek & Moores, 1999). Subduction of active spreading axes presumably played an important role in slab-detachment beneath the Basin-and-Range and the eastern Variscan and Scythian domains. On the other hand, dextral transform motions between Africa and Europe probably contributed to the rapid detachment of subducted slabs associated with the Himalayan-type western and central parts of the Variscan orogen.

OPENING OF THE NEOTETHYS AND THE MELIATA-MALIAK OCEANS

Following subduction of the Palaeotethys sea-floor spreading axis beneath the eastern Variscan and Scythian orogens, increasingly older and mechanically stronger oceanic lithosphere was subducted. Correspondingly, increasingly larger slab-pull forces were exerted on the non-collisional northeastern margin of Gondwana. Moreover, it is likely that the mantle that welled up and radially flowed out beneath Africa exerted drag forces on the base of its lithosphere. Constructive interference of these mantle drag and slab-pull forces presumably controlled the development of a system of Late Carboniferous-Early Permian rifts along the northeastern peripheries of Africa and Arabia that culminated in the Mid-Permian detachment of the ribbon-like, composite continental Cimmerian terranes from Gondwana (Fig. 3). Continued northward subduction of Palaeotethys beneath the southern margin of Eurasia accounted for the gradual northward migration of these terranes and the Late Permian and Triassic opening of Neotethys (Sengör *et al.*, 1984; Robertson *et al.*, 1996; Stampfli, 1996, 2000; Stampfli *et al.*, 1991 and in press).

Moreover, steepening and roll-back of the Palaeotethys subduction zone, that dipped northwards beneath the eastern Variscan and Scythian orogens, is thought to have controlled the Late Permian and Triassic opening of the oceanic Meliata-Maliak (Kozur, 1991; Stampfli *et al.*, 1991), Crimea-Svanetia (Nikishin *et al.*, in press b), Karakaya (Okay & Mostler, 1994) and Küre (Ustaömer & Robertson, 1994, 1997) back-arc basins (Stampfli, 2000, Stampfli *et al.*, in press; Ziegler *et al.*, in press).

LATE PERMIAN AND TRIASSIC RIFTING AND LITHOSPHERIC RE-EQUILIBRATION

During the Late Permian, and particularly the Triassic, the Norwegian-Greenland Sea rift propagated southwards into the North Atlantic and ultimately the Central Atlantic domain. During the Triassic, the Tethys rift system, that can be related to the opening of the Meliata-Maliak and Neotethys oceans, propagated westwards and interfered

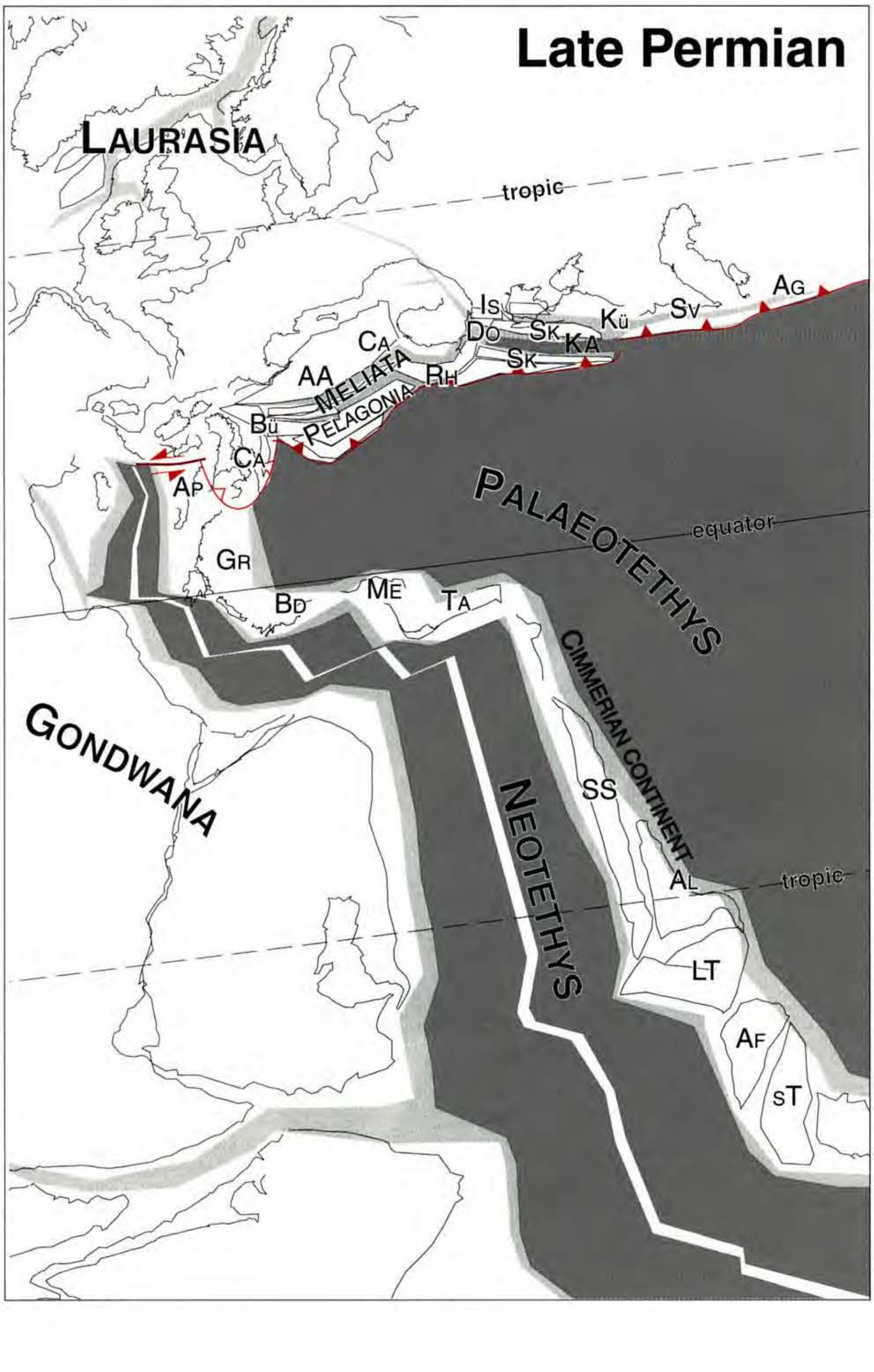


Fig. 3. – Late Permian plate reconstruction, showing opening of Neotethys, detachment of the Cimmerian terranes from the northern margin of Gondwana and opening of back-arc basins along the Eurasian active margin.

Cimmerian Terranes: AP Apulia, GR authochtonous Greece, BD Bey-Daglari, ME Menderes, TA Taurus, SS Sanandaj-Sirjan, AL Alborz, LT Lut-Tabas, AF Central Afghanistan, ST South Tibet.

Eurasian margin: BÜ Bükk, AA Austroalpine, CA Carpathians, RH Rhodope, DO Dobrogea, IS Istanbul, SK Sakarya, EP East Pontides, PL Pelagonia.

Marginal basins: AG Agh-Darband, CR Crimea, KA Karakaya, KÜ Küre, SV Svanetia.

with the Norwegian-Greenland Sea rift system in the Northwest African-Iberian-North Atlantic area. In the process of this, Western and Central Europe, including the Variscan domain, were transected by a complex, multidirectional graben system, some elements of which are superimposed on Permo-Carboniferous fractures (Ziegler, 1988, 1990; Stampfli *et al.*, 1991; Stampfli & Marchant, 1997). Whereas the Permo-Triassic Arctic-North Atlantic and the Triassic West and Central European rifts are essentially non-volcanic, the Late Permian and Triassic Tethyan rifts are characterized by considerable magmatic activity, related to partial melting of the lithospheric thermal boundary layer and upper asthenosphere in response to lithospheric extension (Pamic, 1984; Ziegler, 1988, 1990; Bonin *et al.*, 1987; Bonin, 1989, 1990).

Starting in late Early to early Late Permian times, areas that were not affected by rifting, began to subside in response to the decay of lithospheric thermal anomalies that

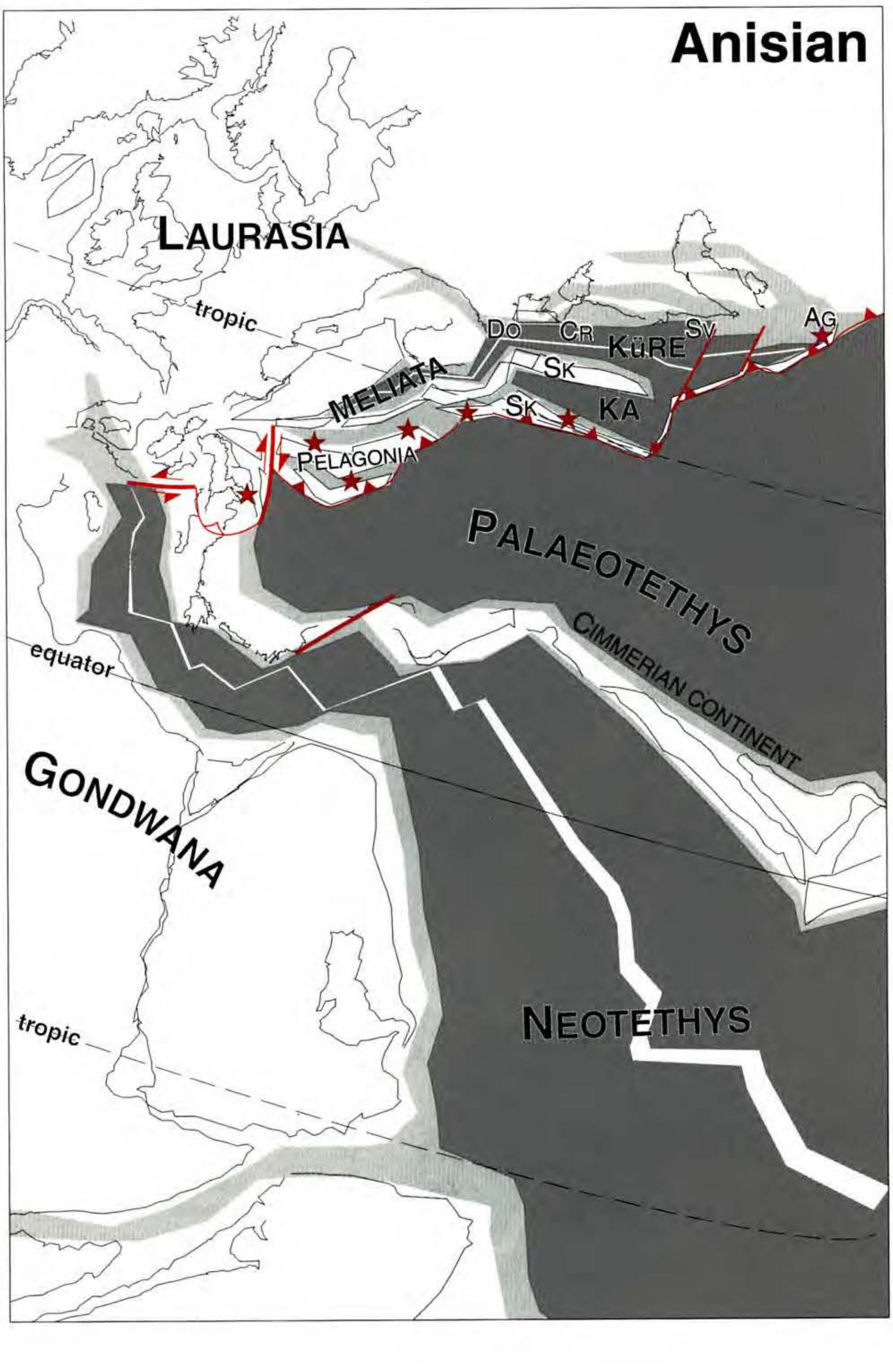


Fig. 4 – Anisian plate reconstruction, illustrating progressive closure of Palaeotethys, opening of the Neotethys and Meliata-Maliak oceans, and initial collision of the Apulia-Greek-Bey-Daglari block with the Pelagonian block and of Cimmerian blocks with the Pontides arc-trench system.

were introduced during the Permo-Carboniferous tectono-magmatic cycle. This is clearly evidenced by the evolution of the Northern and Southern Permian basins that are located in the northern foreland of the Variscan orogen and partly encroach on the latter. In these basins, the continental Upper Rotliegend clastics and the marine Zechstein carbonate-evaporite series accumulated under tectonically rather quiescent conditions (Ziegler, 1990; Plein, 1995; Koronovski, 1999; van Wees *et al.*, 2000). Although the Northern and Southern Permian basins were transected during the Triassic by the North Sea and the Polish-Danish rift systems, their thermal subsidence persisted at least up to the end of the Early Jurassic (Ziegler, 1990; van Wees *et al.*, 2000). Similarly, in the South Alpine domain, Early Permian continental syn-rift series, confined to a system of intramontane transtensional basins, were broadly overstepped by a Late Permian-Early Triassic post-rift sequence consisting of clastics and carbonates. However, this post-rift cycle terminated with the Middle Triassic onset of a new rifting cycle (Bertotti *et al.*, 1993; Cassinis *et al.*, 1997). On a regional scale, progressively larger areas of the deeply truncated Variscan orogen subsided thermally below the erosional base level and were transgressed by the eustatically rising Triassic and Jurassic seas (*e.g.* Paris Basin, South German Franconian Platform; Ziegler, 1990; Schumacher *et al.*, 1999).

CLOSURE OF PALAEOTETHYS AND EARLY CIMMERIAN OROGENY

Late Permian and Triassic opening of the oceanic Neotethys and the Meliata-Maliak back-arc basin had major repercussions on plate kinematics in the western Tethyan area. Progressive closure of the remnant Palaeotethys culminated in the Middle Triassic initial collision of the Cimmerian Apulian-Greek terrane with the Variscan deformed Pelagonia block that had been separated from Europe in conjunction with the opening of the Meliata-Maliak back-arc ocean (Fig. 4). Their suturing gave rise to the "Montenegrian" orogenic pulse of the Southern and Carnic Alps (Brandner, 1984; Castellarin *et*

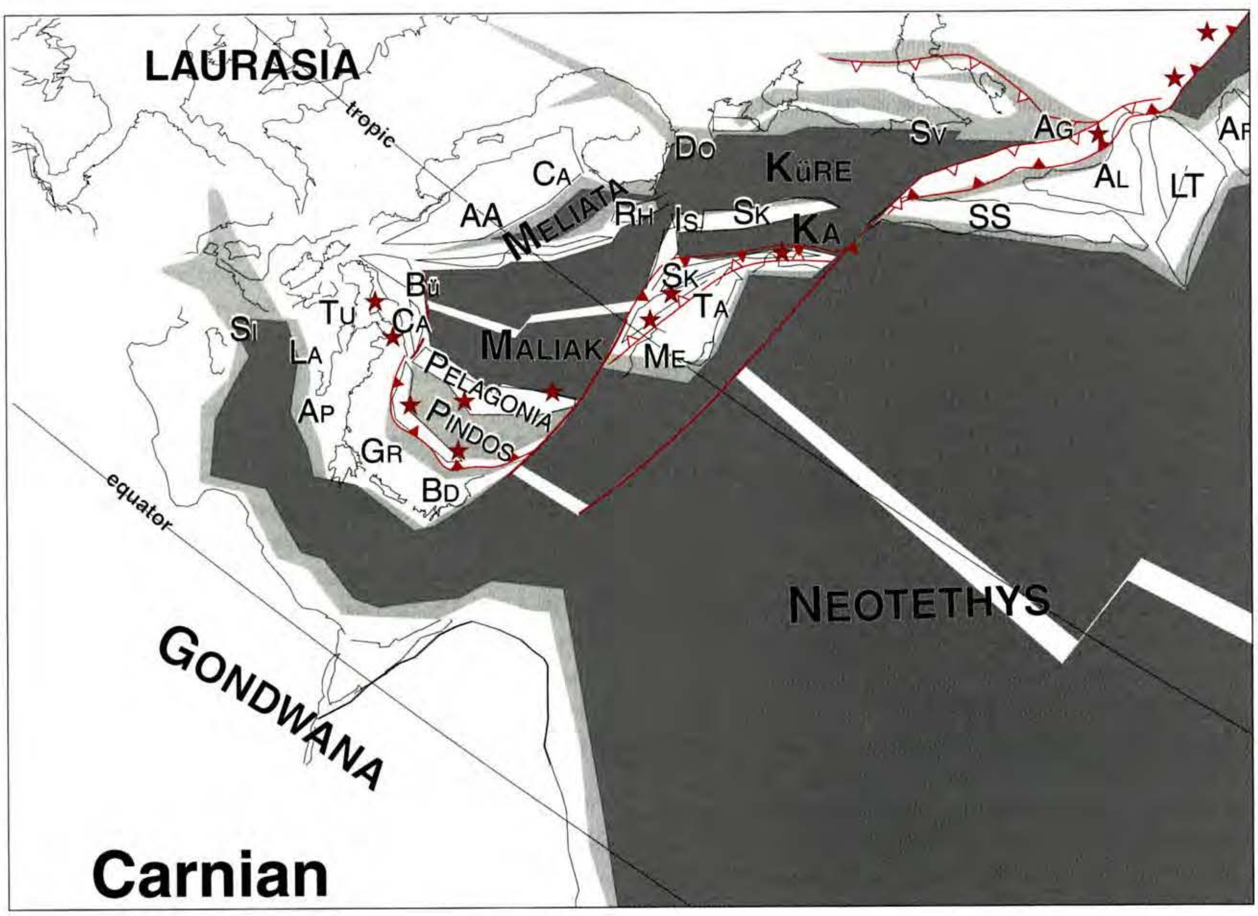


Fig. 5 – Carnian plate reconstruction, illustrating Early Cimmerian accretion of Cimmerian terranes to the Pelagonia block and the Pontides arc-trench system and resulting back-arc compression in the Black Sea domain. The Palaeotethys suture is shown by a broken barbed line. For *abbreviations* see Fig. 3; additional abbreviations: CA Carnic, LA Lagonegro, SI Sicanian, TU Tuscan.

al., 1988), Dinarides, Hellenides and Taurides (Stampfli *et al.*, 1998) that was accompanied by the development of a late Anisian to early Carnian subduction and slab detachment related calc-alkaline to shoshonitic magmatism (Bonadiman *et al.*, 1984; Castellarin *et al.*, 1988; Pe-Piper, 1998; Brack *et al.*, in press), that extended all along the Palaeotethys suture from northern Italy to western Turkey (Stampfli, 2000; Stampfli *et al.*, in press). Moreover, Late Triassic collision of Cimmerian terranes with the Pontides part of the Palaeotethys arc-trench system gave rise to the Cimmerian orogeny during which the Svanetia and Karakaya-Küre back-arc basins were closed (Fig. 5; Nikishin *et al.*, in press b; Stampfli *et al.*, in press).

LATE PALAEOZIC-EARLY MESOZOIC CONTINENTAL SEDIMENTATION

In conjunction with the counter-clockwise rotation of Pangea, the area of Western and Central Europe drifted during the latest Carboniferous out of equatorial latitudes into the northern trade wind belt (Ziegler, 1993 a). At the same time, post-orogenic uplift affected the Variscan domain and its forelands, causing a regional regression. Early Permian continental red beds and subordinate lacustrine deposits, partly overlaying Stephanian coal measures, accumulated under increasingly arid conditions in often isolated intra- and perimontane transtensional and pull-apart basins that evolved in response to Permo-Carboniferous wrench tectonics. Coeval volcanic activity played an important role (Ziegler, 1990). Following termination of the Early Permian tectonomagmatic activity, thermal contraction of the lithosphere governed the subsidence of the Northern and Southern Permian basins in the Variscan foreland; by the end of the Rotliegend these basins had subsided under landlocked conditions below the global sea level (van Wees *et al.*, 2000). Elsewhere, time equivalent strata accumulated in tectonically silled intramontane basins that gradually expanded in response to progressive thermal subsidence of the Variscan crust and the degradation of its palaeorelief. Rifting activity opened the Arctic sea way, through which the Late Permian Zechstein Sea invaded the Northern and Southern Permian basins, as well as a temporary Tethys sea way that extended during the Zechstein 1 cycle from the Svanetia basin, presumably via Dobrogea, into the eastern parts of the Southern Permian basin (Ziegler, 1988, 1990). The low stand in sea level at the Permo-Triassic boundary (Ross & Ross, 1988) induced a regional forced regression, causing in slowly subsiding basins the development of a regional unconformity (Cassinis, 1996). Continental conditions prevailed during the Early Triassic rise in sea level due to a clastic over-supply, compensating for continued thermal and/or rift-induced basin subsidence. This can be related to the development of an efficient drainage system through which erosion products were transported from Scandinavia and the remnant Variscan highlands into the continuously thermally subsiding and gradually expanding Northwest European basin, as well as into the evolving system of rifted basins. Rifting, related to opening of the Neotethys, Meliata-Maliak and Svanetia basins, provided avenues for the Late Permian and particularly the Middle Triassic transgression of the Tethys seas into the West Mediterranean and ultimately into the West and Central European domains, controlling the diachronous termination of continental sedimentation (Ziegler, 1988, 1990, Cassinis *et al.*, 1992; Cassinis, 1996; Marcoux & Baud, 1995; Stampfli *et al*, in press). Communications between the Tethys and Arctic seas were only established during the Early Jurassic (Ziegler, 1988, 1990).

The Late Carboniferous to Early Triassic sedimentary and volcanic series of the Variscan domain can be subdivided into several tectono-stratigraphic sequences that are, however, only grossly correlative. In essence, a latest Carboniferous-Early Permian syn-tectonic and a Late Permian-Early Triassic post-tectonic mega-sequence can be recognized (Cassinis *et al.*, 1992; Krainer, 1993).

Syn-Tectonic Cycle 1

On top of orogenically deformed and erosionally truncated Palaeozoic series, continental and partly marine sedimentation commenced variably during the Westphalian to Early Permian in wrench-induced transtensional and pull-apart basins. The highly variable geometry and internal architecture of these basins, partly related to an alternation of transtension and transpression giving rise to repeated breaks in sedimentation, reflect that many of them evolved under changing stress fields. Such stress field changes may be of a regional as well as a more local nature, with the latter being related to the interaction of a mosaic of crustal blocks delimited by wrench faults under increasing strain (Blès *et al.*, 1989; Burg *et al.*, 1990). Syn-depositional volcanic activity commenced during the Stephanian, reached a peak during the Early Permian and abated gradually during the Late Permian. The frequently observed break in sedimentation at the end of the Early Permian, often associated with variable degrees of basin inversion, reflects a last pulse of wrench deformation that accompanied the terminal phase of the Appalachian orogeny.

Post-Tectonic Cycle 2

During the Late Permian, large areas commenced to subside under a tectonically quiescent regime in response to thermal contraction of the lithosphere, thus defining the second tectono-stratigraphic mega-sequence that extends into Triassic and Jurassic. Generally, this "post-tectonic" sequence broadly overstepped the cycle 1 "syn-tectonic" basins. However, this post-tectonic cycle is not everywhere well expressed as the onset of new rifting activity, related to opening of the Neotethys and the Meliata-Maliak back-arc basin commenced diachronously during Late Permian to Middle Triassic times (Ziegler *et al.*, in press). Similarly, the onset of rifting activity related to southward propagation of the Arctic-North Atlantic rift system is diachronous and ranges from Late Permian to Middle Triassic (Ziegler, 1988, 1990). Furthermore, Middle and Late Triassic compressional tectonics, related to the collision of Cimmerian terranes with the Palaeotethys subduction system, account for the interruption of the post-tectonic cycle 2 in the South and Carnic Alpine, Dinarides, Hellenides, Taurides and Black Sea domains (Nikishin *et al.*, in press b; Stampfli *et al.*, in press).

Correlation of Late Permian-Early Triassic continental and marine strata has to contend with major uncertainties, both at regional and global scales, due to the climatic zonation of continental biota (both latitude and elevation controlled) and the distinct provinciality of shallow marine faunas (Kozur, 1998). This provides for uncertainties in geohistory analyses of continental basins, as well as in palaeogeographic/palaeotectonic-reconstructions.

In this respect, two a-biotic, globally valid markers can play a crucial role in assessing the validity of purely biostratigraphic correlations. The first marker is the Illawarra magnetic reversal (265 Ma) that marks the end of the CPRS and the onset of the PTMS (Menning, 1995). Occurrence of this reversal in Late Permian lower Tatarian strata of Eastern Europe and in Middle Permian Guadalupian ones of North America (Menning & Jin, 1998), illustrates the problematic nature of standard biostratigraphic correlations. The second, albeit less sharp marker is provided by the $\delta^{18}O$, $\delta^{13}C$, $\delta^{34}S$ and $^{87}Sr/^{86}Sr$ isotope anomalies which straddle the Permian-Triassic boundary that is associated with major biotic extinction events (251 Ma; Erwin, 1993; Stanley & Yang, 1994; Faure *et al.*, 1995; Kozur, 1998; Yin & Tong, 1998; Atudorei, 1999). This marker reflects a period of some 1 My during which several severe global environmental crises occurred. Their cause is seen in the massive extrusion of mantle plume-related trap basalts (Siberian Tunguska Province, Emeishan traps of southwestern China; Courtillot *et al.*, 1999; Nikishin *et al.*, in press a) and a voluminous subduction-related volcanism along the Proto-Cordillera and Proto-Altaids (Faure *et al.*, 1995), that gave rise to an increase in CO_2 pressure, an aerosol-induced reduction in solar irradiation and resulting temperature decreases ("volcanic winter" scenario, Kozur, 1998).

Where ever possible, both of these markers should be used to chronologically constrain biostratigraphic zonations and to firm up time scales applied in quantitative subsidence analyses.

PERMO-TRIASSIC MARINE SEDIMENTS AND TECTONICS OF THE WEST-TETHYAN DOMAIN

In the South-European domain we have to deal with several marine basins of Tethyan origin that have undergone different fates during Permo-Triassic times (Stampfli, 2000; Stampfli *et al.*, in press). These are a) the Palaeotethys Basin, which began to opened during the Silurian and was finally closed from west to east during the Permo-Triassic, b) the Neotethys Basin, which began to opened during the late Early Permian in conjunction with the detachment of the Cimmerian composite terrane from Gondwana, and c) a system of back-arc basins, located to the north of the Palaeotethys subduction zone, that began to open during the Late Permian and that were variably closed during the Late Triassic and Jurassic. The former southern Palaeotethys passive margin forms an integral part of the Cimmerian terrane. In our model we consider the East-Mediterranean and Ionian Sea basins as forming part of Neotethys. The Apulian domain is regarded as the westernmost part of the Cimmerian composite terrane (Figs 2 to 5).

Along the northern, active Palaeotethys margin, accretionary prisms and fore-arc sequences developed during Carboniferous until Permian or Triassic times, depending on the timing of closure of the respective Palaeotethys segment. Older elements of the Palaeotethys suture are possibly preserved in the Chios Island (Papanikolaou & Sideris, 1983; Baud *et al.*, 1990; Stampfli *et al.*, 1991) and Karaburun peninsula (Kozur, 1997 a), where pelagic Silurian to Late Carboniferous blocks have been described in a Carboniferous matrix, locally enriched in chrome-spinel (Statteger, 1983). Younger, more external Permo-Triassic fore-arc or foredeep clastic sequences are known from the Hellenides (*e.g.* Liri Flysch, Arna schists, Tyros beds; De Bono, 1999) and the Dinarides (Kozur, 1999). Northward, these flysch-type sequences can be linked to the deep-water Kungurian to Roadian flysch found just south of the Periadriatic line in the Carnic Alps within the Trogkofel clastic sequence (*e.g.* Kozur & Mostler, 1992). In time, the Hellenic-Dinarides flysch basins were replaced by the episutural basins of the Pindos-Budva domain (Fleury, 1980; Gorican, 1993; Degnan & Robertson, 1998). This domain continued to subside from Early Triassic (*e.g.* Vardousia sequence; Ardaens, 1978) until Oligocene times (Richter & Müller, 1993 a, b; Richter *et al.*, 1993). In this area, the Early Triassic is represented by pelagic and volcaniclastic deposits; these are overlain by the Middle Triassic Pindos flysch (Priolithos formation; Degnan & Robertson, 1998), the petrography of which plots in the field of recycled orogens and, thus, characterizes the Early Cimmerian event in these regions. Upwards, the Pindos flysch passes into the pelagic Late Triassic-Early Jurassic Drimos series.

Associated with the northern, active Palaeotethys margin, Permian sediments occur also in a system of back-arc basins. Although these Permian sediments are dominated by continental clastics, deposition of marine carbonates commenced locally already during the late Early Permian (*e.g.* Hydra Island for the Meliata-Maliak rift; Stampfli, 2000; Stampfli *et al.*, in press; De Bono *et al.*, 1999). Roll-back of the Palaeotethys subduction slab certainly commenced during the late Early Permian and induced "back-arc" rifting along the entire northern Palaeotethys margin. East of the palaeo-Apulian promontory, rifting culminated in Late Permian and Triassic sea-floor spreading in the Meliata-Maliak Basin (Figs 2 and 3; Kozur, 1991). In conjunction with Late Permian gentle docking of the Apulian terrane against the western-most segment of the Palaeotethys arc-trench system, opening of the Meliata-Maliak back-arc basin aborted in the South Alpine domain, whereas to the East it continued to open and linked up with the Crimea-Svanetia-Küre Basin (Nikishin *et al.*, in press b) and the Dobrogea (*e.g.* Spathian MORB pillow lava of N-Dobrogea Niculitel formation; Cioflica *et al.*, 1980; Seghedi *et al.*, 1990; Nicolae & Seghedi, 1996). To the SE, the Karakaya Basin, that persisted until Early to Middle Triassic times, can be interpreted as a Marianna-type (intra-oceanic) back-arc basin that was located southward adjacent to the Sakarya micro-continent.

All of these areas are characterised by the presence of Early to Middle Triassic pelagic series, often grading upwards into Late Triassic flysch or molasse-type deposits, and the absence of post-Bashkirian to Late Permian pelagic deposits, with the exception of latest Permian pelagic limestones in the Karakaya complex (Kozur, 1997 b). Late Permian to Middle Triassic back-arc basins occur also further to the East in the Pontides (Agvanis-Tokat Basin; Okay & Sahintürk, 1997), the Caucasus (Nikishin *et al.*, 1997, in press b), NE Iran (Baud & Stampfli, 1989), northern Afghanistan (Boulin, 1988) and in the Pamirs (Khain, 1994; Leven, 1995). East of the Moesian promontory, and due to the Late Triassic collision of Cimmerian terranes with the Eurasian margin (*e.g.* Stampfli *et al.*, 1991; Alavi *et al.*, 1997), these back-arc basins were closed during the Early Cimmerian orogeny (Fig. 5).

The pre-Mid-Permian northern passive margin of Gondwana, facing Palaeotethys, is characterized by continuous Devonian to Early-Middle Triassic platform sediments. With the Mid-Permian separation of the Cimmerian composite terranes, this passive margin prism was detached from Gondwana and, in conjunction with progressive closure of Palaeotethys, ultimately collided with its northern active margin (Figs 2 and 3). In Crete, the Early Permian open marine to pelagic series of the (par)autochthonous Mani unit (König & Kuss, 1980) may represent the oldest exposed elements of the southern Palaeotethys passive margin that had persisted until the Early Triassic. The angular unconformity, that separates the Mani unit from the overlying Late Triassic carbonates, marks the Early Cimmerian diastrophism. A Late Carboniferous (Bashkirian) to Early Triassic pelagic sequence is also observed in the Phyllite-Quartzite unit of Crete (Krahl *et al.*, 1983, 1986; Krahl, 1992); it corresponds to the accretionary prism of Palaeotethys (Stampfli *et al.*, 1995; De Bono, 1999) and represents either a distal pelagic facies of the southern Palaeotethys margin or part of the sedimentary cover of the oceanic Palaeotethys Basin.

The carbonate platform sequence of the Taurus nappes (Gutnic *et al.*, 1979; Demirtasli, 1984) probably represents from Late Permian times onward the post-rift sequence that was deposited on the former rift shoulder and/or in a rim basin flanking the Permo-Triassic East-Mediterranean segment of Neotethys. More internal Taurus sequences (*e.g.* Altiner *et al.*, 1980; Demirel & Kozlu, 1998) show strong affinities with the Alborz sequences (NE Iran) that are defined as the reference Palaeotethys-type margin (Stampfli *et al.*, 1991).

South of these areas, the palaeogeographic origin of the Antalya nappes, involving a deformed passive margin sequence, is still controversial (Dumont, 1976; Robertson & Dixon, 1984; Poisson, 1984; Marcoux *et al.*, 1989; Stampfli *et al.*, 1991; Robertson, 1993; Robertson *et al.*, 1996). Similarities between the Antalya nappes and the Mamonia nappe complex of Cyprus suggest, however, that these units are more likely related to the northern Neotethys margin, rather than to tectonically translated more internal domains. In this context, it should be noted that the Maliak-Pindos back-arc ocean and the East-Mediterranean Neotethys opened simultaneously. Therefore, in terms of syn-rift and post-rift subsidence, similar geological histories can be expected in both areas. Thus, a Maliak-Pindos origin of the Antalya nappes cannot be ruled out.

Similar to the southern Neotethys margin, as defined in Oman (Pillevuit, 1993; Pillevuit *et al.*, 1997), the Mediterranean-Neotethyan series extend westwards as far as Sicily. In the Sosio area of western Sicily, Early Permian to Early Triassic marine sediments are represented by pelagic microfauna (Catalano *et al.*, 1988; Catalano *et al.*, 1991) of the clastic Sicanian Basin sequence that also contains Permian fusulinid limestone olistoliths (Skinner & Wilde, 1966). The oldest fauna in the Sicanian Basin is a late Early Permian pelagic bathyal and shallow water microfauna (Catalano *et al.*, 1992; Vachard *et al.*, 1999), the Pacific affinity (Kozur, 1990) of which suggests that this basin was connected to Palaeotethys (Catalano *et al.*, 1995). However, at this time the Neotethys-East Mediterranean basin had not yet open. Similar deep-water Kungurian to Roadian flysch deposits occur also in the Carnic Alps (*e.g.*

Kozur & Mostler, 1992; Kozur, 1999). Together with the Late Palaeozoic Tuscan sequences, located between these two areas, these occurrences could be regarded as forming part of a remnant Early Permian foredeep basin that was associated with the Palaeotethys accretionary prism.

In contrast, Late Permian Hallstatt-type pelagic limestone, similar to those found in Timor and Oman where they sometimes rest directly on MORB (Niko *et al.*, 1996), are also reported from the Sosio complex (Kozur, 1995), strongly suggesting that by Late Permian times the area was connected to the Neotethys.

The Sicanian and Lagonegro sequences of southern continental Italy (Ciarapica *et al.*, 1990 a) were probably deposited in the same basin. Subsidence of the Lagonegro Basin commenced during the Late Permian and persisted during the Triassic, as indicated by the transition from an Early Triassic outer platform facies to Middle Triassic basinal sequences (Miconet, 1988). These sequences are separated by Middle Anisian slope deposits that contain olistostroms and olistolithes, some of which are derived from an Upper Permian carbonate platform (Ciarapica *et al.*, 1990 a, b). This Anisian basin deepening event could be regarded as being related to the final suturing of the Apulian promontory to Variscan Europe (Figs 4 and 5; Stampfli & Mosar, 1999). Pelagic sedimentation dominated the Lagonegro Basin from Middle Triassic until Oligocene times, and thus precludes during that time any important extensional or compressional deformation phases.

CONCLUSIONS

The latest Carboniferous to Triassic stratigraphic and associated magmatic record of the Variscan domain reflects fundamental changes in its megatectonic setting. These changes are related to the late Westphalian termination of syn-orogenic crustal shortening, followed by the Stephanian-Autunian wrench-induced collapse of the Variscan orogen that, at the onset of the Late Permian, gave way to regional thermal subsidence of the lithosphere. However, this post-tectonic cycle of basin subsidence terminated diachronously with the onset of a new rifting cycle that governed the break-up of Pangea along its Palaeozoic and Late Precambrian sutures. Major elements of this break-up system were the southward propagating Arctic-North Atlantic and the westward propagating Tethys rift systems. These linked up in the North Atlantic domain and propagated southward into the Central Atlantic and Gulf of Mexico. Evolution of the Tethys rift system reflects repeated plate kinematic changes in the western Tethys realm. These entailed the Late Permian and Triassic opening of Neotethys and a system of back-arc basins, followed by the closure of remnant Palaeotethys and of some of the Permo-Triassic back-arc basins during the Early Cimmerian orogeny.

The latest Carboniferous-Early Triassic evolution of the Variscan domain mirrors the fundamental plate boundary reorganization that accompanied and followed the terminal suturing phases of Pangea and that underlies its Mesozoic break-up. Changes in the outer core convection system underlay the development of the CPRS and the resumption of frequent magnetic reversals with the early Tatarian Illawarra reversal that, 15 My later, was followed by major plume-related volcanism at the Permo-Triassic boundary. Late Permian and Triassic gradual development of the modern bi-polar mantle convection system provided for regional uplift of the central parts of Pangea and contributed significantly to the Mesozoic break-up of Pangea.

Acknowledgements – The authors thank their colleagues, particularly those of the IGCP-369 and the EUROPROBE projects, for many fruitful discussion through which they have greatly contributed to this paper. G.M. Stampfli acknowledges the support by the Swiss National Funds research grants No. 20-28943.90, 20-39494.93, 20-49114.96 and 20-53646.98. Parts of the models presented in this paper resulted from fruitful discussion with Dr. H. Kozur, whose contribution is acknowledged here. P.A. Ziegler thanks Prof. G. Cassinis for inviting him to present this paper at the Brescia conference, thus giving the impulse to prepare this compilation.

REFERENCES

ALAVI M., VAZIRI H., SEYED-EMAMI K. & LASEMI Y., 1997. The Triassic and associated rocks of the Nakhlak and Aghdarband areas in central and northeastern Iran as remnants of the southern Turanian active continental margin. *Geol. Soc. Amer. Bull.* 109: 1563-1575.

ALTINER D., BAUD A., GUEX J. & STAMPFLI G., 1980. La limite Permien-Trias dans quelques localités du Moyen-Orient: recherches stratigraphiques et micropaléontologiques. *Riv. Ital. Paleont. Stratigr.*, 85 (3-4): 683-714.

ARDAENS R., 1978. Géologie de la chaîne du Vardoussia, comparaison avec le massif de Koziakas (Grèce continentale). *Thèse 3 cycle*, Univ. Lille: 234 pp.

ARTHAUD F. & MATTE P., 1977. Late Paleozoic strike-slip faulting in Southern Europe and North Africa: results of a right-lateral shear between the Appalachians and Urals. *Geol. Soc. Amer. Bull.*, 88: 1305-1320.

ATUDOREI N-V., 1999. Constraints on the Upper Permian to Upper Triassic marine carbon isotope curve. Case studies from the Tethys. *Ph.D. thesis*, Univ. Lausanne: 160 pp.

BADERTSCHER N. & BURKHARD M., 1998. Inversion alpine du graben Permo-Carbonifère de Savan-Dorénaz et sa relation avec le chevauchement de la Nappe des Morcles sus jacente. *Eclogae geol. Helv.*, 91: 359-373.

BALLY A.W. & SNELSON S., 1980. Realms of subsidence. In: A.D. Miall (ed.), Facts and Principles of World Petroleum Occurrence. *Can. Soc. Petrol. Geol.*, Mem. 6: 9-94.

BARD J-P., 1997. Démembrement anté-mésozoique de la chaîne varisque d'Europe occidentale et d'Afrique du Nord: rôle essentiel des grands décrochements transpressifs dextres accompagnant la rotation-translation horaire de l'Afrique durant le Stéphanien. *C. R. Acad. Sci., Paris*, sér. II a, 324: 693-704.

BAUD A. & STAMPFLI G, 1989. Tectonogenesis and evolution of a segment of the Cimmerides: the volcano-sedimentary Triassic of Aghdarban (Kopet-Dagh, North-East Iran). In: Sengör A.M.C. (ed.), *Tectonic evolution of the Tethyan region*. Kluwer Acad. Publ., Amsterdam: 265-275.

BAUD A., JENNY C., PAPANIKOLAOU D., SIDERIS C. & STAMPFLI G., 1990. New observations on the Permian stratigraphy in Greece and geodynamic interpretation. *Bull. Soc. Geol. Greece*, XXV: 187-206.

BENEK R., KRAMER W., MCCANN T., SCHECK M., NEGENDANK J.F.W., KORNICH D., HUEBSCHER H-D. & BAYER U., 1996. Permo-Carboniferous magmatism of the Northeast German Basin. *Tectonophysics*, 266: 379-404.

BERTOTTI G., PICOTTI V., BERNOULLI D. & CASTELLARIN A., 1993. From rifting to drifting: tectonic evolution of the South-Alpine upper crust from the Triassic to the Early Cretaceous. *Sediment. Geol.*, 86: 53-76.

BLÈS J.L., BONIJOLY D., CASTAIGN C. & GROS Y., 1989. Successive post-Variscan stress fields in the European plate (French Massif Central and its borders): comparison with geodynamic data. *Tectonophysics*, 169: 265-277.

BONADIMAN C., COLTORTI M. & SIENA F., 1994. Petrogenesis and T-fo2 estimates of the Monzoni complex (Central Dolomites, Southwestern Alps): a Triassic shoshonite intrusion in a transcurrent geodynamic setting. *Europ. J. Mineral.*, 6: 943-966.

BONIN B., 1989. Permian volcano-sedimentary events in Corsica: a geological record of a waning Variscan orogeny and its transition to divergent plate boundary processes. *Rend. Soc. Geol. Ital.*, 42: 139-141.

BONIN B., 1990. From orogenic to anorogenic settings : evolution of granitoid suites after a major orogenesis. *Geol. J.*, 25: 260-270.

BONIN B., PLATEVOET B. & VIALETTE Y., 1987. The geodynamic significance of alkaline magmatism in the western Mediterranean compared with West Africa. *Geol. J.*, 222: 361-387.

BONIN B., BRÄNDLIN P., BUSSY F., DESMONS J., EGGENBERGER U., FINGER F., GRAF K., MARRO C., MERCOLLI I., OBERHÄNSLI R., PLOQUIN A., VON QUADT A., VON RAUMER J., SCHALTEGGER U. & STEYER H.P., 1993. Late Variscan magmatic evolution of the Alpine basement. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic Geology of the Alps*. Springer-Verlag, Berlin, Heidelberg, New York, London: 171-201.

BOTT M.P.H., 1990. Stress distribution and plate boundary force associated with collision mountain ranges. *Tectonophysics*, 182: 193-209.

BOTT M.P.H., 1993. Modelling of plate-driving mechanisms. *J. Geol. Soc.*, London, 150: 941-951.

BOULIN J., 1988. The Hercynian and Eocimmerian events in Afghanistan and adjoining regions. *Tectonophysics*, 148: 253-278.

BOUSQUET R., GOFFÉ B., HENRY P., LE PICHON X. & CHOPIN C., 1997. Kinematic, thermal and petrological model of the Central Alps: Lepontine metamorphism in the upper crust and eclogitisation of the lower crust. *Tectonophysics*, 273: 105-127.

BRACK P., RIEBER H. & URLICHS M., in press. Pelagic successions in the Southern Alps and their correlation with the Germanic Middle Triassic. *Zbl. Geol. Paläont.*, Part 1 (1998) (7-8).

BRANDNER R., 1984. Meeresspiegelschwankungen und Tektonik in der Trias der NW Tethys. *Jb. Geol. A-B*, Wien, 126: 435-475.

BRAUN J. & BEAUMONT C., 1989. Contrasting styles of lithospheric extension: implications for differences between Basin and Range Province and rifted continental margins. In: Tankard A.J. & Balkwill H.R. (eds), *Extensional tectonics and stratigraphy of the North Atlantic margins*. Am. Assoc. Petrol. Geol., Mem 46: 53-80.

BREITKREUZ C. & KENNEDY A., 1999. Magmatic flare-up at the Carboniferous/Permian boundary in the NE German Basin revealed by SHRIMP zircon ages. *Tectonophysics*, 302: 307-326.

BURG J-P., BRUN J-P. & VAN DEN DRIESSCHEN J., 1990. Le Sillon Houiller du Massif Central français: faille de transfert pendant l'amincissement crustal de la chaîne varisque? *C.R. Acad. Sci., Paris*, sér. II, 311: 147-152.

BURG J-P., VAN DEN DRIESSCHEN J. & BRUN, J-P., 1994. Syn- and post-thickening extension: mode and consequences. *C.R. Acad. Sci., Paris*, sér. II, 319: 1019-1032.

CADEK O., KYVALOVA H. & YUEN D., 1995. Geodynamical implications from the correlation of surface geology and seismic tomographic structure. *Earth and planet. Sci. Lett.*, 136: 615-627.

CASSINIS G., 1996. Upper Carboniferous to Permian stratigraphic framework of southwestern Europe and its implications – An overview. In: Moullade B.M. & Nairn A.E.M. (eds), *The Phanerozoic geology of the World. I The Paleozoic, B*. Elsevier, Amsterdam: 110-167.

CASSINIS G., TOUTIN-MORIN N. & VIRGILI C., 1992. A general outline of the Permian continental basins in Southwestern Europe. In: Sweet W.C., Yang Z.Y., Dickins J.M. & Yin H.F. (eds), *Permo-Triassic events in the Eastern Tethys*. Cambridge University Press: 60-77.

CASSINIS G., PEROTTI C.R. & VENTURINI C., 1997. Examples of late Hercynian transtensional tectonics in the Southern Alps (Italy). In: Dickins J.M. (ed.), *Late Paleozoic and Early Mesozoic circum-Pacific events and their global correlation*. Cambridge University Press: 41-50.

CASTELLARIN A., LUCCHINI F., ROSSI P.L., SELLI L. & SIMBOLI G.,

1988. The Middle Triassic magmatic-tectonic arc development in the Southern Alps. *Tectonophysics*, 146: 79-89.

CATALANO R., DI STEFANO P. & KOZUR H., 1988. New results in the Permian and Triassic stratigraphy of western Sicily with special reference to the section at Torrente San Calogero, SW of Pietra di Salome (Sosio Valley). *Atti 74 Congr. Naz. Soc. Geol. Italia*, Vol A: 119-125.

CATALANO R., DI STEFANO P. & KOZUR H., 1991. Permian circum-pacific deep-water faunas from the western Tethys (Sicily, Italy) – new evidences for the position of the Permian Tethys. In: Channell J.E.T., Winter E.L. & Jansa L.F. (eds), *Paleogeography and Paleoceanography of Tethys*. Palaeogeogr., Palaeoclimatol., Palaeoecol., 87: 75-108.

CATALANO R., DI STEFANO P. & KOZUR H., 1992. New data on Permian and Triassic stratigraphy of western Sicily. *N. Jb. Geol. Paläont., Abh.*, 184: 25-61.

CATALANO R., DI STEFANO P. & VITALE F.P., 1995. Structural trends and paleogeography of the central and western Sicily belts: new insight. *Terra Nova*, 7: 189-199.

CIARAPICA G., CIRILLI S., MARTINI R., PANZELLI FRATONI R., ZANINETTI L. & SALVINI-BONNARD G., 1990 a. Reworked foraminifera in the Triassic Monte Facito formation, Lagonegro basin (Southern Apennines). *Boll. Soc. Geol. Ital.*, 109: 143-149.

CIARAPICA G., CIRILLI S., PANZELLI FRATONI R., PASSERI R. & ZANINETTI L., 1990 b. The Monte Facito formation (Southern Apennines). *Boll. Soc. Geol. Ital.*, 109: 135-142.

CIOFLICA G., LUPU M., NICOLAE I. & VLAD S., 1980. Alpine ophiolites of Romania: tectonic setting, magmatism and metallogenesis. *An. Inst. Geol. Geofiz.*, 56: 79-96.

CONEY P.J., 1987. The regional tectonic setting and possible causes of Cenozoic extension in the North American Cordillera. In: Coward M.P., Dewey J.F. & Hancock P.L. (eds), *Continental extensional tectonics*. Geol. Soc., London, Spec. Publ. 28: 177-186.

CORTESOGNO L., DALLAGIOVANNA G., GAGGERO L. & VANOSSI M., 1993. Elements of the Paleozoic history of the Ligurian Alps. In:. von Raumer J.F & Neubauer F. (eds), *Pre-Mesozoic Geology in the Alps*. Springer-Verlag, Berlin: 257-277.

CORTESOGNO L., CASSINIS G., DALLAGIOVANNA G., GAGGERO L., OGGIANO G., RONCHI A., SENO S. & VANOSSI M., 1998. The Variscan post-collisional volcanism in Late Carboniferous-Permian sequences of Ligurian Alps, Southern Alps and Sardinia (Italy): a synthesis. *Lithos*, 45: 305-328.

COWARD M.P., 1993. The effects of Late Caledonian and Variscan continental escape tectonics on basement structure, Paleozoic basins kinematics and subsequent Mesozoic basin development in NW Europe. In: Parker J.R. (ed.), *Petroleum geology of Northwest Europe: proceedings of the 4th Conference*. Geol. Soc., London: 1095-1108.

COURTILLOT V., JAUPART C., MANIGHETTI I., TAPPONIER P. & BESSE J., 1999. On causal links between flood basalts and continental breakup. *Earth and planet. Sci. Lett.*, 166: 177-195.

DALLMEYER R.D., FRANKE W. & WEBER K., 1995. *Pre-Permian geology of Central and Eastern Europe*. Springer-Verlag, Berlin: 604 pp.

DE BONO A., 1999. Pelagonian margins in Central Evia Island (Greece). Stratigraphy and geodynamic evolution. *Thesis*, Lausanne.

DE BONO A., MARTINI R., ZANINETTI L., HIRSCH F. & STAMPFLI G.M., 1999. Pelagonian Permo-Triassic stratigraphy in Central Evvia island (Greece). In: *Intern. Field Conference on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations"*, Brescia, Sept. 1999, Abstr. Vol.: 92-94.

DEGNAN P.J. & ROBERTSON A.H.F., 1998: Mesozoic-early Tertiary passive margin evolution of the Pindos ocean (NW Peloponnese, Greece). *Sediment. Geol.*, 117: 33-70.

DEMIREL I.H. & KOZLU H., 1998. Evaluation of burial history, thermal maturity and source-rock assessment of the Upper Paleozoic succession of the eastern Taurus region, southern Turkey. *Marine Petroleum Geol.*, 14: 867-877.

DEMIRTASLI E., 1984: Stratigraphic evidence of Variscan and early Alpine tectonics in southern Turkey. In: Dixon J.E. & Robertson A.H.F. (eds), *The geological evolution of the Eastern Mediterranean*. Geol. Soc., London, Spec. Publ. 17: 129-146.

DEWEY J.F., 1988. Extensional collapse of orogens. *Tectonics*, 7: 1123-1139.

DILEK Y. & MOORES E.M., 1999. A Tibetan model for the early Tertiary western United States. *J. Geol. Soc.*, London, 156: 929-941.

DUMONT J.F., 1976. Etudes géologiques dans les Taurides occidentales: les formations paléozoiques et mésozoiques de la coupole de Karacahisar (province d'Isparta, Turquie). *Thèse 3e cycle*, Univ. Paris-Sud (Orsay): 213 pp.

EATON G.P., 1982. The Basin and Range Province: origin and tectonic significance. *Ann. Rev. Earth Planet. Sci.*, 8: 409-440.

EIDE E.A. & TORSVIK T.H., 1996. Paleozoic supercontinental assembly, mantle flushing, and genesis of the Kiaman Superchron. *Earth and planet. Sci. Lett.*, 144: 389-402.

EISBACHER G.H., LÜSCHEN E. & WICKERT F., 1998. Crustal scale thrusting and extension in the Hercynian Schwarzwald and Vogesen, Central Europe. *Tectonics*, 8: 1-12.

ERWIN D.H., 1993. *The great Paleozoic crisis. Life and death in the Permian*. Columbia Univ. Press, New York: 327 pp.

FAURE K., DE WIT M.J. & WILLIS J.P., 1995. Late Permian global coal hiatus linked to ^{13}C-depleted CO_2 flux into the atmosphere during the final consolidation of Pangea. *Geology*, 23: 507-510.

FLEITOUT L. & FROIDEVAUX C., 1982. Tectonics and topography for a lithosphere containing density heterogeneities. *Tectonics*, 1: 21-56.

FLEURY J.-J., 1980. Les zones de Gavrovo-Tripolitza et du Pinde-Olonos (Grèce continentale et Péloponèse du nord). Evolution d'une plate-forme et d'un bassin dans leur cadre alpin. *Soc. géol. Nord.*, Publ. 4: 473 pp.

GORICAN S., 1993. Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budva zone (Dinarides, Montenegro). *Mém. Geol.*, Lausanne, 18: 120 pp.

GUILLOU L. & JAUPART C., 1995. On the effect of continents on mantle convection. *J. geophys. Res.*, 100: 14217-14238.

GUTNIC M., MONOD O., POISSON A. & DUMONT J.F., 1979. Géologie des Taurides occidentales (Turquie). *Mem. Soc. géol. France*, 137 (LVIII): 112 pp.

HAMILTON W., 1987. Crustal extension in the Basin and Range Province, southwestern United States. In: Coward M.P., Dewey J.F. & Hancock P.L. (eds), *Continental extension tectonics*. Geol. Soc., London, Spec. Publ. 28: 155-176.

HEDEMANN H-A., SCHUSTER A., STANCU-KRISTOFF G. & LÖTSCH J., 1984. Die Verbreitung der Kohleflötze des Oberkarbon in Nordwestdeutschland und ihre stratigrafische Einstufung. *Fortschr. Geol. Rheinld. Westf.*, 52: 39-88.

HENK A., 1995. Late Variscan exhumation histories of the southern Rhenohercynian Zone and western Mid-German Crystalline Rise: results from thermal modelling. *Geol. Rdsch.*, 84: 578-590.

HENK A., 1999. Did the Variscides collapse or were they torn apart? -A quantitative evaluation of the driving forces for post-convergent extension in Central Europe. *Tectonics* (in press).

IRVING E. & PARRY L.G., 1963. The magnetism of some Permian rocks from New South Wales. *Geophys. J. r. astron. Soc.*, 7: 395-411.

JANSSEN M.E., STEPHENSON R.A. & CLOETINGH S., 1995. Temporal and spatial correlation between changes in plate motions and the evolution of rifted basins in Africa. *Geol. Soc. Amer. Bull.*, 107: 1317-1332.

JONES C.H., WERNICKE B.P., FARMER G.L., WALKER J.D., COLEMAN D.S. & MCKENNA L.W., 1992. Variations across and along a major continental rift: an interdisciplinary study of the Basin and Range Province, western USA. *Tectonophysics*, 213: 57-96.

JOWETT E.C. & JARVIS G.T., 1984. Formation of foreland rifts. *Sediment. Geol.*, 41: 51-72.

KHAIN V.E., 1994. Geology of Northern Eurasia (Ex-USSR). *Beitr. Reg. Geol. der Erde*, 24: 346-385.

KÖNIG H. & KUSS S., 1980. Neue Daten zur Biostratigraphie des permotriadischen Autochthons der Insel Kreta (Griechenland). *N. Jb. Geol. Paläont., Abh.* 9: 525-540.

KORONOVSKI P.H., 1999. Origin and evolution of the Polish Rotliegend Basin. *Polish Geol. Inst.*, Spec. Pap. 3: 93 pp.

KOZUR H., 1990. Deep-water Permian in Sicily and its possible connection with the Himalaya-Tibet region. In: *5th Himalaya-Tibet-Karakorum workshop*, Milano. Abstr. vol.

KOZUR H., 1991. The evolution of the Hallstatt ocean and its significance for the early evolution of the Eastern Alps and western Carpathians. In: Channel J.E.T., Winterer E.L. & Jansa L.F. (eds), *Palaeogeography and palaeoceanography of Tethys*. Palaeogeogr., Palaeoclimatol., Palaeoecol., 87: 109-135.

KOZUR H., 1995. First evidence of Middle Permian Ammonitico Rosso and further new stratigraphic results in the Permian and Triassic of the Sosio Valley area, Western Sicily. In: *1st Croatian geol. Congr.*, Opatija. 1: 307-310.

KOZUR H., 1997 a. First discovery of Muellerisphaerida (*inc. sedis*) and Eoalbaillella (Radiolaria) in Turkey and the age of the siliciclastic sequence (clastic series) in Karaburun peninsula. *Freiberger Forschh.*, C 466: 33-59.

KOZUR H.W., 1997 b. Pelagic Permian and Triassic of the western Tethys and its paleogeographic and stratigraphic significance. In: *Berg und Hüttenmännischer Tag*. Freiburg., Abstr. vol.: 21-25.

KOZUR H.W., 1998. Some aspects of the Permian-Triassic boundary (PTB) and of the possible causes for the biotic crisis around this boundary. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 143: 227-272.

KOZUR H.W., 1999. Permian development in the western Tethys. In: *Proc. Intern. Symp. on Shallow Tethys 5*, Chiang Mai, Thailand: 101-135.

KOZUR H. & MOSTLER H., 1992. Erster paläontologischer Nachweis von Meliaticum und Süd-Rudabànyaicum in den nördlichen Kalkalpen (Österreich) und ihre Beziehungen zu den Abfolgen in den Westkarpaten. *Geol. Paläont. Mitt. Innsbruck*, 18: 87-129.

KRAHL J., 1992. The young Paleozoic and Triassic Tethyan rocks in the external Hellenides on Crete, the northern border of Gondwana. In: *8th Congr. Geol. Soc. Greece*: 59-60.

KRAHL J., KAUFMANN G., KOZUR H., RICHTER D., FÖRSTER O. & HEINRITZI F., 1983. Neue Daten zur Biostratigraphie und zur tektonischen Lagerung der Phyllit-Gruppe und der Trypali-Gruppe auf der Insel Kreta (Griechenland). *Geol. Rdsch.*, 72: 1147-1166.

KRAHL J., KAUFFMANN G., RICHTER D., KOZUR H., MÖLLER I., FÖRSTER O., HEINRITZI F. & DORNSIEPEN U., 1986: Neue Fossilfunde in der Phyllit-Gruppe Ostkretas (Griechenland). *Z. Dtsch. geol. Ges.*, 137: 523-536.

KRAINER K., 1993. Late and Post-Variscan sediments of the Eastern and Southern Alps. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic geology of the Alps*. Springer-Verlag, Berlin, Heidelberg, New York, London: 537-564.

LE PICHON X., HENRY P. & GOFFÉ B., 1997. Uplift of Tibet: from eclogites to granulites – implications for the Andean Plateaus and the Variscan Belt. *Tectonophysics*, 273: 57-76.

LEVEN E.J., 1995. Permian and Triassic of the Rushan-Pshart zone (Pamir). *Riv. Ital. Paleont. Stratigr.*, 101: 3-16.

LORENZ V. & NICHOLLS L.A., 1976. The Permocarboniferous Basin and Range Province of Europe: an application of plate tectonics. In: Falke H. (ed.), *The continental Permian in Central, West and South Europe*. NATO Advanced Study Institute. Ser. C. Math. Phys. Sci., D. Reidel Publ. Co., C. 22: 313-342.

LORENZ V. & NICHOLLS L.A., 1984. Plate and intraplate processes of Hercynian Europe during the Late Palaeozoic. *Tectonophysics*, 107: 25-56.

MALAVIEILLE J., 1993. Late orogenic extension in mountain belts: insight from the Basin and Range and the late Palaeozoic Variscan belt. *Tectonics*, 12: 1115-1130.

MALAVIEILLE J., GUIHOT P., COSTA S., LARDEAUX J.M. & GARDIEN V., 1990. Collapse of the thickened Variscan crust in the French Massif Central: Mont Pilat extensional shear zone and St. Etienne Late Carboniferous basin. *Tectonophysics*, 177: 139-149.

MARCOUX J. & BAUD A., 1995. Late Permian to Late Triassic Tethyan paleoenvironments. Three snapshots: Late Murgabian, Late Anisian, Late Norian. In: Nairn A.E.M., Ricou L-E., Vrielynck B. & Dercourt J. (eds), *The Tethys Ocean, Tethyan oceans and margins*, vol. 8: 153-190.

MARCOUX J., RICOU L.E., BURG J.P. & BRUN J.P., 1989. Shear sense criteria in the Antalya and Alanya thrust system, SW Turkey; evidence for a southward emplacement. *Tectonophysics*, 161: 81-91.

MARTINEZ-GARCÍA E. & WAGNER R.H., 1982. Una cuenca marina del Estephaniense superior en el Noroeste de España. *Trabajos de Geologia*, Univ. Orviedo, 12: 119-124.

MARX J., HUEBSCHER H-D., HOTH K., KORICH D. & KRAMER W., 1995. Vulkanostratigraphie und Geochemie der Eruptivkomplexe. In: Plein E. (ed.), Norddeutsches Rotliegendbecken. *Courier Forsch.-Inst. Senkenberg*, 183: 54-83.

MATTE P., 1991. Accretionary history and crustal evolution of the Variscan belt in Western Europe. *Tectonophysics*, 196: 309-337.

MATTE P., 1995. Southern Uralides and Variscides: comparison of their anatomies and evolution. *Geol. Mijnbow*, 74: 151-166.

MÉNARD G. & MOLENAR P., 1988. Collapse of a Hercynian Tibetan Plateau into a Late Palaeozoic European Basin and Range Province. *Nature*, London, 334: 235-237.

MENNING M., 1995. A numerical time scale for the Permian and Triassic periods: an integrated time analysis. In: Scholle P., Peryt T.M. & Ulmer-Scholle D.S. (eds), *Permian of the Northern Continents*. Springer-Verlag, Berlin, Heidelberg. Vol 1: 77-97.

MENNING M. & JIN Y.G., 1998. Comment on "Permo-Triassic magnetostratigraphy in China: the type section near Taiyuan, Shanxi Province, North China" by B.J.J. Embleton, M.W. McElhinny, X. Ma, Z. Zang & Z.X. Li. *Geophys. J. Intern.*, 133: 213-261.

MENNING M., WEYER D., DROZDZEWSKI G. & VAN AMEROM H.W.J., 1997. Carboniferous time scales: revised 1997 time scale A (min. ages) and time scale B (max. ages), use of geological time indicators. *Carboniferous Newsletter*, 15: 26-28.

MICONET P., 1988. Evolution mésozoique du secteur de Lagonegro. *Mem. Soc. Geol. Ital.*, 41: 321-330.

NEUBAUER F. & VON RAUMER J.F., 1993. The Alpine basement - linkage between Variscides and East-Mediterranean Mountain Belts. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic geology of the Alps*. Springer-Verlag, Berlin: 641-668.

NEUMANN E-R., OLSEN K.H. & BALDRIDGE W.S., 1995. The Oslo Rift. In: Olsen K.H. (ed.), *Continental rifts: Evolution, structure, tectonics*. Elsevier, Amsterdam: 345-373.

NICOLAE I. & SEGHEDI A., 1996. Lower Triassic basic dyke swarm in North Dobrogea. *Rom. J. Petrology*, 77: 31-40.

NIKISHIN A.M., ZIEGLER P.A., STEPHENSON R.A., CLOETINGH S.A.P.L., FURNE A.V., FOKIN P.A., ERSHOV A.V., BOLOYTOV S.N., KOROTAEV

M.V., ALEKSEEV A.S., GORBACHEV V.I., SHIPILOV E.V., LANKREIJER A., BEMBINOVA E.YU. & SHALIMOV I.V., 1996. Late Precambrian to Triassic history of the East European Craton: dynamics of sedimentary basin evolution. *Tectonophysics*, 168: 23-63.

NIKISHIN A.M., CLOETINGH S., BRUNET M.-F., STEPHENSON R.A., BOLOTOV S.N. & ERSHOV A.V., 1997. Scythian Platform, Caucasus and Black Sea regions: Mesozoic-Cenozoic tectonic history and dynamics. In: Crasquin S. & Barrier E. (eds), *Stratigraphy and evolution of the Peri-Tethyan platforms*. PeriTethys Mém. 3, Mém. Mus. Nat. Hist. Nat., Paris, 177: 163-176.

NIKISHIN A.M., ZIEGLER P.A., ABBOTT D., BRUNET M-F. & CLOETINGH S., in press a. Permo-Triassic intraplate magmatism and rifting: implications for mantle plumes and mantle dynamics. *Tectonophysics* (submitted).

NIKISHIN A.M., ZIEGLER P.A., BOLOTOV S.N., MAZAREVIH B.P., PANOV D.I., BRUNE M.F., KORATEV M.V. & TIKHOMIROV P., in press b. Mesozoic and Cenozoic evolution of the Scythian Platform-Back Sea-Caucasus Domain. In: Ziegler P.A., Cavazza W., Robertson A.H.F. & Crasquin-Soleau S. (eds), *PeriTethyan rift/wrench basins and passive margins*. PeriTethys Mém. 6, Mém. Mus. Nat. Hist. Nat., Paris, Vol. 186.

NIKO S., PILLEVUIT A. & NISHIDA T., 1996. Early Late Permian (Wordian) non-ammonoid cephalopods from the Hamrat Duru Group, central Oman Mountains. *Trans. Proc. Palaeont. Soc. Japan*, N.S. 183: 522-527.

OKAY A.I. & MOSTLER H., 1994. Carboniferous and Permian radiolarite blocks from the Karakaya complex in Northwest Turkey. *Turkish J. Earth. Sci*., 3: 23-28.

OKAY A.I. & SAHINTÜRK Ö., 1997. Geology of the eastern Pontides. In: Robinson A.G. (ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Region. *Amer. Assoc. Petrol. Geol*., Mem. 68: 291-311.

OLDOW J.S., BALLY A.W., AVÉ LALLEMANT H.G. & LEEMAN W.P., 1989. Phanerozoic evolution of the North American Cordillera; United States and Canada. In: Bally A.W. & Palmer A.R. (eds), *The geology of North America - An overview*. Geol. Soc. Amer. The Geology of North America, Vol. A: 139-232.

ONKEN O., WINTERFELD C. & DITTMAR U., 1999. Accretion of a rifted passive margin - the Late Palaeozoic Rhenohercynian fold and thrust belt (Mid-European Variscides). *Tectonics*, 18: 75-91.

PAMIC J.J., 1984. Triassic magmatism of the Dinarides in Yugoslavia. *Tectonophysics*, 109: 273-307.

PAPANIKOLAOU D. & SIDERIS C., 1983. Le Paléozoïque de l'autochtone de Chios: une formation à bloc de type wildflysch d'âge Permian (pro parte). *C.R. Acad. Sci. Paris*, 297: 603-606.

PARSONS T., 1995. The basin and range Province. In: Olsen K.H. (ed.), *Continental rifts: evolution, structure, tectonics*. Elsevier, Amsterdam: 277-324.

PAVONI N., 1993. Pattern of mantle convection and Pangea break-up, as revealed by the evolution of the African plate. *J. Geol. Soc*., London, 150: 927-964.

PE-PIPER G., 1998. The nature of Triassic extension-related magmatism in Greece: evidence from Nd and Pb isotope geochemistry. *Geol. Mag*., 135: 331-348.

PILLEVUIT A., 1993. Les blocs exotiques du Sultanat d'Oman, évolution paléogéographique d'une marge passive flexurale. *Mém. Géol*., Lausanne, 17: 249 pp.

PILLEVUIT A., MARCOUX J., STAMPFLI G. & BAUD A., 1997. The Oman Exotics: a key to the understanding of the Neotethyan geodynamic evolution. *Geodinamica Acta*, 10: 209-238.

PILLOUD C., 1991. Structure et deformation alpines dans le synclinal Permo-Carbonifère de Savan-Dorénaz (Massif des Aiguilles Rouges, Valais). *Mém. Géol*., Lausanne, 9: 101 pp.

PLEIN E., 1995. Norddeutsches Rotliegendbecken. *Courier Forsch.-Inst. Senkenberg*, 183: 193 pp.

POISSON A., 1984. The extension of the Ionian trough into southwestern Turkey. In: Dixon J.E. & Robertson A.H.F. (eds), *The geological evolution of the Eastern Mediterranean*. Geol. Soc., London, Spec. Publ. 17: 241-249.

RICHTER D. & MÜLLER C., 1993 a. Die Flysch-Zonen Griechenlands VI. Zur Stratigraphie des Flysches der Pindos-Zone zwischen der Querzone von Kastaniotikos und dem Südpeloponnes (Griechenland). *N. Jh. Paläont., Mh*., H. 8: 449-476.

RICHTER D. & MÜLLER C., 1993 b. Der "Erste Flysch" in der Pindos-Zone (Griechenland). *N. Jb. Geol. Paläont., Mh*., H. 4: 209-226.

RICHTER D., MÜLLER C. & MIHM A., 1993. Die Flysch-Zonen Griechenlands V. Zur Stratigraphie des Flysches der Pindos-Zone im nördlichen Pindos-Gebirge zwischen der albanischen Grenze und der Querzone von Kastaniotikos (Griechenland). *N. Jb. Geol. Paläont., Mh*., H. 5: 257-291.

RICOU L-E., 1995. The plate tectonic history of the past Tethyan ocean. In: Nairn A.E.M., Ricou L-E., Vrielynck B. & Dercourt J. (eds), *The Tethys Ocean. The ocean basins and margins*, Plenum Press, New York & London, vol. 8: 3-70.

ROBERTSON A.H.F., 1993. Mesozoic-Tertiary sedimentary and tectonic evolution of Neotethyan carbonate platforms, margins and small ocean basins in the Antalya Complex, southwest Turkey. *Intern. Assoc. Sediment*., Spec. Publ.. 20: 415-465.

ROBERTSON A.H.F. & DIXON J.E., 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: Dixon J.E. & Robertson A.H.F. (eds), *The geological evolution of the Eastern Mediterranean*. Geol. Soc., London, Spec. Publ. 17: 1-74.

ROBERTSON A.F., DIXON J.E., BROWN S., COLLINS A., MORRIS A., PICKETT E., SHARP I. & USTAÖMER T., 1996. Alternative tectonic models for the Late Palaeozoic-Early Tertiary development of Tethys in the Eastern Mediterranean region. In: Morris A. & Tarling D.H. (eds), *Palaeomagnetism and tectonics of the Mediterranean Region*. Geol. Soc., London, Spec. Publ. 105: 239-263.

ROSS C.A. & ROSS J.R.P., 1988. Late Paleozoic transgressive-regressive deposition. In: Wilgus C.K., Posamentier H., Ross C.A. & Kendall C.G.St.C. (eds), *Sea-level changes: an integrated approach*. Soc. Econ. Paleont. Mineral., Spec. Publ. 42: 227-247.

SCHMID S.M., 1993. Ivrea Zone and adjacent South Alpine basement. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic geology of the Alps*. Springer-Verlag, Berlin: 567-583.

SCHÖNLAUB H.P., 1993. Stratigraphy, biogeography and climatic relationships of the Alpine Palaeozoic. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic geology of the Alps*. Springer-Verlag, Berlin: 65-91.

SCHUMACHER M., CLOETINGH S. & ZIEGLER P.A., 1999. Post-Variscan evolution of the Central European lithosphere: constraints from quantitative subsidence analyses. *J. Conference Abstr*., 1, Abstract: p. 292

SEGHEDI I., SZAKACS A. & BALTRES A., 1990. Relationships between sedimentary deposits and eruptive rocks in the Consul unit (North Dobrogea) - implications on tectonic interpretations. *Dari de Seama ale Sedintelor Institul Geologie Geofizica*, 74: 125-136.

SENGÖR A.M.C., YILMAZ Y. & SONGURLU O., 1984. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys. In: Dixon J.E. & Robertson A.F.H. (eds), *The geological evolution of the Eastern Mediterranean*. Geol. Soc., London, Spec. Publ. 17: 77-112.

SKINNER J.W. & WILDE G.L., 1966. Permian Fusulinids from Sicily. *Univ. Kansas Paleont. Contr*., 8: 1-16.

SMYTHE D.K., RUSSELL M.J. & SKUCE A.G., 1995. Intra-continental rifting inferred from major late Carboniferous quartz-dolerite dyke swarms of NW Europe. *Scott. J. Geol*., 31: 151-162.

STAMPFLI G.M., 1996. Intra-Alpine terrane: a Palaeotethyan remnant in the Alpine Variscides. *Eclogae geol. Helv.*, 89: 13-42.

STAMPFLI G.M., 2000. Tethyan oceans. In: Bozkurt E., Winchester J.A. & Piper J.D.A. (eds), *Tectonics and magmatism in Turkey and surrounding areas*. Geol. Soc., London, Spec. Publ., 173: 1-23.

STAMPFLI G.M. & MARCHANT R.H., 1997. Geodynamic evolution of the Tethyan margins of the Western Alps. In: Pfiffner O.A., Lehner P., Heitzmann P.Z., Müller St. & Steck A. (eds), *Deep structure of the Swiss Alps*. Birkhäuser A.G., Basel: 223-239.

STAMPFLI G.M. & MOSAR J., 1999. The making and becoming of Apulia. *Mem. Sci. Geol.*, Spec. Vol., 3d workshop Alpine Geology, Padova: 141-154.

STAMPFLI G.M., MARCOUX J. & BAUD A., 1991. Tethyan margins in space and time. In: Channel J.E.T., Winterer E.L. & Jansa L.F. (eds), *Paleogeography and paleoceanography of Tethys*. Palaeogeogr., Palaeoclimatol., Palaeoecol., 87: 373-410.

STAMPFLI G.M., DE BONO A. & VAVASSIS I., 1995. Pelagonian basement and cover in Euboea (Greece). In: *EUG 8*, Strasbourg, 7, Abstracts: p. 180.

STAMPFLI G.M., MOSAR J., DE BONO A. & VAVASSIS I., 1998. Late Palaeozoic, early Mesozoic plate tectonic of the western Tethys. *Bull. Geol. Soc. Greece*, 32: 113-120.

STAMPFLI G.M., MOSAR J., FAVRE P., PILLEVUIT A. & VANNAY A-J., in press. Late Palaeozoic to Mesozoic evolution of the Western Tethyan Realm: the Neotethys-East Mediterranean Basin connection. In: Ziegler P.A., Cavazza W., Robertson A.H.F. & Crasquin-Soleau S. (eds), *PeriTethyan rift/wrench basins and passive margins*. PeriTethys Mém. 6, Mém. Mus. Nat. Hist. Nat., Paris, Vol. 186.

STANLEY S.M. & YANG X., 1994. A double mass extinction at the end of the Paleozoic era. *Science*, 266: 1340-1344.

STATTEGER K., 1983. Chromspinell in klastischem Karbon von Chios, Ägäis. *Anzeiger Österr. Akad. Wiss.* 1, 1-2.

St. JOHN B., 1986. Antarctica - geology and hydrocarbon potential. In: Halbouty M.T. (ed.), Future Petroleum Provinces of the World. *Amer. Assoc. Petrol. Geol.*, Mem. 40: 55-100.

TAIT J.A., BACHDADSE V., FRANKE W. & SOFFEL H.C., 1997. Geodynamic evolution of the European Varsican fold belt: palaeomagnetic and geological constraints. *Geol. Rdsch.*, 86: 585-598.

UNRUG R., HARANCZYK C. & CHOCZK-JAMINSKA M., 1999. Easternmost Avalonian and Armorican-Cadomian terranes of central Europe and Caledonian-Variscan evolution of the polydeformed Krakow mobile belt: geological constraints. *Tectonophysics*, 302: 133-157.

USTAÖMER T. & ROBERTSON A.H.F., 1994. Late Palaeozoic marginal basin and subduction-accretion: the Palaeotethyan Küre complex, Central Pontides, northern Turkey. *J. Geol. Soc.*, London, 151: 291-305.

USTAÖMER T. & ROBERTSON A.H.F., 1997. Tectonic-sedimentary evolution of the North-Tethyan margin in the central Pontides of northern Turkey. In: Robinson A.G. (ed.), *Regional and petroleum geology of the Black Sea and surrounding region*. Amer. Assoc. Petrol. Geol., Mem 68: 255-290.

VACHARD D., MARTINI R. & ZANINETTI L., 1999. Permian Fusulinides from Sicily: new biostratigraphic data. In: *Intern. Field Conf. on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations"*, Brescia, Sept. 1999, Abstr. vol.: 90-91.

VAN WEES J-D., STEPHENSON R.A., ZIEGLER P.A., BAYER U., MCCANN T., DADLEZ R., GAUPP R., NARKIEWICZ M., BITZER F. & SCHECK M., 2000. On the origin of the Southern Permian Basin, Central Europe. *Mar. Petrol. Geol.*, 17: 43-59.

VERRALL P., 1989. Speculations on the Mesozoic-Cenozoic tectonic history of the Western United States. In: Tankard J.A. & Balkwill H.R. (eds), *Extensional tectonics and stratigraphy of the North Atlantic margins*. Amer. Assoc. Petroleum Geol., Mem. 46: 615-631.

VIGNERESSE J.L., 1999. Intrusion level of granitic massifs along the Hercynian belt: balancing the eroded crust. *Tectonophysics*, 307: 277-295.

VISSER J.N.J. & PRAEKELT H.E., 1998. Late Palaeozoic crustal block rotation within the Gondwana sector of Pangea. *Tectonophysics*, 287: 201-212.

VON RAUMER J.F., 1998. The Palaeozoic evolution of the Alps: from Gondwana to Pangea. *Geol. Rdsch.*, 87: 407-435.

WERNICKE B.P., 1992. Cenozoic extensional tectonics of the U.S. cordillera. In: Burchfiel B.C., Lipman P.W. & Zoback M.L. (eds), *The Cordilleran orogen*. U.S. Geol. Soc. Amer., Geology of North America, Vol. G, 3: 553-582.

WESTAWAY R., 1999. The mechanical feasibility of low-angle normal faulting. *Tectonophysics*, 308: 407-443.

YIN H. & TONG J., 1998. Multidisciplinary high-resolution correlation of the Permian-Triassic boundary. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 143: 199-211.

ZIEGLER P.A., 1988. Evolution of the Arctic-North Atlantic and the Western Tethys. *Amer. Assoc. Petrol. Geol.*, Mem 43: 198 pp.

ZIEGLER P.A., 1989. *Evolution of Laurussia - a study in Late Palaeozoic plate tectonics*. Kluver Academic Publishers, Dordrecht: 102 pp.

ZIEGLER P.A., 1990. *Geological atlas of Western and Central Europe*, 2nd. Ed. Shell Intern. Petroleum Mij. B.V. and Geol. Soc. London: 239 pp.

ZIEGLER P.A., 1993 a. Plate-moving mechanisms: their relative importance. *J. Geol. Soc.*, London, 150: 927-940.

ZIEGLER P.A., 1993 b. Late Palaeozoic-Early Mesozoic plate reorganization: Evolution and demise of the Variscan fold belt. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic Geology in the Alps*. Springer-Verlag, Berlin, Heidelberg, New York, London: 203-216.

ZIEGLER P.A., CLOETINGH S., GUIRAUD R. & STAMPFLI G.M., in press. PeriTethyan Platforms: dynamics of rifting and basin inversion. In: Ziegler P.A., Cavazza W., Robertson A.H.F. & Crasquin-Soleau S. (eds), *PeriTethyan rift/wrench basins and passive margins*. PeriTethys Mém. 6, Mém. Mus. Nat. Hist. Nat., Paris, Vol. 186.

ZONENSHAIN L.P., KUZMIN M.I. & NATAPOV L.M., 1990. *Geology of the USSR: a plate-tectonic synthesis*. Amer. Geophys. Union, Washington. Geodyn. Ser. 20: 242 pp.

1.1. ITALY

EARLY PERMIAN PALAEOFAULTS AT THE WESTERN BOUNDARY OF THE COLLIO BASIN (VALSASSINA, LOMBARDY)

DARIO SCIUNNACH[1]

Key-words – Permian; Orobic Alps; palaeofaulting; red beds; petrofacies.

Abstract – Detailed field mapping at the 1:10,000 scale in the western Orobic Anticline revealed that the boundary between two intrusive bodies in the Southalpine Basement corresponds to an Early Permian palaeofault.
The distribution of the overlying Cisuralian volcanics and clastics (volcanic member of the Collio Formation; Ponteranica Conglomerate, here reported for the first time west of the Biandino Valley), in turn unconformably sealed by upper Guadalupian? to Lopingian red beds (Verrucano Lombardo), might indicate tectonic subsidence of the hanging-wall of another Early Permian normal fault, marking the western boundary of the Collio basin, where coarse-grained alluvial clastics and, further to the east, sandy and muddy sediments were deposited.

Parole chiave – Permiano; Alpi Orobiche; paleofaglie; strati rossi; petrofacies.

Riassunto – Un rilievo geologico di dettaglio in scala 1:10,000 al margine occidentale dell'Anticlinale Orobica ha evidenziato che il limite tra due corpi intrusivi del Basamento Sudalpino corrisponde in realtà ad una paleofaglia del Permiano Inferiore. La distribuzione dei soprastanti depositi vulcanici e terrigeni cisuraliani (membro vulcanico della Formazione di Collio; Conglomerato del Ponteranica, qui descritto per la prima volta ad ovest della Val Biandino), a loro volta ricoperti in discordanza da depositi alluvionali del Guadalupiano superiore?-Lopingiano (Verrucano Lombardo), potrebbe indicare la subsidenza tettonica del tetto strutturale di una seconda faglia normale del Permiano Inferiore che segna il confine occidentale del bacino del Collio, in cui si deposero sedimenti clastici grossolani e, muovendo verso est, arenaceo-pelitici.

INTRODUCTION AND PREVIOUS STUDIES

The Italian program of geological mapping at the 1:50,000 scale (CARG: Catenacci, 1995), attended to for the territory of Lombardy by Regione Lombardia, can be seen as an opportunity to revise both the stratigraphic succession and the tectonic framework of the central Southern Alps. The study area of the present case history is located at the northwestern corner of sheet 076 "Lecco", corresponding to the western end of the Orobic Anticline (Fig. 1). There, a volcanic to terrigenous succession of Permian to Anisian age overlies the Southalpine crystalline basement, here consisting of low- to medium-grade Variscan paraderivates intruded by early post-Variscan plutons.

The study area was considered in the comprehensive monographs of Crommelin (1932), Merla (1933) and De Sitter & De Sitter-Koomans (1949). A thorough stratigraphic revision of the Upper Carboniferous to Triassic succession just east of the study area was provided by Casati & Gnaccolini (1967); the post-Variscan intrusive complex was studied in detail by Pasquaré (1967) and Thöni *et al.* (1992, *cum bibl.*). The relationships between the Variscan basement and its Permian cover were described in Casati (1968) and Gaetani *et al.* (1987).

GEOLOGICAL FRAMEWORK

Crystalline basement

• *Metamorphic host rocks.* Melanocratic micaschists and paragneisses, locally yielding relics of andalusite (Fig. 2A), kyanite, garnet and staurolite and displaying widespread quartz rods, pass to foliated quartzites (Morbegno Gneiss, "Gneiss minuti a biotite" *Auct.*); prominent contact effects by the adjacent plutons are documented by extensive growth of randomly-oriented phyllosilicates (biotite, chlorite) and cordierite. The analysis of quartz rods failed to reveal compositional or textural features, such as relics of stable lithic grains, alignments of ultrastable heavy minerals, or syntaxial quartzose overgrowths, hinting at a primary sedimentary origin; thus, quartz has to be considered as entirely neoblastic.

[1] Struttura Analisi e Informazioni Territoriali, Regione Lombardia, Piazza Duca d'Aosta 4, 20124 Milano, Italy.

Two main deformation phases are recognised: the first marks the development of a widespread S1 foliation, on which a S2 crenulation cleavage is superposed; locally, tight crenulation causes isoclinal folding of the S1 surface and disruption of the transposed hinges. A late metamorphic overprint is recorded by mild – although widespread – kinking of the pre-existing fabrics (S3).

• *Post-variscan plutons.* A large system of sills and laccoliths, mostly consisting of finely crystalline, biotite-rich quartz-diorites (Val Biandino Granodiorite), passes westwards to coarser biotite-rich granodiorites, in which widespread poikilitic quartz encloses plagioclase phenocrysts ("Cortabbio diorite"; Fig. 2B); a large mass of leucocratic hypabyssal granites, displaying large K-feldspar porphyrocrysts in a granophyric microcrystalline groundmass ("Vle Biagio Granite" of De Sitter & De Sitter-Koomans, 1949; Fig. 2C), is confined to the Bindo-Prato San Pietro area.

Lower Permian volcanic-sedimentary succession

• *Collio Formation.* The paroxysmal effusion of intermediate to acidic ignimbrites (benmoreites to rhyolites), yielding zircon ages at 287 (Cadel, 1986) and 283 My (Schaltegger & Brack, 1999) which correspond to the Sakmarian-Artinskian in the time scale of Menning (1995), was followed by episodic eruptions of bimodal products (mugearites-andesites to dacites-rhyolites; preliminary unpublished data by the Author), alternating to stages of volcanic quiescence during which, east of the study area, clastic sedimentation took place.

The contact between the Orobic crystalline basement and the basal Volcanic Member *Auct.* of the Collio Formation (*breviter* Collio volcanics in this paper) is invariably tectonic, and underlined by a blanket, up to a few metres-thick, of black cataclasites (Casati & Gnaccolini, 1967; Casati, 1968) yielding boron mineralisations (Zhang *et al.*, 1994). This tectonic basal contact hampers a precise assessment of the thickness of the Lower Permian volcanics, whereas thickness estimated for the overlying Ponteranica Conglomerate, here bracketed between the Collio volcanics and the Verrucano Lombardo, are more accurate.

The hypothesis according to which the Valsassina intrusions would represent the magma chambers of the Collio volcanics (Merla, 1933; Cadel, 1986), although rea-

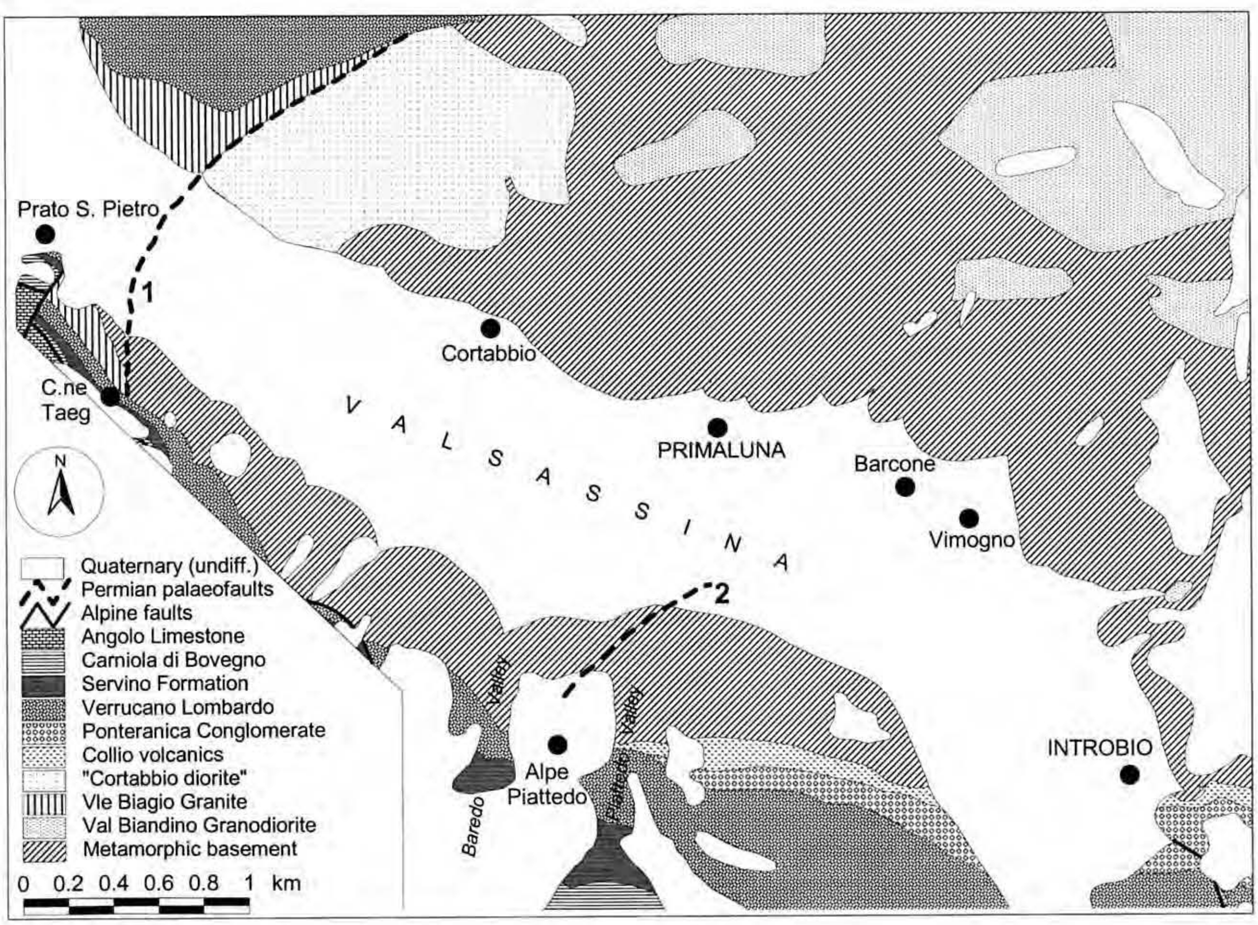


Fig. 1 – Geological sketch map of the study area. Numbers 1, 2 refer to the palaeofaults described in text. The northeastern corner of the study area was mapped in collaboration with G.B. Siletto.

sonable, is difficult to demonstrate because the outcrops lack evidence of a physical continuity between the plutons and the volcanics.

• *Ponteranica Conglomerate.* Coarse-grained clastics become predominant in the upper Collio Fm. Poorly-sorted cobble conglomerates, with angular to subangular volcanic and metamorphic clasts by far prevailing over quartz pebbles, sharply overlie the Collio volcanics from Alpe Piattedo to the Acquaduro Valley (Introbio), where they are eventually cut out by the Valtorta Fault. The few coarse-grained sandstones intercalated to these conglomeratic red beds (Fig. 2E) yielded detrital modes (Fig. 3) clustering in

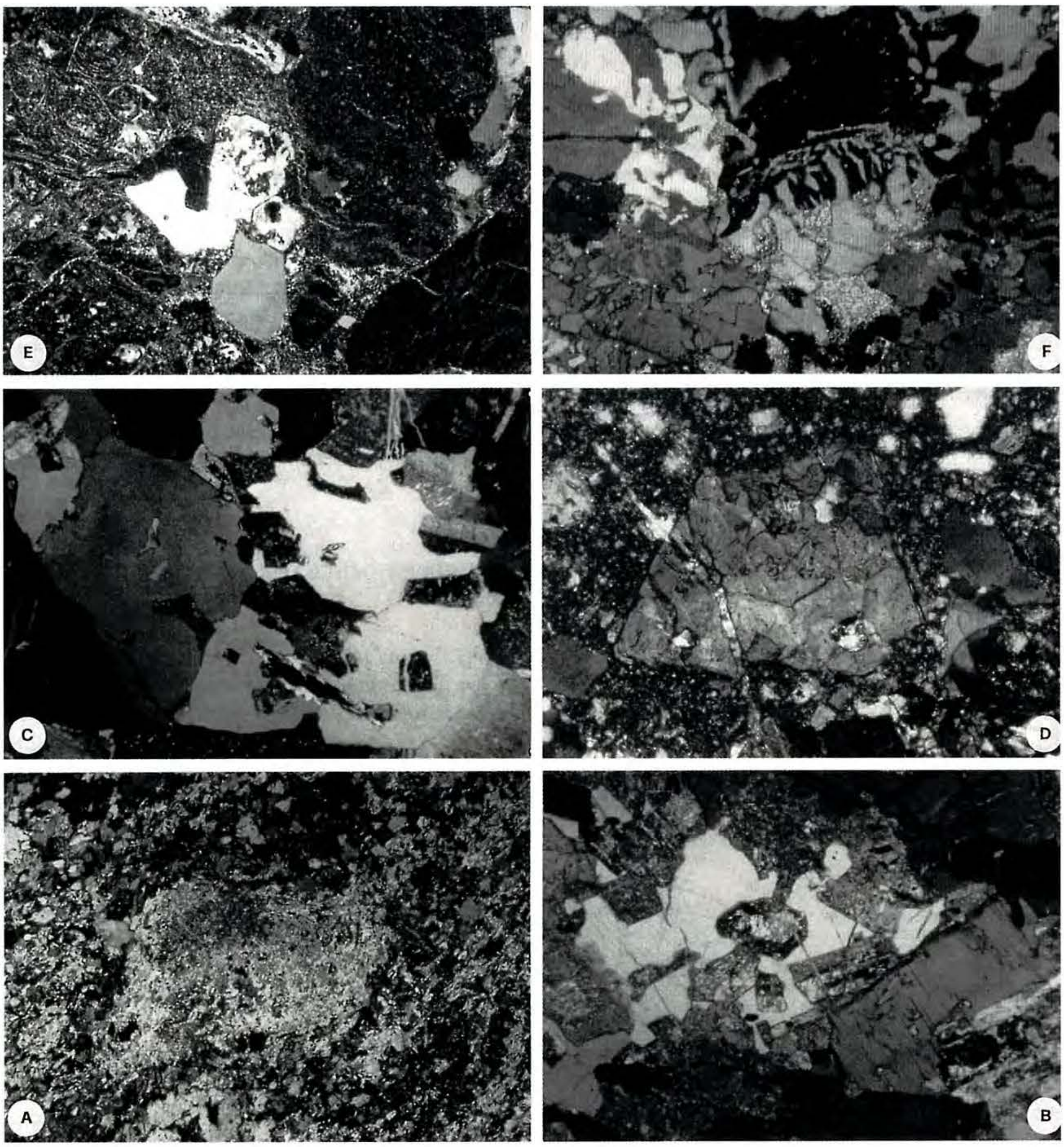


Fig. 2 – Representative photomicrographs for the studied rock types. A. Rotated andalusite? porphyroblast in a phyllonitic sericite paragneiss (metamorphic basement), Cortabbio, 11x. B. Biotite-rich granodiorite ("Cortabbio diorite") with plagioclase phenocrysts implicated by poikilitic quartz, Cortabbio, 17x. C. Leucocratic granite with granophyric implications ("Vle Biagio Granite"), Bindo, 17x. D. Tourmaline-rich cataclasite, Cortabbio/Cortenova boundary fault, 67x. E. Very coarse-grained volcanic arenite with volcanic lithics displaying biotite and embayed quartz phenocrysts, as well as spherulitic structures (Ponteranica Conglomerate), Pizzo dei Tre Signori area, 11x. F. Granophyre pebble in the Verrucano Lombardo conglomerate facies, Introbio, 13x. All photos are in cross-polarised light.

the Lower Permian petrofacies P0 (Q = 10±5, F = 20±8, L = 70±8; C/Q = .17±.13; P/F = .82±.09; V/L = .99±.01), which characterises the sedimentary member of the Collio Formation (Sciunnach *et al.*, 1999). Compositional identity has to be regarded as a reliable indication of physical continuity of clastic bodies at basin scale; the described red beds, displaying lower textural maturity and mineralogical stability with respect to the overlying Verrucano Lombardo, can be thus correlated with the Ponteranica Conglomerate and interpreted as its western end. The Ponteranica Conglomerate, absent on basement highs – due to either non-deposition or erosion – and up to 150 m-thick in the study area, was deposited in footwall-sourced fan-deltas, bordering tectonically-controlled lacustrine basins; thickness locally exceeds 600 m (Casati & Gnaccolini, 1967), as a result of pronounced tectonic subsidence. Regional correlation with the section dated by Schaltegger & Brack (1999) constrains the age of deposition to the Early Permian, possibly to the Artinskian.

Upper Permian to Anisian sedimentary succession.

• *Verrucano Lombardo.* Wine red conglomerates, pebbly cross-bedded sandstones and siltstones, arranged in decametric fining-upward cyclothems, rest either unconformably on the Collio clastics (Casati & Gnaccolini, 1967) or non-conformably on the Early Permian basement highs (Garzanti & Sciunnach, 1997), documenting widespread subsidence of a pre-existing basin-and-swell palaeotopography (Gaetani *et al.*, 1987; Cassinis *et al.*, 1988). The Verrucano Lombardo was largely deposited in a vast braidplain; rounding of volcanic pebbles and sharp variations in thickness (increasing from less tha 150 to over 400 m, west to east, in the Introbio area) are consistent with transport, under high topographic gradients, of detritus derived from sources located some tens of kilometres to the west. Actually, rare pebbles with granophyric structure (Fig. 2F) could be tentatively restored to a source rock coeval with the Cuasso al Monte granophyre (Buletti, 1985), although their local concentration might even suggest provenance from nearby sources. Age is constrained as mostly Late Permian (latest Guadalupian? to Lopingian) due to stratigraphic position and regional correlation with the roughly coeval Val Gardena Sandstone.

• *Servino to Bellano Formations.* Quartzose clastics passing upwards to poorly exposed and strongly deformed marly dolostones and silty marls (Servino Formation) are overlain by badly tectonised, evaporitic vuggy dolostones (Carniola di Bovegno). These transitional units, deposited after transgression of a shallow epicontinental sea on the Verrucano Lombardo braidplain, form a continuous cataclastic belt at the tectonic contact between the Orobic Anticline and the Northern Grigna thrust sheet. In the latter, the Carniola di Bovegno is overlain by the coarse-grained clastics of the Anisian Bellano Formation, deposited in fan-delta setting, and laterally by the silty member of the Angolo Limestone (Gaetani *et al.*, 1987; Sciunnach *et al.*, 1996).

OUTCROP EVIDENCE FOR EARLY PERMIAN PALAEOFAULTS

Fault 1 (Figs 1, 4) is exposed along the talweg of a small stream (Fig. 5) marking the administrative boundary between the towns of Primaluna and Cortenova. It is underlined by black cataclasites and separates the Vle Biagio Granite (hanging-wall) from the "Cortabbio diorite" (footwall); the latter includes slivers of the metamorphic host rocks (Fig. 4). Both units are sealed by a thick sheet of red beds (Verrucano Lom-

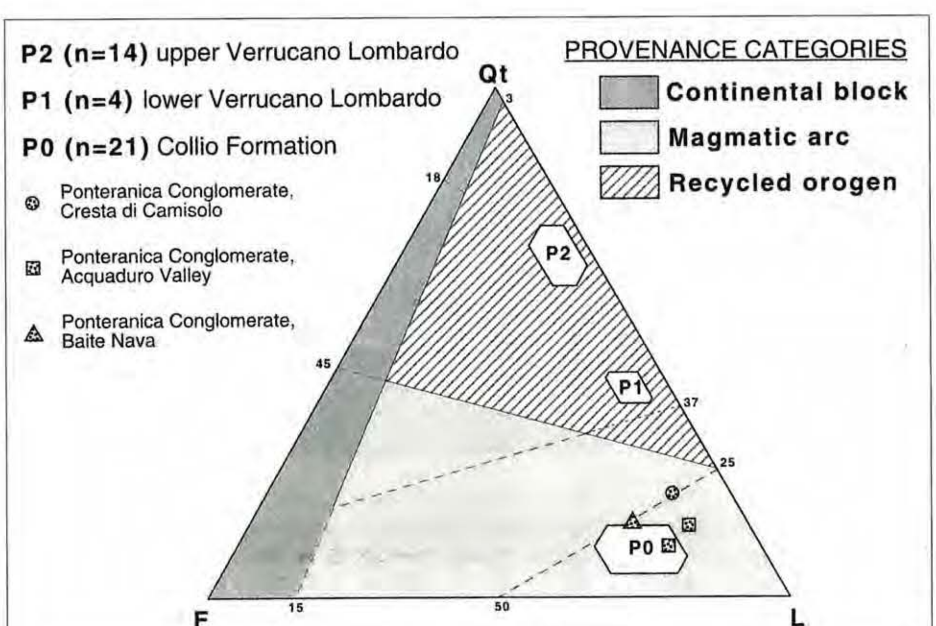


Fig. 3 – QtFL plot of the Ponteranica Conglomerate sandstones compared to the petrofacies recognised in the Permian succession of the Orobic Alps by Sciunnach *et al.* (1996, 1999). Polygons are one standard deviation each side of the mean.

bardo) that appears to be unfaulted, and just gently buckled by the large-scale, open folding of the Orobic Anticline. It is noteworthy that the same outcrop pattern as in Fig. 1 had been already described in Crommelin (1932), where the rock units were mapped correctly, but their mutual geometrical relationships were not interpreted in terms of prealpine faulting; fault 1 is also pictured in Schönborn (1992, fig. 17) as a pre-Verrucano fault, but without any comment in the text. On the path leading from Prato San Pietro to C.ne Taeg, a non-conformable stratigraphic contact of the Verrucano Lombardo on the "Vle Biagio Granite" is observed; the topmost 2÷3 metres of

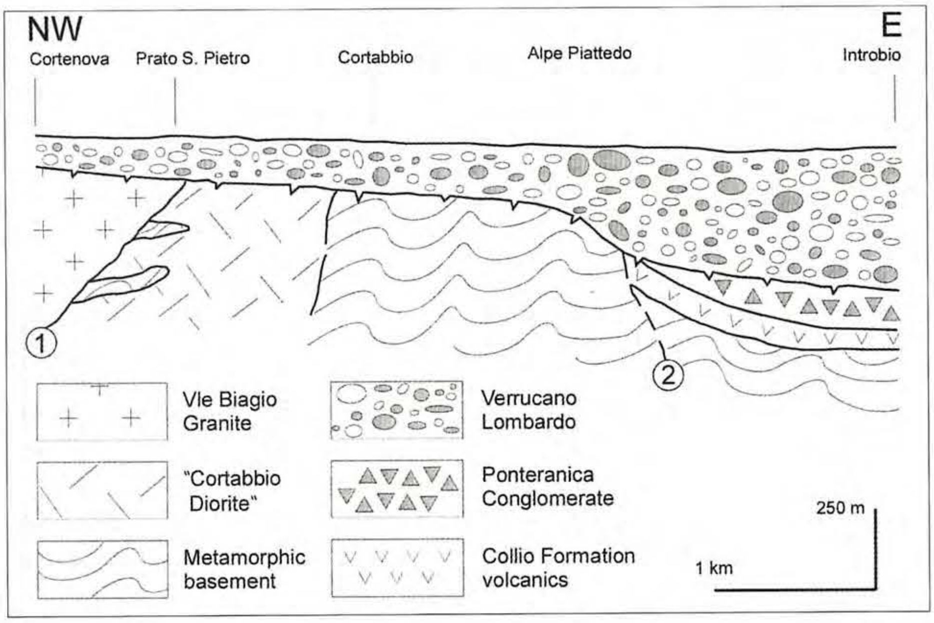


Fig. 4 – Simplified stratigraphic scheme for the studied succession (vertical exaggeration 2x). The upper datum plane is given by the inferred Permian-Triassic boundary.

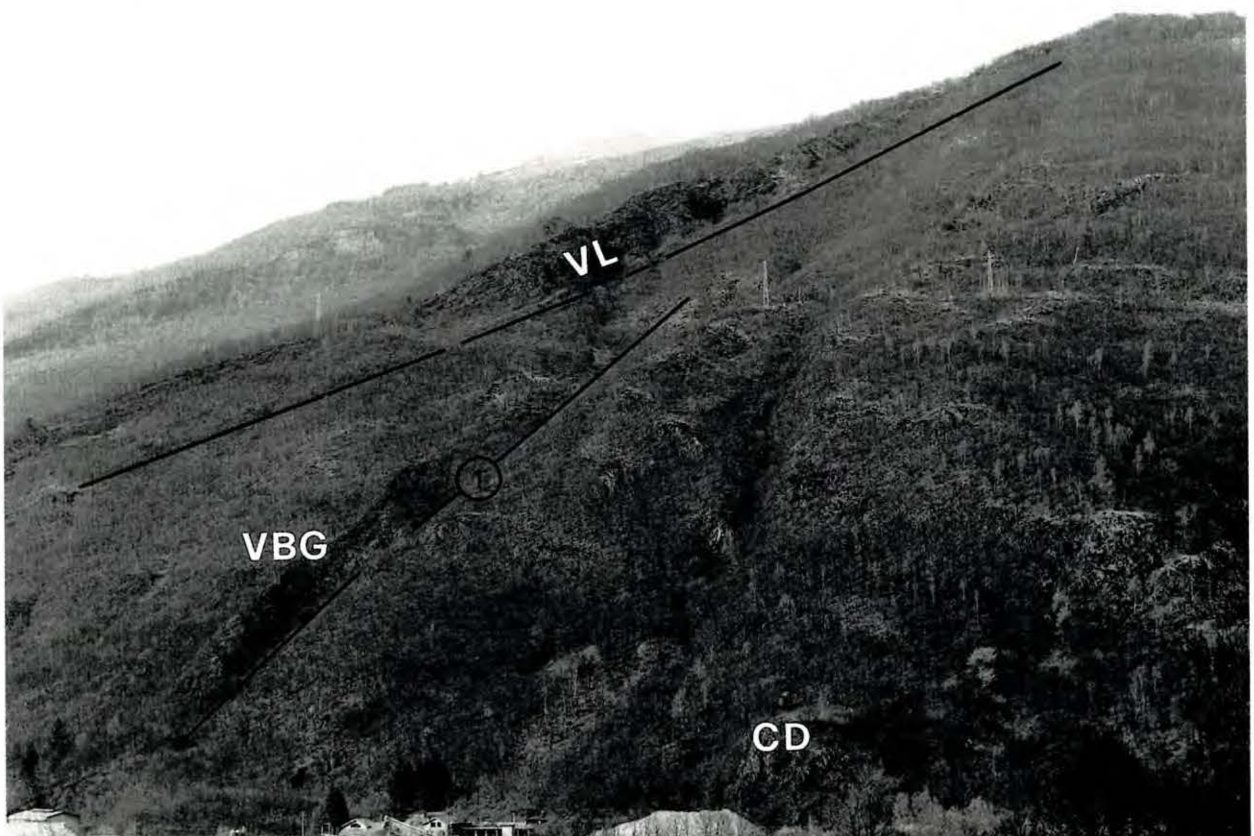


Fig. 5 – Palaeofault 1 in outcrop along the northwestern slope of Valsassina. CD = "Cortabbio diorite", VBG = "Vle Biagio Granite", VL = Verrucano Lombardo.

the granite below the non-conformity are reddened and deeply weathered, probably as a result of prolonged subaerial exposure during the Permian.

The black cataclasites yielded abundant tourmaline (Fig. 2D), occurring as euhedral crystals up to 3 mm in length. According to WDS analysis (Tab. 1), tourmaline can be classified as a solid solution of dravite and schorl and related to Ca-poor metapelites, metapsammites and quartz-tourmaline rocks according to Henry & Guidotti (1985). In the Orobic Alps, glassy tourmalinites at the tectonic contact between basement and volcanic cover have been interpreted in terms of contact by boron-rich hydrothermal fluids with aluminous host rocks, that might correspond to the Collio sediments (Zhang *et al.*, 1994) as well as to the associated volcanics.

Around Alpe Piattedo (Introbio), previously unrecognised outcrops of Ponteranica Conglomerate are restored to the western end of a clastic wedge that pinches out towards a structural high to the west and is sealed by a continuous blanket of Verrucano Lombardo red beds; thickness of the latter strongly and abruptly increases from northwestern Valsassina to the Introbio area, probably as a result of a pre-existing basin-and-swell palaeotopography (Gaetani *et al.*, 1987) that is inferred to have been controlled by a normal fault (2 in Figs 1, 4). It is reasonable to assume that the deposition of the Ponteranica conglomerate wedge was triggered by the tectonic subsidence of the eastern hanging-wall.

Oxides, weigth %		Element stoichiometry		
B_2O_3	10.56	B	3.000*	
SiO_2	36.69	Si	6.035	
Al_2O_3	30.55	Al	5.921	
TiO_2	1.14	Ti	0.141	
FeO	8.01	Fe	1.102	2.983
MnO	0.05	Mn	0.007	
MgO	7.07	Mg	1.733	
CaO	0.36	Ca	0.063	
Na_2O	2.25	Na	0.717	0.784
K_2O	0.02	K	0.004	
Total	96.70	Structural formula on the basis of 24.5 + 4.5 oxygens		

Tab. 1 - WDS microanalysis on tourmaline from the cataclasite underlining fault 1. FeO is meant to include possible Fe_2O_3; the weight of B_2O_3 is calculated from the theoretical stoichiometric value (*).

CONCLUSIONS

• *Cortabbio/Cortenova boundary fault (1).* Age of this pre-alpine fault is fairly well constrained. The proposed geometrical scheme (Fig. 4) clearly shows that faulting post-dates the emplacement of the plutons and pre-dates the deposition of the Verrucano Lombardo: the faulting event is thus safely constrained to the Early Permian. In fact, the post-Hercynian plutons of the western Orobic Alps have been mostly dated as Late Carboniferous to earliest Permian (Thöni *et al.*, 1992; Siletto *et al.*, 1993 *cum bibl.*), whereas the Verrucano Lombardo is usually ascribed to the Upper Permian due to its stratigraphic position; however, its base might even reach locally into the Guadalupian (mid-Permian) as suggested by the occurrence of the Kiaman/Illawarra paleomagnetic reversal in the roughly coeval Val Gardena Sandstones (Dachroth, 1976; Mauritsch & Becke, 1983). In the Early Permian, the most important phase of extensional tectonics in the central Southern Alps is related to the development of the rapidly-subsiding Collio basin, that can be ascribed to the Autunian in the Orobic Anticline (Casati & Gnaccolini, 1967) and can be dated all over its outcrop area as largely Sakmarian to Artinskian according to the zircon ages by Cadel (1986) and Schaltegger & Brack (1999; time scale after Menning, 1995). Fault geometry and widespread granophyric structures in the Vle Biagio Granite (hanging-wall) seem to indicate a normal displacement of the latter with respect to the deeper-seated "Cortabbio diorite". Downthrow of the northwestern hanging-wall would imply the opening of a trough-shaped basin in an area lacking Lower Permian sediments; this might indicate that the fault was associated with an early stage of extensional collapse of the Hercynian orogen, possibly influenced by positive buoyancy of sectors of the range intruded by plutons (Val Biandino complex) with respect to the adjacent, intrusion-free areas (Taceno district, Collio basin). Moreover, the fault forms an angle of about 45° with the base of the Verrucano Lombardo; normal faults are commonly inclined by at least 60° due to mechanical convenience criteria, so it is likely that 1) either the whole considered sector of the Southalpine basement was tilted by at least 15° prior to deposition of the Verrucano Lombardo, 2) or the fault was lystric and Permian erosion, coupled with isostatic compensation and uplift of the Hercynian orogen, cut deep into the Southalpine Basement where the fault plane was asymptotically tending to horizontal.

• *Alpe Piattedo fault (2).* Coarse-grained clastics of Early Permian age, testifying to proximal alluvial fan facies, are superposed to the Collio volcanics as westwards as Alpe Piattedo. The western boundary of the area where the Lower Permian volcanics are preserved was interpreted in Gaetani *et al.* (1987) as a normal fault, accommodating the sharp increase in thickness of the Verrucano Lombardo from nothwestern Valsassina to the Introbio area. Such an increase, however, is partly accounted for by the occurrence of the Ponteranica Conglomerate; the resulting stratigraphic scheme also allows to better constrain the age of normal faulting, which seemingly shortly followed the volcanic activity and triggered deposition of the volcanic detritus eroded from the footwall in the adjacent hanging-wall troughs. The inferred Alpe Piattedo palaeofault seemingly marks the western boundary of the articulated Early Permian Collio Basin; its NE strike matches the regional trend of basin boundary faults in the Novazza-Val Vedello district (Cadel, 1986 *cum bibl.*).

Acknowledgements – The paper benefitted from useful discussions with A. Boriani, E. Sciesa and G.B. Siletto, as well as from careful review by G. Cassinis. Technical assistance by D. Biondelli (WDS microanalysis), R. Crespi (photomicrographs) and C. Malinverno (thin sections) is gratefully acknowledged. Field and lab work supported by CARG grants.

REFERENCES

BULETTI M., 1985. Petrographisch-geochemische Untersuchungen im Luganer Porphyrgebiet. *Diss. Univ. Bern*: 157 pp.

CADEL G., 1986. Geology and uranium mineralization of the Collio Basin (Central Southern Alps, Italy). *Uranium*, 2: 215-240.

CASATI P., 1968. Rapporti tra il basamento cristallino e le formazioni del Permiano presso Introbio in Valsassina (Lombardia). *Rend. Sci. Ist. Lomb.*, A 101 (1967): 866-872.

CASATI P. & GNACCOLINI M., 1967. Geologia delle Alpi Orobie occidentali. *Riv. Ital. Paleont. Stratigr.*, 73: 25-162.

CASSINIS, G., MASSARI, F., NERI C. & VENTURINI, C., 1988. The Continental Permian in the Southern Alps (Italy). A Review. *Z. geol. Wiss.*, 16/11-12: 1117-1126.

CATENACCI V., 1995. Il progetto di realizzazione della nuova cartografia geologica ufficiale del territorio nazionale. *Boll. Soc. Geol. Ital.*, 114: 107-130.

CROMMELIN R.D., 1932. La Géologie de la Valsassina et de la région adjacente au Nord. Eduard Ijdo, Leiden: 59 pp.

DACHROTH W., 1976. Gesteinmagnetische Marken im Perm Mitteleuropas (Ein Beitrag zur Anwendung gesteinmagnetischer Daten in der Stratigraphie). *Geol. Jb.*, E10: 3-63.

DE SITTER L.U. & DE SITTER-KOOMANS C.M., 1949. Geology of the Bergamasc Alps, Lombardia, Italy. *Leid. Geol. Medd.*, 14: 1-257.

GAETANI M., GIANOTTI R., JADOUL F., CIARAPICA G., CIRILLI S., LUALDI A., PASSERI L., PELLEGRINI M., TANNOIA G., 1987. Carbonifero, Permiano e Triassico dell'area lariana. *Mem. Soc. Geol. Ital.*, 32: 5-48.

GARZANTI E. & SCIUNNACH D., 1997. Permo-Triassic evolution – constraints from the sedimentary record. *Ofioliti*, 22: 147-151.

HENRY D.J. & GUIDOTTI C.V., 1985. Tourmaline as a petrogenetic indicator mineral: an example from the staurolite-grade metapelites of Maine. *Amer. Mineral.*, 70: 1-15.

MAURITSCH H.J. & BECKE M., 1983. A magnetostratigraphic profile in the Permian (Gröden Beds, Val Gardena Formation) of the Southern Alps near Pualaro. *IGCP Newsletter*, 5: 80-86.

MENNING M., 1995. A Numerical Time Scale for the Permian and Triassic Periods: An Integrated Time Analysis. In: Scholle P.A., Peryt T.M. & Ulmer-Scholle D.S. (eds), *The Permian of Northern Pangea Vol. 1*, Springer-Verlag: 77-97.

MERLA G., 1933. Geologia della Valsassina da Introbbio a Bellano. *Mem. Geol. Geogr. G. Dainelli*, 4: 1-44.

PASQUARÉ G., 1967. Analisi geologico-strutturale del complesso intrusivo di Val Biandino (Alpi Orobie Occidentali). *Mem. Soc. Geol. Ital.*, 6: 343-357.

SCHALTEGGER U. & BRACK P., 1999. Short-lived events of extension and volcanism in the Lower Permian of the Southern Alps (Northern Italy, Southern Switzerland). *EUG '99*, D02:4A/02: F1: 296-297.

SCHÖNBORN G., 1992. Alpine tectonics and kinematic models of the Central Southern Alps. *Mem. Sci. Geol.*, Padova, 44: 229-393.

SCIUNNACH D., GARZANTI E. & CONFALONIERI M.P., 1996. Stratigraphy and petrography of Upper Permian to Anisian terrigenous wedges (Verrucano Lombardo, Servino and Bellano Formations; western Southern Alps). *Riv. Ital. Paleont. Stratigr.*, 102: 27-48.

SCIUNNACH D., CONFALONIERI M.P. & GARZANTI E., 1999. Petrofacies of the Upper Carboniferous to Permian continental clastics of the central Southern Alps, Italy. *19th IAS Meeting, Abstr. Vol.*: 225-227.

SILETTO G.B., SPALLA M.I., TUNESI A., LARDEAUX J.M. & COLOMBO A., 1993. Pre-Alpine Structural and Metamorphic Histories in the Orobic Southern Alps, Italy. In: von Raumer J.F. & Neubauer F. (eds), *Pre-Mesozoic Geology in the Alps*. Springer-Verlag: 585-598.

THÖNI M., MOTTANA A., DELITALA M.C., DE CAPITANI L. & LIBORIO G., 1992. The Val Biandino composite pluton: A late Hercynian intrusion into the South-Alpine metamorphic basement of the Alps (Italy). *N. Jb. Mineral. Mh.*, H. 12: 545-554.

ZHANG J.S., PASSCHIER C.W., SLACK J.F., FLIERVOET T.F. & DE BOORDER H., 1994. Cryptocrystalline Permian tourmalinites of possible metasomatic origin in the Orobic Alps, Northern Italy. *Econ. Geol.*, 89: 391-396.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 45-50

TETRAPOD FOOTPRINTS FROM THE LOWER PERMIAN OF WESTERN OROBIC BASIN (N. ITALY)

UMBERTO NICOSIA [1], AUSONIO RONCHI [2] and GIUSEPPE SANTI [2]

Key words – footprints; Permian; Southern Alps; stratigraphy.

Abstract – Large numbers of tetrapod footprints have recently been discovered within sediments pertaining to the Early Permian Collio Fm. in the Western Orobic Basin (between the upper Varrone and upper Gerola valleys, Lombardy, Italy).
They can be ascribed to the following taxa: *Amphisauropus latus* Haubold, 1970, *A. imminutus* Haubold, 1970, *Dromopus lacertoides* (Geinitz, 1861) and *Varanopus curvidactylus* (Moodie, 1929).
This low-diversity ichnoassociation is coeval with those of Central Europe and North America and can also be correlated with that yielded from the lower portion of the Brescian Collio Fm. The geological setting as well as the stratigraphic position of the track-bearing sequence is outlined below, together with a discussion of some hypotheses for the presence of this low-diversity ichnoassociation.

Parole chiave – impronte; Permiano; Sudalpino; Stratigrafia.

Riassunto – Un gran numero di impronte di tetrapodi è stato rinvenuto recentemente in terreni appartenenti alla sommità stratigrafica della Formazione di Collio (Permiano inferiore) nel bacino Orobico occidentale (tra l'Alta Val Varrone e l'Alta Val Gerola, Lombardia, Italia). Si tratta delle seguenti icnospecie: *Amphisauropus latus* Haubold, 1970, *A. imminutus* Haubold, 1970, *Dromopus lacertoides* (Geinitz, 1861) e *Varanopus curvidactylus* (Moodie, 1929). Questa icnoassociazione, caratterizzata da una bassa diversità, è coeva con le associazioni del Permiano inferiore dell'Europa Centrale e del Nord America e può inoltre essere correlata con quella rinvenuta nella parte inferiore della Formazione di Collio, nell'omonimo bacino triumplino. Oltre all'inquadramento geologico e stratigrafico della successione di terreni che ha fornito tali impronte, vengono di seguito discusse varie ipotesi sulle possibili cause di tale ristretta icnoassociazione.

INTRODUCTION AND GEOLOGICAL SETTING

Late Palaeozoic tetrapod footprints from sediments cropping out both in the Lower Permian of the central Southern Alps and in the Upper Permian of the Dolomites have been known since the late 19th century (see Conti *et al.*, 1991, for a historical review).

Recently, numerous tetrapod footprints have been found in the Permian deposits of the Western Orobic Prealps (upper Gerola-Inferno and Varrone valleys, Lombardy, Italy) (Fig. 1).

The footprints come from the uppermost levels of the local Collio Fm. and have been ascribed to *Amphisauropus latus* Haubold, 1970, *A. imminutus* Haubold, 1970, *Dromopus lacertoides* (Geinitz, 1861) and *Varanopus curvidactylus* (Moodie, 1929) (Plate 1 and Fig. 3).

This association is closely comparable to a similar one recorded in the lower portion of the Collio Fm. cropping out within the Collio Basin in the Brescia region, and to the similar and coeval Early Permian association of Central Europe and North America.

The first to report the presence of tetrapod footprints, but on the eastern side of the Orobic Basin (eastern Brembana Valley) was Dozy (1935), who ascribed these forms to *Anhomoicnium orobicum* and *Onychicnium escheri*. The first of them was later attributed to an extramorphological imprint of *Batrachichnus salamandroides* (Haubold, 1996), while the other taxon was considered as *incertae sedis* (?*Actibates*) (Haubold, 1971).

Many years after, Casati & Gnaccolini (1967) and Casati & Forcella (1988) reported scarce findings of some tetrapod footprints in the area close to Rifugio Falc and Pizzo Varrone.

Concerning the geology and stratigraphy of the area, the first detailed studies were undertaken by Porro (1931, 1932); subsequently, De Sitter & De Sitter-Koomans (1949 and references therein) published a wide geological map of the Bergamo Alps, putting together the contributions and

[1] Dipartimento di Scienze della Terra, Università "La Sapienza", P.le A. Moro 5, 00185 Roma, Italy.
[2] Dipartimento di Scienze della Terra, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy.

surveys of many other authors. For a more up-to-date stratigraphic framework of the Western Orobic Basin (including a 1:25,000 geological map), we must refer to the work of Casati & Gnaccolini (1967). The stratigraphy of the whole area is also reported by the same authors in the Illustrative Notes of Sheet 18 "Sondrio", 1:100,000 Geological Map of Italy (Bonsignore *et al.*, 1971).

As in the other Late Paleozoic basins of the Southern Alps, in the Orobic Basin two main tectonosedimentary cycles can be recognised: the first one, spanning from the Late Carboniferous(?) to the Early Permian, is mainly represented by a volcanosedimentary lithosome (*i.e.* the Collio Fm. and heteropic formations) deposited in intramontane lacustrine-to-alluvial troughs; the second one, Late Permian in age and separated by a regional unconformity, is represented by a coarse-to-fine alluvial blanket, named the Verrucano Lombardo-Arenaria di Val Gardena (to the west or east of the Adige Valley respectively), which has filled the previous depressions and spread over wide areas.

STRATIGRAPHY

Northeast of Pizzo Varrone, where the richest ichnofossil-bearing strata are located, a 130 m thick stratigraphic section was described in the Collio Fm (up to several hundreds of metres in the area).

It is represented by grey-to-reddish shales and arenites (referred to as the "Scisti di Carona", so-called by De Sitter & De Sitter-Koomans, 1949) with medium to coarse pebbly sandstone and microconglomerate layers interfingered in the lower part. These latter could represent the distal portions of coarse detritic alluvial fan deposits named "Conglomerato di Ponteranica" (Casati & Gnaccolini, 1965).

As a whole, the section (Fig. 2) is very well bedded in centimetre to decimetre-scale layers, mostly representing minor sedimentary cycles with frequent scours or convex erosional bases and internal fining-upwards sequences. Sedimentary structures such as planar and cross-laminations, as well as trough cross-bedding, can commonly be observed; on the bedding surfaces, climbing and wave-ripple marks, raindrop casts, mudcracks and burrows are also frequent. This part of the formation, from which the ichnofossils come, can be related to a flat alluvial plain cut by small ephemeral streams and shallow lakes, pertaining to a semi-arid environment.

The presence within arenitic layers of imbricated black clay-chips of intraformational origin suggests frequent changes in water energy and abrupt increases in erosional power.

In the aforementioned section, macrofloral fragments (*Walchia* sp.), purple-red silicified wood stems of centimetre to decimetre-scale, freshwater coelenterates (hydromeduse), stromatolitic mounds and algal oncolites were also recognised by the authors. These forms are associated with yellow ochre carbonate and ferroan dolomite beds and concretions. It is also worth remembering the recent discovery, close to this site, of significant three-dimensional macrofloral remains of the conifer *Cassinisia orobica* (Kerp *et al.*, 1996).

In the described section, the boundary between the Collio Fm. and the overlying Verrucano Lombardo Fm. is

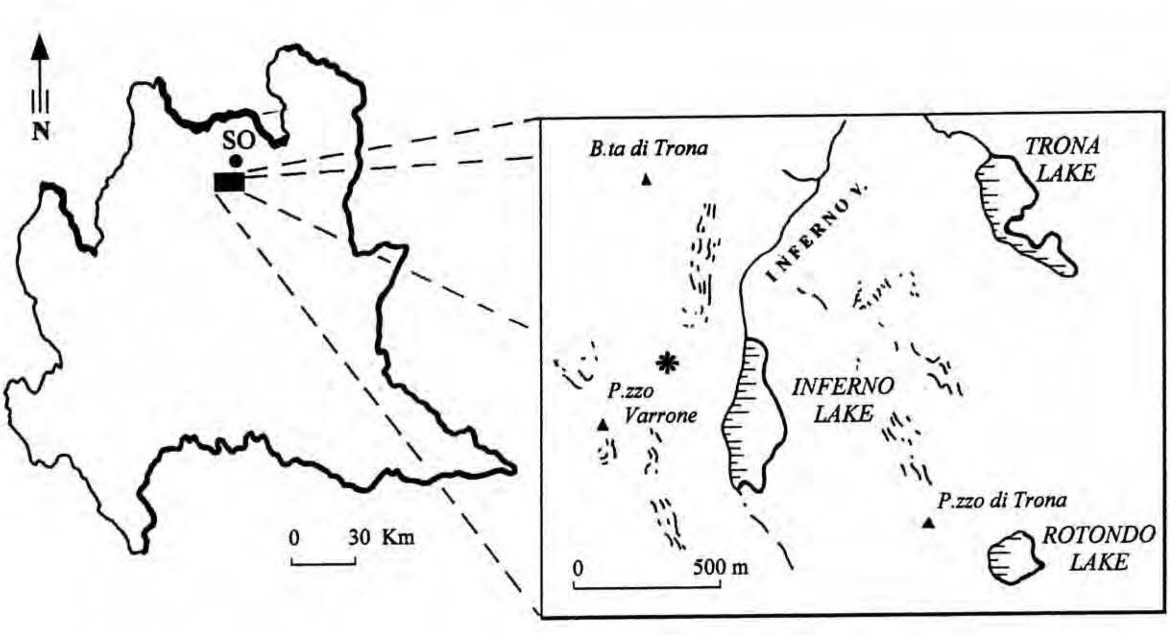


Fig. 1 – Location of the investigated area.

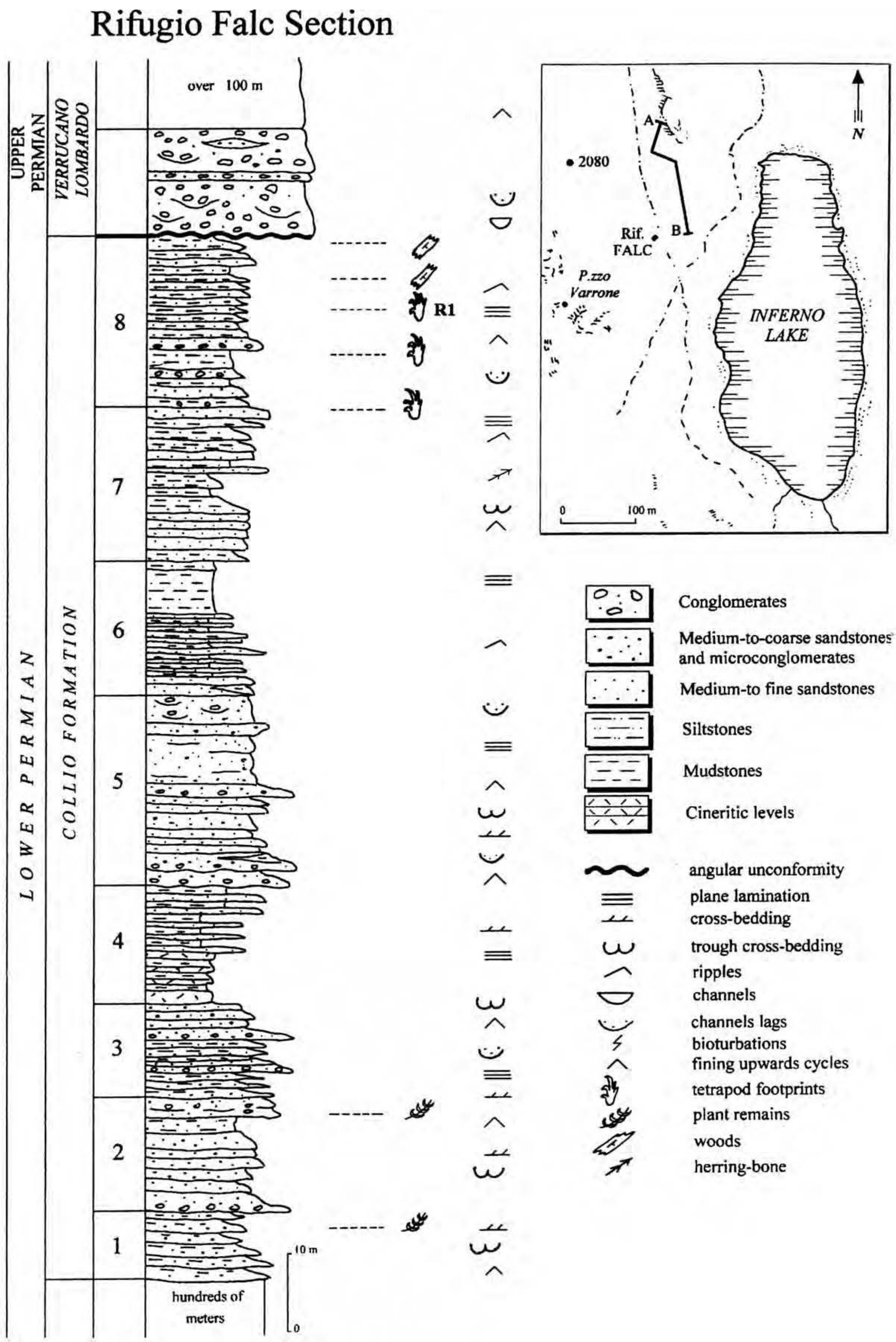


Fig. 2 – Stratigraphical section close to Rifugio Falc.

marked by an angular unconformity (locally more than 20°). The reddish deposits of the latter formation are represented by pebble-to-cobble conglomerates, sandstones and subordinate siltstones of a braided river environment.
These deposits, cropping out in the study area with a thickness of nearly 100 m, mark the inception of the Late Permian major sedimentary cycle, which has been recognised over the whole southern Alps region. The stratigraphic log was measured from a few metres above the unconformity (between Verrucano and Collio Fm.) up to q. 2150 on the western shore of the Inferno Lake. From the base it has been subdivided into eight different lithostratigraphical units.

ICHNOLOGY

As is usual for Early Permian tetrapod footprint associations, the Gerola Valley ichnofauna is represented by a few taxa (Plate 1 and Fig. 3). These are more frequently recognised within the corresponding North American and central European Permian associations (Haubold, 1996; Schult, 1995). The relatively low diversity does not permit firm conclusions, but nevertheless the presence of an ichnoassociation of at least four taxa allows us to distinguish it with respect to the *Dromopus didactylus* monotypical ichnoassociation which characterises the highest portion of the Lower Permian in the Collio Fm. type area (Conti *et al.*, 1997). Conversely, the ichnofauna from the Gerola Valley is rather similar to that recognised by Ceoloni *et al.* (1987) in the lower portion of the Collio Fm. in the Trompia Valley (see also the up-to-date data in Conti *et al.*, 2000).

With respect to this last ichnoassociation, the main differences are the lack of *Batrachichnus* and *Ichniotherium* and the already-debated presence of *Varanopus curvidactylus* (Plate 1) in place of *Camunipes cassinisi*. The only noticeable difference between the low diversity of the aforementioned Orobic Basin fauna and the Lower Permian European ones is the lack in the former basin of *Batrachichnus, Ichniotherium, Limnopus* and *Dimetropus*. These last two ichnogenera are also lacking within the association of the Brescia region, and at this time could be considered as forms restricted to the more northern regions of Laurasia.

BIO- AND CHRONOSTRATIGRAPHICAL CONSIDERATIONS

The generally low number of ichnotaxa from Permian sediments has previously been interpreted in two different ways. The usual interpretation considers this a result of an actual Early Permian 'low diversity'; however, this interpretation presents some problems, it being difficult to imagine a long-lasting fauna so reduced in number. A second interpretation considers the low number of ichnotaxa a result of a 'taxonomical compression', related to an assumed very low power of resolution for footprints. In this hypothesis each ichnogenus would represent a bone-based family of reptiles (Lucas, 1998).

We could suggest a third hypothesis that can be defined as 'deposition time compression'. In this case the low number of ichnotaxa could be related to a very short time interval in which all the Lower Permian track-bearing sediments were laid down. This last hypothesis is supported by recent geochronometric data (Cassinis *et al.*, 1999, and in press), by the recognition of the increasing importance and areal effect of stratigraphic gaps present within most of the

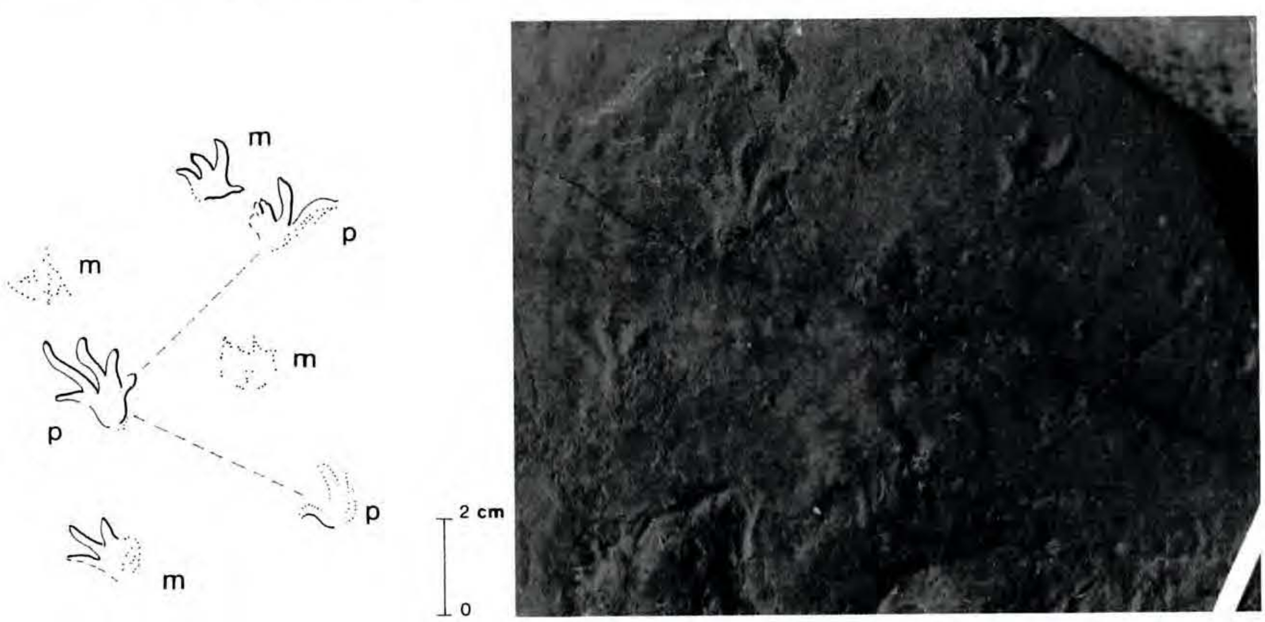


Fig. 3 - Slab with tracks of *Amphisauropus imminutus* Haubold, 1970.

Permian basins, and by the downward compression of the Rotliegend (following the calibration of the Tambach Fm. by Sumida *et al.*, 1996).

Conti *et al.* (1997) used the central Alps Lower Permian ichnofauna, systematically studied mainly on a complete section sampled bed by bed in the Collio Fm., to establish a faunal unit (Collio FU) and the associated faunal age (Collio FA). This last was in its turn subdivided into two faunal subages (Rabejac FsA and Tregiovo FsA)(Conti *et al.*, 1997; Cassinis *et al.*, 2000). This was a first attempt at establishing a sequence of Permian biochronological units. These can usefully replace the less meaningful use of biozones or associations (Boy & Fichter, 1982; Holub & Kozur, 1981), or the subdivision of the continental deposits by means of

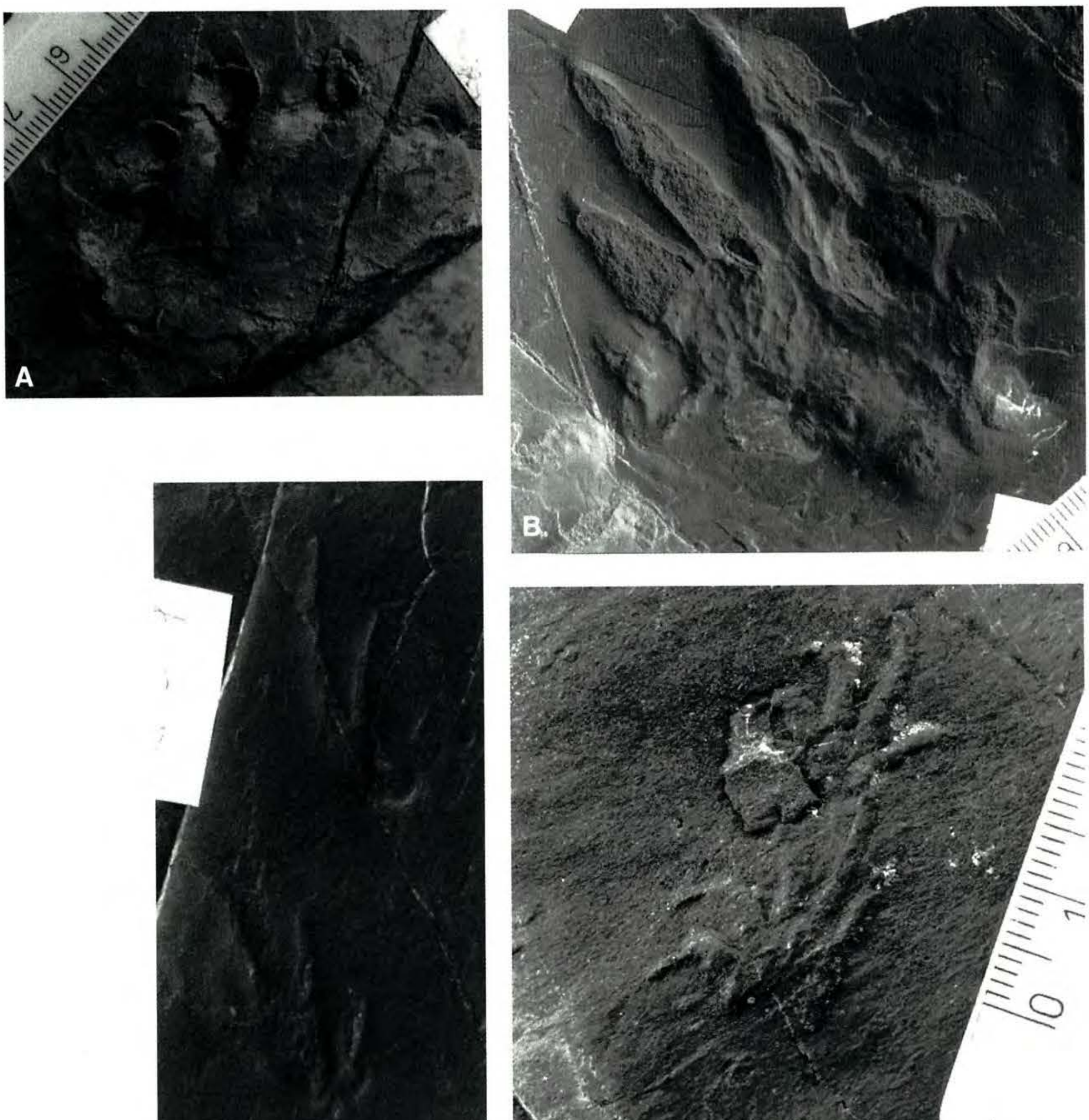


Plate 1 – A. *Amphisauropus latus* Haubold, 1970. Inferno Valley (N. Italy). Left pes. B. Extramorphological variation of *Amphisauropus latus* Haubold, 1970 ("*Laoporus dolloi*"). Inferno Valley (N. Italy). C. *Dromopus lacertoides* (Geinitz, 1861). Inferno Valley (N. Italy). Couple manus-pes left. D. *Varanopus curvidactylus* (Moodie, 1929). Inferno Valley (N. Italy). Couple manus-pes left.

marine stages, or, in the worst case, the so-called 'continental stages' of the European geological tradition.

The new finds allow the use of the Rabejac FsA, ascribing to the outcrops of the upper Val Varrone and Gerola valleys an age corresponding to the depositional age of the lower portion of the Collio Fm. If this is confirmed, the unconformity between the Collio Fm. and the second-cycle Verrucano Lombardo deposits could correspond to a larger gap in this area than in the Collio Basin, including also the time interval in which sediments ascribed to the Tregiovo FsA were laid down. This hypothesis also fits well with the marginal paleogeographical position of the section in relation to the more depocentral locations of other sections.

Acknowledgements – The authors wish to thank Prof. G. Cassinis for stratigraphic discussion, and Dr F. Penati (Curator of the Natural History Museum of Morbegno) and E. Ruffoni (ENEL, Morbegno) for their precious collaboration. H. Haubold is also acknowledged for the careful review of the text. This work has been carried out at Pavia and Roma Universities, supported by MURST (40% Resp. G. Cassinis) and C.N.R.

REFERENCES

Boy J. A. & Fichter J., 1982. Zur Stratigraphie des Saarpfälzischen Rotliegenden (?Ober-Karbon - Unter Perm: SW Deutschland). *Z. dtsch. geol. Ges.*, 133: 607-642.

Bonsignore G., Casati P., Crespi R., Fagnani G., Liborio G., Montrasio A., Mottana A., Ragni U., Schiavinato G. & Venzo S., 1971. Note illustrative della Carta Geologica d'Italia, alla scala 1:100.000, Fogli 7 e 18 Pizzo Bernina e Sondrio. *Ministero Ind. Comm. e Artig., Dir. Gen. Min., Serv. Geol. d'Italia*, Nuova Tecnica Grafica, Roma.

Casati P. & Forcella F., 1988. Alpi Orobie . In *"Il Bollettino" CAI* – Annuario del Comitato Scientifico Centrale, 87: 81-86.

Casati P. & Gnaccolini M., 1965. Una nuova formazione paleozoica dell'alta Val Brembana: La Formazione del Ponteranica. *Riv. Ital. Paleont. Stratigr.*, 70: 791-804.

Casati P. & Gnaccolini M., 1967. Geologia delle Alpi Orobie occidentali. *Riv. Ital. Paleont. Stratigr.*, 73: 25-162.

Cassinis G., Nicosia U., Pittau P. & Ronchi A., 1999. Palaeontologic and radiometric data from the Permian deposits of the Southern Alps (Italy), and their stratigraphic implications. 14e *Journée thématique de l'Association des Géologues du Permien*, Paris, 18 June 1999, vol. résumés: 6-7.

Cassinis G., Nicosia U., Ronchi A. & Santi G., 2000. Impronte di tetrapodi nel Permiano orobico e loro implicazioni stratigrafiche. Nota preliminare. *Rend. Ist. Lomb. Accad. Sci. e Lett.*, B 132 (1998): 197-217.

Cassinis G., Nicosia U., Pittau P. & Ronchi A., in press. Palaeontological and radiometric data from the Permian deposits of the central-eastern Southern Alps (Italy), and their stratigraphic implications. *Association des géologues du Permien*, Paris, Mém. 2.

Ceoloni P., Conti M.A., Mariotti N., Mietto P. & Nicosia U., 1987. Tetrapod footprints from Collio Formation (Lombardy, Northern Italy). *Mem. Sci. Geol.*, Padova, 39: 213 233.

Conti M.A., Mariotti N., Mietto P. & Nicosia U., 1991. Nuove ricerche sugli icnofossili della Formazione di Collio in Val Trompia (Brescia). *Natura Bresciana.* Ann. Mus. Civ. Sc. Nat., Brescia, 26 (1989): 109-119.

Conti M.A., Mariotti N., Nicosia U. & Pittau P., 1997. Succession of selected bioevents in the continental Permian of the Southern Alps (Italy), improvements in intrabasinal and interregional correlation. In: Dickins J.M., Yang Zunyi, Yin Hongfu, Lucas S.G. & Acharyya S.K. (eds), *Late Paleozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation.* World and Regional Geology. Cambridge Univ. Press, 10: 51-64.

Conti M.A., Leonardi G., Mietto P. & Nicosia U., 2000. Orme di tetrapodi non dinosauriani nel Paleozoico e Mesozoico in Italia. In: Leonardi G. & Mietto P. (eds), *Dinosauri in Italia. Le orme giurassiche dei Lavini di Marco (Trentino) e gli altri resti fossili italiani.* Accademia Editoriale, Pisa: 13 pp.

De Sitter L.U. & De Sitter-Koomans C.M., 1949. Geology of the Bergamasc Alps, Lombardy, Italy. *Leidse geol. Meded.*, 14: 1-257.

Dozy J.J., 1935. Einige Tierfährten aus dem unteren Perm der Bergamasker Alpen. *Paläontol. Z.*, 17 (1/2): 45-55.

Haubold H., 1971. Ichnia Amphibiorum et Reptiliorum Fossilium. In: Kuhn O. (ed.), *Handbuch der Palaeoherpetologie/Encyclopedia of Palaeoherpetology.* Fischer-Verlag, Stuttgart-Portland, USA: 124 pp.

Haubold H., 1996. Ichnotaxonomie und Klassifikation von Tetrapodenfährten aus dem Perm. *Hallesches Jb. Geowiss.*, B 18: 23-88.

Holub V. & Kozur H., 1981. Revision einiger Tetrapodenfährten des Rotliegenden und biostratigraphische Auswertung der Tetrapodenfährten des Obersten Karbon und Perm. *Geol. Paläont. Mitt. Innsbruck*, 11: 149-193.

Kerp H., Penati F., Brambilla G., Clement-Westerhof J. A. & Van Bergen P. F., 1996. Aspects of Permian palaeobotany and palynology. XVI. Three-dimensionally preserved stromatolite-incrusted conifers from the Permian of the Western Orobic Alps (Northern Italy). *Rev. Palaebot. Palynol.*, 91: 63-84.

Lucas S.G., 1998. Permian tetrapod biochronology. *Permophiles*, 32: 17-23.

Porro C., 1931. Rapporti fra gli scisti cristallini a sud-est di Gerola e le formazioni permiane (Catena Orobica). *Rend. R. Ist. Lomb. Acc. Sc. e Lett.*, ser. 2, 64: 771-787.

Porro C., 1932. Dal Pizzo dei Tre Signori al Monte Ponteranica (Alpi Valtellinesi). Studio geologico. *Mem. Rend. R. Ist. Lomb. Acc. Sc. e Lett.*, 22: 253-404.

Schult M.F., 1995. Vertebrate trackways from the Robledo Mountains Member of the Hueco Formation, South-Central New Mexico. In: Lucas S. G. & Heckert A. B. (eds), *Early Permian footprints and facies.* New Mexico Museum of Natural History and Sciences Bull., 6: 115-126.

Sumida S.S., Berman D.S & Martens T., 1996. Biostratigraphic correlations between the Lower Permian of North America and Central Europe using the first record of an assemblage of terrestrial tetrapods from Germany. *PaleoBios*, 17: 1-12.

THE LOWER PERMIAN IN THE OROBIC ANTICLINES (LOMBARDY SOUTHERN ALPS): CRITERIA FOR FIELD MAPPING TOWARDS A STRATIGRAPHIC REVISION OF THE COLLIO FORMATION

FRANCO FORCELLA [1], DARIO SCIUNNACH [2] and GIAN BARTOLOMEO SILETTO [2]

Key words – Permian; Southern Alps; geological mapping; lithofacies, stratigraphy.

Abstract – Detailed field mapping at the 1:10,000 scale in the Orobic and Cedegolo Anticlines requires a balanced approach to the stratigraphic subdivision of the Collio Formation.
A scheme of mapping lithofacies for this complex unit is proposed and tested in the three Orobic Anticlines, aiming at a stratigraphic revision of the Lower Permian in the central Southern Alps that, however, needs further detailed mapping and analytical work.

Parole chiave – Permiano; Alpi Meridionali; rilevamento geologico; litofacies; stratigrafia.

Riassunto – Il rilevamento geologico di dettaglio alla scala 1:10,000 nelle Anticlinali Orobica e di Cedegolo necessita di un approccio bilanciato alla suddivisione stratigrafica della Formazione di Collio. Uno schema di litofacies mappabili per questa complessa unità viene qui proposto e verificato nelle tre Anticlinali Orobiche, nell'ottica di una revisione stratigrafica del Permiano Inferiore nel Sudalpino centrale che, tuttavia, richiederà ulteriore lavoro analitico e di terreno.

INTRODUCTION

In the framework of the Italian project of geological mapping at the 1:50,000 scale (CARG; Catenacci, 1995), two areas of about 75 and 50 km^2 have been mapped at the 1:10,000 scale in the Orobic and Cedegolo Anticlines (Lombardy Southern Alps; Fig. 1). There, one of the most problematic geological objects to cope with is the Lower Permian Collio Fm., a complex continental succession of volcanic and clastic rocks, locally exceeding 1000 m in thickness, largely deposited in a transtensional tectonic setting (Massari, 1988). After the original description by Gümbel (1880), who restricted the use of this term to the dark plant-bearing shales and sandstones of Autunian age in Val Trompia, the name "Collio Formation" has been extended even in the type area to embrace the whole volcanic and volcaniclastic succession bracketed between the crystalline basement (± the aporphyric Basal Conglomerate) and the Verrucano Lombardo, thus enclosing also the volcanic plateau underlying the typical "Collio" sediments (Cassinis, 1966). Strong lateral variability of facies and thickness documents syntectonic deposition in hanging-wall basins accomodating the clastic sediments from footwall source areas.

The stratigraphic reference framework in the study areas subdivides the Collio Fm. simply into a "volcanic" lower member and a "sedimentary" upper member (Casati & Gnaccolini, 1967; Dozy, 1933); on the other hand, an accurate study carried out in the Trabuchello-Cabianca Anticline (Cadel *et al.*, 1996) proposes to subdivide the "volcanic" lower member into 18 lithozones and the "sedimentary" upper member into 6 facies, that are admittedly difficult to correlate outside their type sections and form a stratigraphic framework too detailed for the purposes of regional mapping. In the attempt at balancing these different approaches into a coherent lithostratigraphy that can be employed all over the study areas, a preliminary facies mapping has been carried out. The complex problems of stratigraphic nomenclature related to the Collio Fm. are beyond the scope of this paper, and the lithostratigraphic rank of this unit, although needing reconsideration, will not be questioned.

[1] Dipartimento di Scienze Geologiche e Geotecnologie, piazza della Scienza 4, Università di Milano-Bicocca, I - 20126 Milano, Italy.
[2] Ufficio Progetti speciali per la Geologia e la Sismica, D.G. Territorio e Edilizia Residenziale, Regione Lombardia, via Filzi 22, 20124 Milano, Italy.

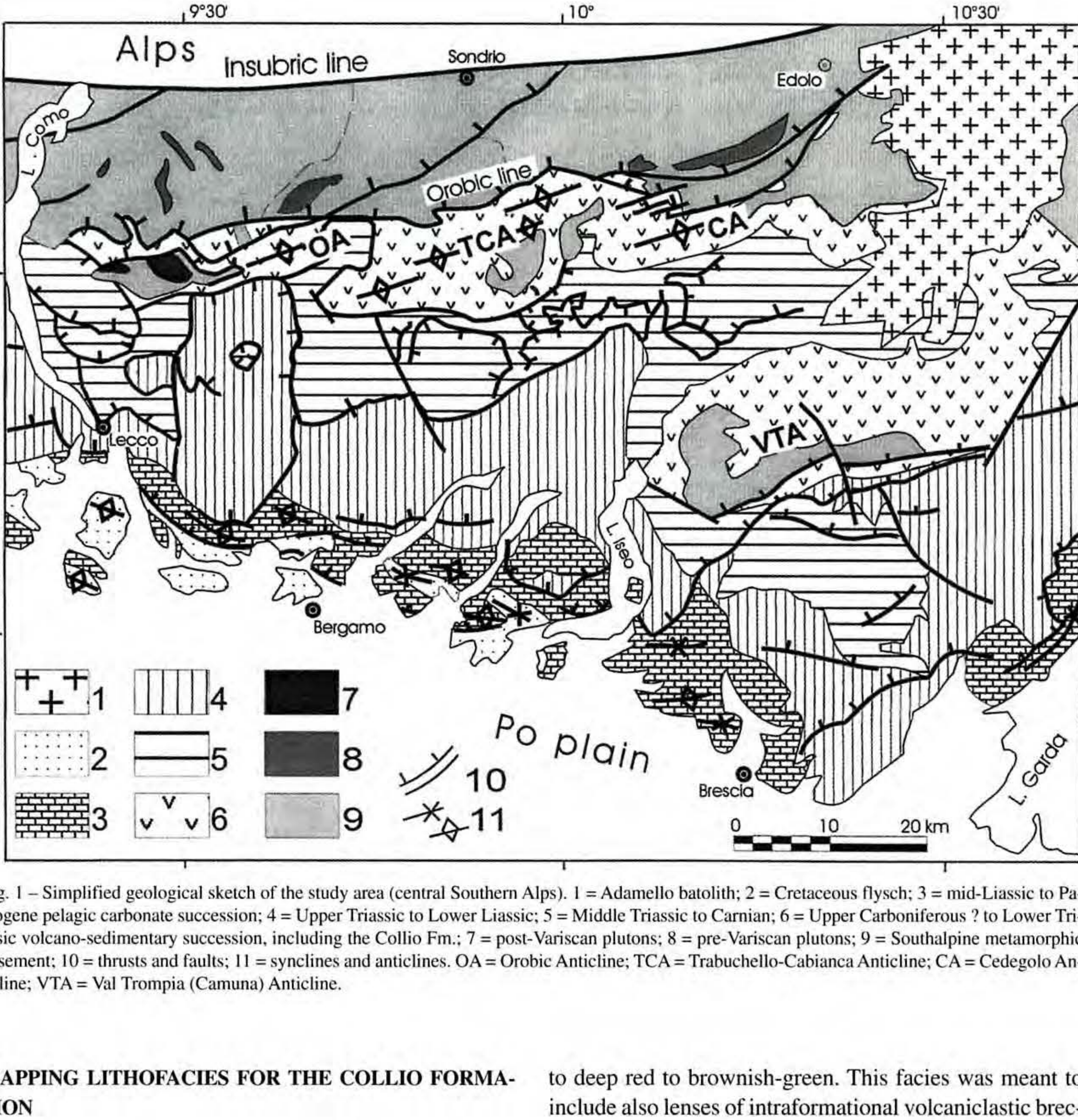


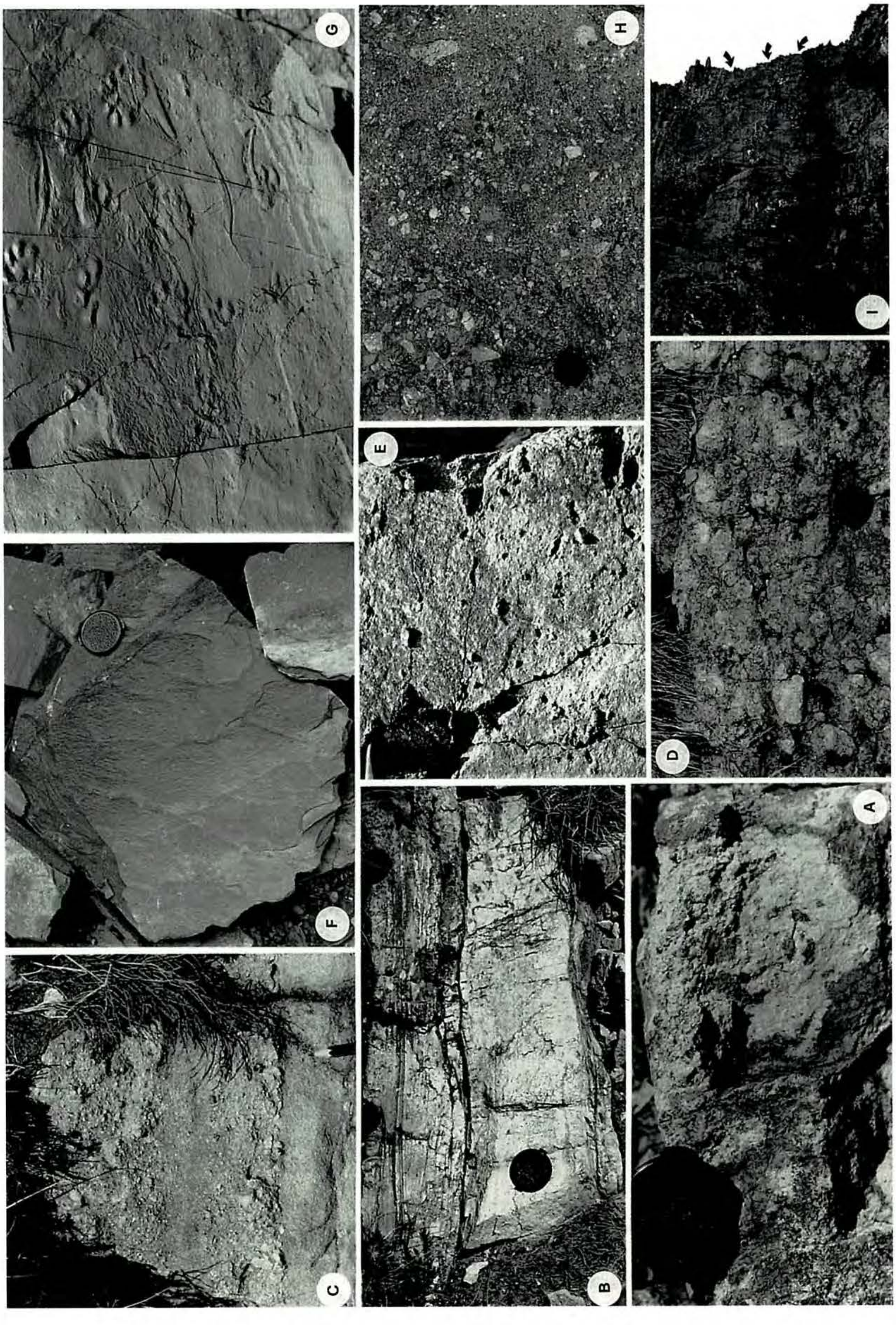
Fig. 1 – Simplified geological sketch of the study area (central Southern Alps). 1 = Adamello batolith; 2 = Cretaceous flysch; 3 = mid-Liassic to Paleogene pelagic carbonate succession; 4 = Upper Triassic to Lower Liassic; 5 = Middle Triassic to Carnian; 6 = Upper Carboniferous ? to Lower Triassic volcano-sedimentary succession, including the Collio Fm.; 7 = post-Variscan plutons; 8 = pre-Variscan plutons; 9 = Southalpine metamorphic basement; 10 = thrusts and faults; 11 = synclines and anticlines. OA = Orobic Anticline; TCA = Trabuchello-Cabianca Anticline; CA = Cedegolo Anticline; VTA = Val Trompia (Camuna) Anticline.

MAPPING LITHOFACIES FOR THE COLLIO FORMATION

In our proposal, the lithofacies to be systematically mapped in the field (Figs 2, 3) form a relatively narrow range and are listed below. They are somehow oversimplified with respect to the complexity of facies characters observed in the field, as they were established to allow easy recognition even in small outcrops. The lithofacies are listed in a rough stratigraphic order from base to top, but, owing to the episodic character of volcanism and to the mobility of the depositional environment, exceptions, repetitions and gaps may be locally present (Fig. 4).

V_1 – Tabular welded tuffs and lapillistones (locally preserving *fiammae* and thus correctly classified as ignimbrites) of benmoreitic to rhyolitic composition, with variable amount of porphyrocrysts and degree of welding, up to massive porphyries, ranging in colour from whitish to deep red to brownish-green. This facies was meant to include also lenses of intraformational volcaniclastic breccias consisting of 100% angular volcanic clasts welded in an aphanitic matrix. A rough bedding is locally recognised, underlined by thin tuffaceous interlayers, but in

Fig. 2 – Representative outcrops of facies described in the three Orobic Anticlines. A = welded lapillistone in amalgamated beds (small arrow at a bedding plane) with variable degree of porphyricity and welding (V1, Orobic Anticline); B = laminated tuff with preserved depositional structures (V1, Orobic Anticline); C = normal to inverse grading (FU then CU) in a lapilli tuff with lithic and pomiceous volcanic grains (V2, Orobic Anticline); D = intraformational volcanic breccia (V2, Orobic Anticline); E = volcaniclastic paraconglomerate (S1, Orobic Anticline; hammer head at the top left corner for scale); F = mud-cracks in grey mudrocks (S3, Trabuchello-Cabianca Anticline); G = tetrapod footprints and tail marks preserved in fine-grained sandstone (S2, Trabuchello-Cabianca Anticline; field of the photograph approximately 1 m; walking direction to the right); H = Ponteranica Conglomerate pebble to cobble breccia (S4, Orobic Anticline); I = ferroan carbonate beds alternating to bedded sandstones (S5, Cedegolo Anticline).


G
H
I
E
D
F
A
C
B

general is pervasively overprinted by the Alpine cleavage.
V_2 – Massive to bedded breccias and arenites ("epiclastics") with poorly-sorted, angular clasts exclusively volcanic in origin embedded in a salt-and-pepper sandy matrix; abundant plagioclase is recognised in the arenites.
V_3 – Massive lava flows, deep green to almost black in colour, of mugearitic to "andesitic" composition, scattered at various stratigraphic levels and fed by porphyrite dykes. Black femics and saussurritized pale green plagioclase are locally observed; aphyric textures are, however, more common.
V_4 – Volcanic breccias, locally interpreted as agglomerates, to cinerites with poorly-sorted angular to volcanic clasts and rounded to euhedral quartz clasts. Volcanic

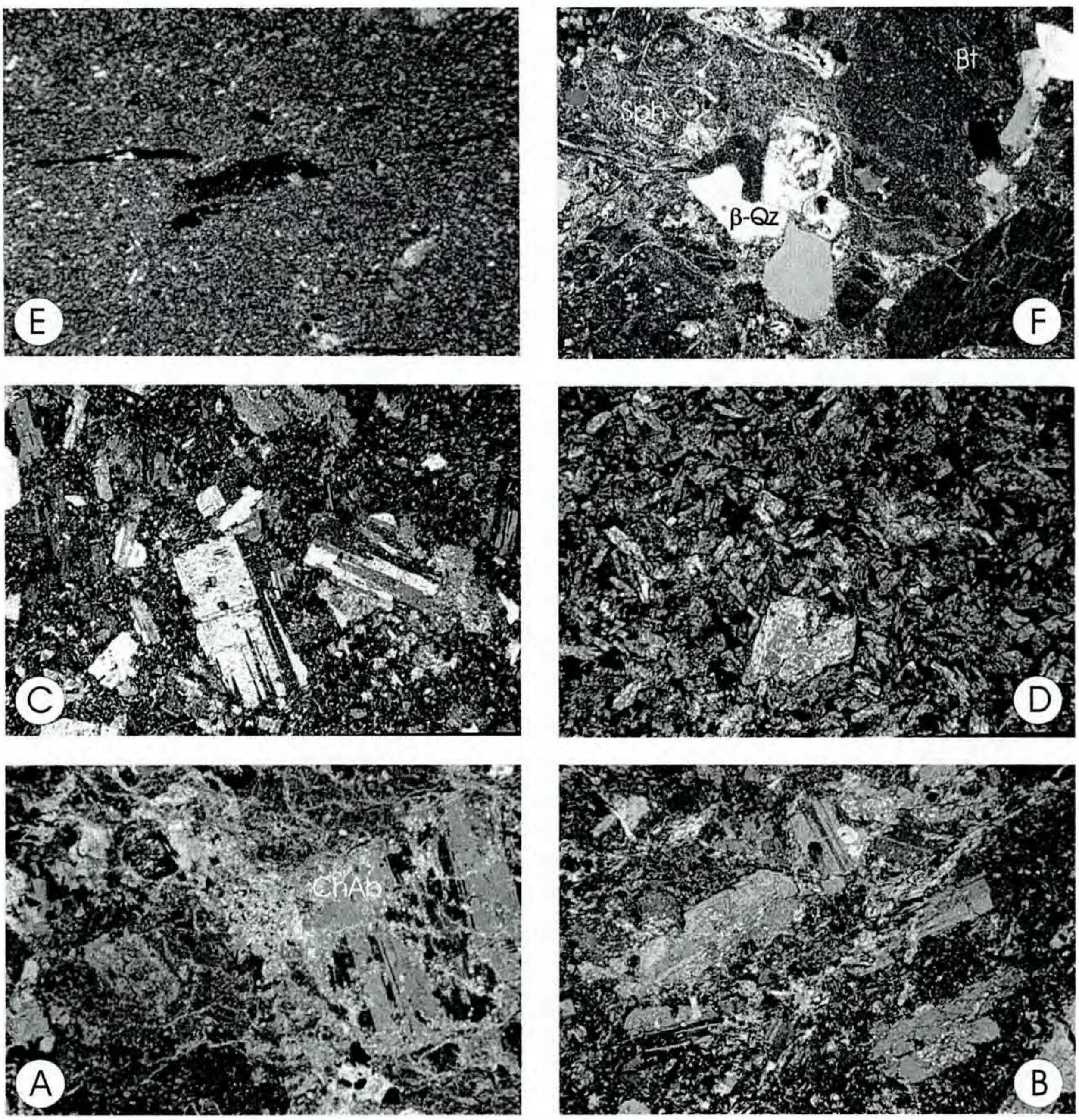


Fig. 3 – Representative photomicrographs of facies described in the Orobic Anticline. A, B = weathered intermediate ignimbrites (benmoreites; V1, Pradini Valley section), displaying feldspar phenocrysts locally transformed into chessboard-albite (ChAb); C = fresh trachybasalt? lava flow (V3, Caprile area); D = sericitised mugearite lava flow (V3, Pradini Valley section) with a plagioclase lathwork encasing large calcite-chlorite pseudomorphs after femic phenocrysts (amphiboles ?); E = black shale (S3, Pradini Valley section) including imbricated carbon-rich chips; F = very coarse-grained, moderately sorted volcanic arenite (S4, Pradini Valley section) rich in volcanic lithics displaying spherulitic structures (Sph) and containing embayed quartz (β-Qz) as well as leached biotite (Bt) phenocrysts. All photos are in cross-polarised light, magnification 14x, except F (9x).

clasts are usually flattened due to the Alpine deformation. Cinerites form lenses interbedded in the breccias.

S_1 – Medium- to coarse-grained, grey to pink volcanic arenites, displaying abundant fresh detrital feldspar and scattered white mica flakes when examined with the hand lens; white mica flakes are locally concentrated on the bedding planes in the finer-grained fraction. Layers are up to several tens of cm-thick, mostly homogeneous in grain size but locally displaying a rough grading, either normal or inverse. Subordinate intercalations of pelites, pyroclastics and conglomerates occur.

S_2 – Prevailing fine- to medium-grained, dark grey volcanic arenites, in layers a few cm to less than 20 cm-thick, fining upwards to black pelites rich in white mica flakes (sand/mud ratio > 1). A variety of sedimentary structures (load casts, commonly asymmetrical but locally symmetrical ripple-marks, mud-cracks ...) is displayed.

S_3 – Grey to black siltstones and shales with subordinate intercalations of fine-grained sandstone (sand/mud ratio >1), locally transformed into flagstones and slates by anchizonal conditions reached during the Alpine Orogeny.

S_4 – Pebble to cobble conglomerates, alternating to coarse-grained pebbly sandstones, deposited in proximal alluvial fans. In the Pizzo dei Tre Signori area this facies has been formally introduced as a distinct unit, occupying a precise stratigraphic position (Ponteranica Conglomerate; Casati & Gnaccolini, 1967), whereas in the Trabuchello-Cabianca Anticline the term "Monte Aga Conglomerate" has been recently introduced (Cadel *et al.*, 1996). Distinct conglomerate bodies characterised by peculiar clast composition should be mapped separately.

S_5 – Coarse-grained arenites to conglomerates with Fe-carbonate interlayers up to 50 cm-thick, that might represent lacustrine carbonates and evaporites.

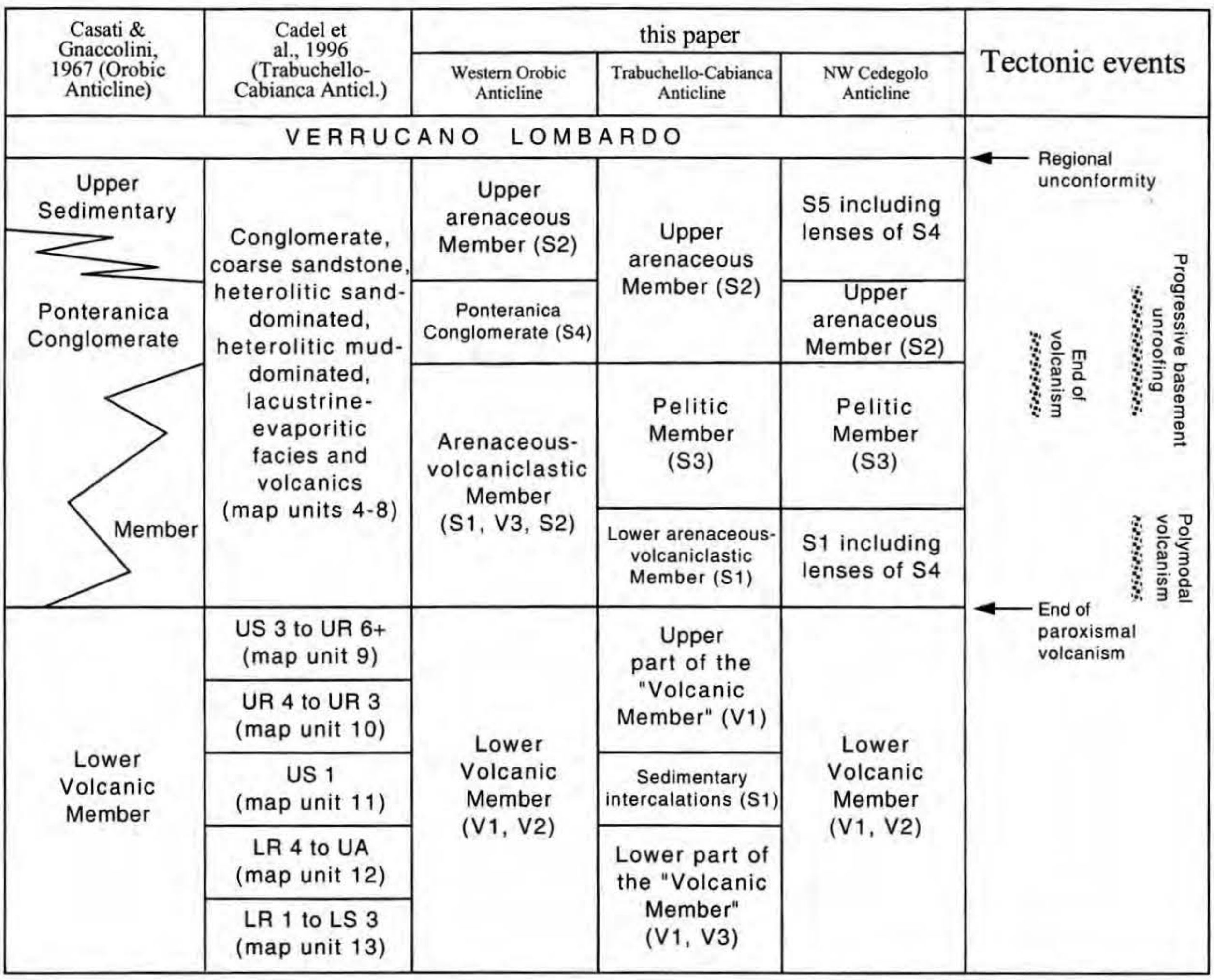


Fig. 4 – Simplified scheme depicting the vertical organisation of the mapping lithofacies proposed for the Collio Fm. in the present paper, compared with the reference frameworks available from the literature. Indications for interpreting the proposed lithofacies as a result of tectonic and magmatic events are also provided. Correlation of mapping lithofacies across adjacent anticlines is a mere graphic device; in fact, the assumption of a physical continuity among the Early Permian basins presently exhumed in the three Orobic Anticlines has to be regarded as undemonstrated, and stratigraphic correlation would require much better age constraints than available.

PIZZO DEI TRE SIGNORI AREA

Although severe faulting and folding of the Collio Fm., as well as poor exposure of its sedimentary upper part, commonly hamper a detailed measurement of this unit from base to top, the sandier facies exposed in the Orobic Anticline allowed description of two stratigraphic sections (Casati & Gnaccolini, 1967). In the reference Pradini Valley section, nearly 1000 m-thick, facies V_1, V_2, S_1, V_3, S_2 and S_4 (in first appearance order) are represented: V_1 ignimbrites are essentally intermediate Na-alkaline products (benmoreites), and V_3 mugearite flow, 20 m-thick, is found 92 m above the oldest sediments. Petrographic analysis on sandstones sampled both in the Orobic and Trabuchello-Cabianca Anticlines revealed that, despite marked lateral variability of facies and wide grain size range, composition of the Collio sandstones is remarkably uniform over an area extending for more than 35 km west to east and cluster into a single petrofacies (P0 of Sciunnach *et al.*, 1999). No significant stratigraphic trends were recognised, consistent with the short time span recently indicated for the deposition of the Collio Formation in the Val Trompia Basin (Schaltegger & Brack, 1999).

MONTE CABIANCA-PIZZO DEL DIAVOLO DI TENDA AREA

A few transverses, from the northern slopes of Monte Cabianca to the Lago Rotondo and up to the Monte Aga - Pizzo del Diavolo divide, allowed us to group the lithozones and facies of Cadel *et al.* (1996) into the following mapping units:

1. Lower part of the "Volcanic member" of the Collio Fm., corresponding to lithozones LR1÷LR5 + UA of Cadel *et al.* (1996) and to facies V_1, V_3 of the present paper.
2. Sedimentary intercalations in the "Volcanic member": prevailing volcanic arenites, commonly in fining-upwards beds with basal conglomerate lags. This interval corresponds to lithozone US1 of Cadel *et al.* (1996) and to facies S_1 of the present paper.
3. Upper part of the "Volcanic member": lapilli welded tuffs (ignimbrites), more or less lithified, with frequent epiclastic intercalations. This interval represents lithozones UR1÷UR6 of Cadel *et al.* (1996) and facies V_1 of the present paper.
4. Lower arenaceous-volcaniclastic member: prevailing coarse-grained arenites, alternating to epiclastics and tuffs displaying a more pervasive cleavage. This member is poor in sedimentary structures and, in the study area, exhibits an overall higher strain with respect to the upper arenaceous-volcaniclastic member. It largely corresponds to the "thick-bedded coarse sandstone facies" of Cadel *et al.* (1996) and to facies S_1 of the present paper.
5. pelitic member ("heterolitic mud-dominated facies"; Cassinis *et al.*, 1986): prevailing dark pelites that preserve sedimentary structures with thin intercalations of volcanic ashes. This member commonly displays a pervasive slaty cleavage related to transpositive folding; corresponds to facies S_3 of the present paper.
6. upper arenaceous-volcaniclastic member ("heterolitic sand-dominated facies"; Cassinis *et al.*, 1986): prevailing grey to greenish sandstones, largely medium to fine-grained, rich in sedimentary structures. Corresponds to facies S_2 of the present paper.

Sandstones and pelites pass laterally to heteropic conglomerates ("conglomerate and pebbly sandstone facies"; Cassinis *et al.*, 1986; corresponding to facies S_4 of the present paper), the composition of which substantially reflects the overall composition of sandstones, once the grain size-induced variations are taken into account.

CEDEGOLO ANTICLINE

The development of Alpine folds, thrusts and pervasive cleavage makes stratigraphic reconstruction of the Collio succession quite difficult (Albini *et al.*, 1994). Three main tectonic units can be distinguished at map scale, each of them displaying a peculiar sedimentary succession (see also the companion paper by Forcella & Siletto, this volume).

In the northern and structurally higher tectonic unit, the following lithofacies can be observed (from bottom to top): volcanics (V_1), coarse heterolitic conglomerates with arenaceous matrix (S_4), prevailing fine- to medium-grained dark grey arenites (S_1), prevailing black pelites with subordinate arenites (S_3), grey to greenish arenites with tabular and cross-lamination (S_2) and coarse-grained conglomerate bodies bounded by synsedimentary faults (S_4).

In the intermediate tectonic unit, massive to roughly-bedded ignimbrites, highly variable in thickness and degree of welding (V_1), are followed upsection by volcanic arenites with variable thickness (S_1), by siltstones and shales (S_3), prevailing fine- to medium-grained arenites (S_2), and eventually by coarse-grained arenites with Fe-carbonates interlayers (S_5).

In the southern tectonic unit, ignimbrites and welded tuff (V_1) are followed upsections by "epiclastics" (V_2) and agglomerates to cinerites (V_4), heteropic with S_2, S_3 and S_5.

In both the intermediate and southern units (P.zo Recastello, M. Cimone and M. Gleno) boudinaged levels of ferroan carbonates (facies S_5) are intercalated in facies S_2 and S_3.

CONCLUSIONS

Marked lateral variability of facies, thickness, geochemistry of volcanic products and subsidence patterns in the different sectors of the wide area in which the Collio Formation was deposited indicates lithofacies mapping as the most viable tool to unravel stratigraphic and geometric relationships among the Collio lithosomes. Organisation of mapping lithofacies into a coherent stratigraphic framework, eventually leading to a stratigraphic revision of the Collio Fm., appears to be still premature at the moment and requires further detailed field work, as well as better age constraints.

Acknowledgements – The authors are deeply indebted to Prof. Arrigo Gregnanin for participation to field trips, geochemical analyses and useful discussions; to Prof. Giuseppe Cassinis for participation to field trips and review of the draft; and to Prof. Rodolfo Crespi for assistance in microphotography.

REFERENCES

Albini S., Battaglia D., Bellini G., Bigoni C., Carminati E., Ceriani S., Forcella F., Gosso G., Guizzetti D., Oliva A., Rebay G., Siletto G.B. & Spalla M.I., 1994. Alpine deformations and pre-Alpine remnants in the north-eastern Orobic Alps, Southalpine belt. In: Montrasio A. & Sciesa E. (eds), *Proc. Symp. "CROP - Alpi Centrali"*. Quad. Geodin. Alpina e Quaternaria, 2: 25-39.

Cadel G., Cosi M., Pennacchioni G. & Spalla M.I., 1996. A new map of the Permo-Carboniferous cover and Variscan metamorphic basement in the Central Southern Alps - Italy. Structural and stratigraphic data. *Mem. Sci. Geol.*, Padova, 48: 1-53.

Casati P. & Gnaccolini M., 1967. Geologia della Alpi Orobie occidentali (with a geological map). *Riv. Ital. Paleont. Stratigr.*, 73: 25-162.

Cassinis G., 1966. La Formazione di Collio nell'area-tipo dell'alta Val Trompia (Permiano inferiore bresciano). *Riv. Ital. Paleont. Stratigr.*, 72: 507-588.

Cassinis G., Dal Piaz G.V., Eusebio A., Gosso G., Martinotti G., Massari F., Milano P.F., Pennacchioni G., Perello M., Pessina C.M., Roman E., Spalla M.I., Tosetto S. & Zerbato M., 1986. Report on a structural and sedimentological analysis in the uranium province of the Orobic Alps, Italy. In: Van Wambeke L. (Guest-ed.), *Uranium exploration: results of European communities programme*. Uranium, 2: 241-260.

Catenacci V., 1995. Il progetto di realizzazione della nuova cartografia geologica ufficiale del territorio nazionale. *Boll. Soc. Geol. Ital.*, 114: 107-130.

Dozy J.J., 1933. Die Geologie der Catena Orobica zwischen Corno Stella und Pizzo del Diavolo di Tenda. *Leidse geol. Meded.*, 6: 133-230.

Forcella F. & Siletto G.B., this volume. Structure and stratigraphy of the Permo-Carboniferous cover and Variscan metamorphic basement in the northern Serio Valley (Orobic Alps, Southern Alps - Italy): recognition of Permian faults.

Gümbel C.W. von, 1880. Geognostische Mitteilungen aus den Alpen. IV. Ein geognostischer Streifzug durch die Bergamasker Alpen. *Sitzber. K. Ak. Wiss. München, Math.-Nat. Kl.*, 10/2: 164-240.

Massari F., Conti M.A., Fontana D., Helmold K., Mariotti N., Neri C., Nicosia U., Ori G.G., Pasini M. & Pittau P., 1988. The Val Gardena Sandstone and the *Bellerophon* Formation in the Bletterbach gorge (Alto Adige, Italy): biostratigraphy and sedimentology. *Mem. Sci. Geol.*, Padova, 40: 229-273.

Schaltegger U. & Brack P., 1999. Short-lived events of extension and volcanism in the Lower Permian of the Southern Alps (Northern Italy, Southern Switzerland). *EUG '99*, D02:4A/02: F1: 296-297.

Sciunnach D., Confalonieri M.P. & Garzanti E., 1999. Petrofacies of the Upper Carboniferous to Permian continental clastics of the central Southern Alps, Italy. *19th IAS Meeting*, Abstr. vol.: 225-227.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 59-64

STRUCTURE AND STRATIGRAPHY OF THE PERMO-CARBONIFEROUS COVER AND VARISCAN METAMORPHIC BASEMENT IN THE NORTHERN SERIO VALLEY (OROBIC ALPS, SOUTHERN ALPS - ITALY): RECOGNITION OF PERMIAN FAULTS

Franco FORCELLA [1] and Gian Bartolomeo SILETTO [2]

Key words – Alpine tectonics; Permian extensional tectonics; Southern Alps; Lombardia.

Abstract – An area belonging to the South-Alpine domain of the Lombardic Orobic Alps (Italy) is considered, in particular the eastern sector of the Anticlines belt that represents a major structural partition of the chain. It is formed by a polydeformed (D_1-D_2)Variscan metamorphic basement unconformably covered by Late Paleozoic sedimentary and volcanic sequences.
Alpine compressional events are related to southward-verging thrusting phases (D_3). The regional thrust geometry is outlined by large cuspate synforms of sedimentary rocks, locally boudinaged along cataclastic zones. A D_3 deformation phase produced a crenulation cleavage in basement rocks and a pervasive cleavage in the sedimentary cover, with axial planar to meso- and megascopic folds, which often makes stratigraphic reconstruction difficult. Moreover, the spatial correlation of individual thrust planes is often hampered by variously intersecting faults which transfer or interrupt the individual thrust sheets.
None the less, three main units can be distinguished on the map, displaying sedimentary successions that change in thickness and lithofacies in relation to the main Alpine thrusts, which therefore represent inverted Permian normal faults.

Parole chiave – tettonica alpina; tettonica estensionale permiana; Alpi Meridionali; Lombardia.

Riassunto – In questa nota viene descritto l'assetto stratigrafico e tettonico di un tratto del settore nord-orientale della catena sudalpina lombarda. Esso fa parte dell'unità strutturale denominata, con terminologia semplicistica, "Anticlinali Orobiche".
Queste sono costituite da un basamento cristallino varisico rappresentato da varie litofacies e una storia metamorfica evolutasi dalla facies anfibolitica a quella scisti verdi e da una copertura sedimentaria terrigena e vulcanica.
Tale copertura, di età Carbonifero sup.(?)-Permiano, si è deposta in ambiente continentale subaereo e/o fluvio-lacustre e mostra evidenti variazioni sia nello spessore che nelle litofacies in corrispondenza delle principali superfici di sovrascorrimento d'età alpina.
Questo fatto induce a pensare che esse rappresentino l'inversione di faglie normali prodotte dalla tettonica transtensiva tardovarisica, responsabile, alla scala locale, della formazione dei bacini ospitanti le suddette successioni stratigrafiche. Nell'area sono state distinte tre principali unità tettoniche generate dalla fase compressionale alpina.
Esse sono grossolanamente allineate in senso WSW-ENE, caratterizzate da (i) piegamenti poliarmonici sud-vergenti a diversa scala, intersecati da clivaggio di piano assiale (D3) regionalmente persistente, e (ii) ritagliate da *thrust* minori e sistemi di faglie successive.
Una fase tettonica più recente (tardo- e post-alpina) è rappresentata da sistemi di faglie estensionali ad elevata inclinazione o da piani di taglio pellicolari che sezionano pinnacoli rocciosi in precaria staticità. Nel suo insieme, il tratto di catena esaminato mostra l'impronta di un diffuso collasso gravitazionale.

INTRODUCTION

In the northern part of the southern Orobic Alps, in a roughly EW-trending belt, a Carboniferous(?) to Lower Permian terrigenous-volcanic succession lies unconformably on the Variscan metamorphic basement. The general stratigraphic succession, starting with the "Basal Conglomerate" (Upper Carboniferous? – Lower Permian), is mainly represented by the volcaniclastic - lacustrine Collio Fm. (Lower Permian), suggesting as a whole a mobile, transtensive depositional environment, followed by the clastic Verrucano Lombardo (Upper Permian) and the mixed clastic-carbonate Servino (Scythian – Lower Anisian). The belt is presently structured in a series of *en*

[1] Dipartimento di Scienze Geologiche e Geotecnologie, piazza della Scienza 4, Università di Milano - Bicocca, I-20126 Milano, Italy.
[2] Ufficio Progetti speciali per la Geologia e la Sismica, D.G. Territorio e Edilizia Residenziale, Regione Lombardia, via Filzi 22, I-20124 Milano, Italy.

échelon ENE-trending anticlines (De Sitter, 1963; De Sitter & De Sitter-Koomans, 1949, and following literature) which roughly correspond to former Permian basins inverted during the Alpine orogeny. The junctions between the anticlines are areas of intense and complicated deformation. In this paper we investigate the region of the junction between the Trabuchello-Cabianca anticline (to the W) and the Cedegolo anticline (to the E) in the upper Serio Valley (Fig. 1). Here, three main tectonostratigraphic units, separated by inverted extensional faults, can be recognised, each characterised by a specific sedimentary succession and geometric setting. The lithofacies classification used in the following is that proposed by Forcella *et al.* (this volume). In particular, in this paper and in Fig. 2, both the volcanic, volcaniclastic and the sedimentary facies of Lower Permian age are categorised into the Collio Fm. following the mapping tradition in the Orobic (or Brembano) Collio basin.

THE NORTHERN TECTONOSTRATIGRAPHIC UNIT

In a huge area of the northern unit (to the E), micaschists, gneisses and minor amphibolites crop out, in which a polyphase Variscan metamorphic evolution is recorded (Albini *et al.*, 1994; Spalla *et al.*, 1999), from amphibolite facies (D1 relict folds and schistosity) to greenschist facies (D2 meso- and macro-scale folds and pervasive foliation). To the west of the Malgina Valley, the basement is capped by the Permian volcanic and clastic succession (Fig. 2). The stratigraphic succession normally starts with pelitic to arenaceous purplish beds, often burrowed and rich in detrital micas. This lithofacies appears at various levels in the Lower Permian succession of the Southern Alps (*e.g.* "Pietra Simona" member of the Dosso dei Galli Fm.). Coarse conglomerates, mainly composed of quartz pebbles in an arenaceous matrix, with a rough bedding, over-

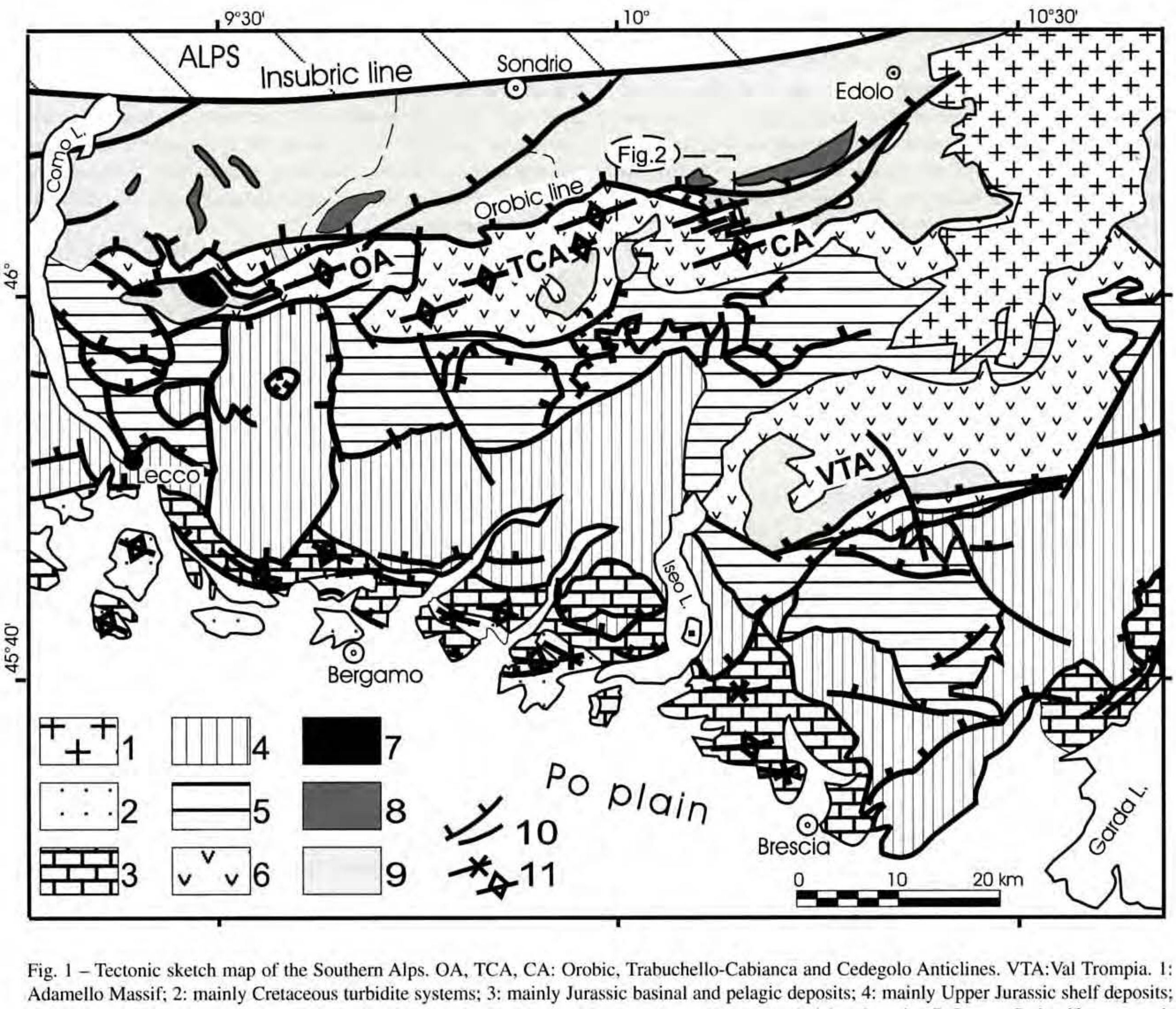


Fig. 1 – Tectonic sketch map of the Southern Alps. OA, TCA, CA: Orobic, Trabuchello-Cabianca and Cedegolo Anticlines. VTA:Val Trompia. 1: Adamello Massif; 2: mainly Cretaceous turbidite systems; 3: mainly Jurassic basinal and pelagic deposits; 4: mainly Upper Jurassic shelf deposits; 5: Anisian-Carnian deposits; 6: undifferentiated Upper Carboniferous (?) – Permian – lowermost Anisian deposits; 7: Permo-Carboniferous granitoids; 8: Variscan metagranitoids; 9: Variscan metamorphic rocks; 10: main thrusts and faults; 11: axial surface trends of main folds.

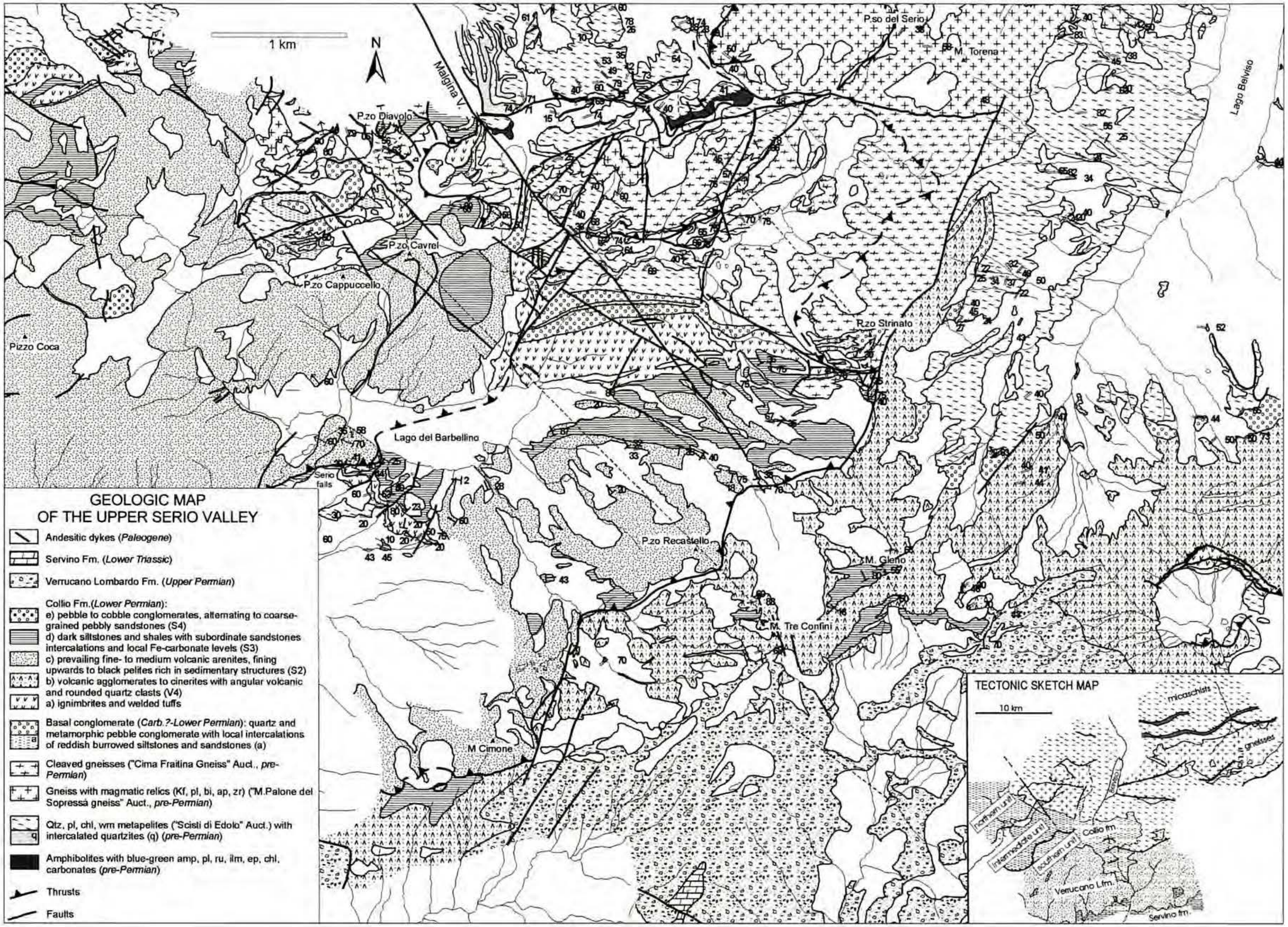


Fig. 2 – Geological map of the Upper Serio Valley.

lie or are interfingered with the purplish pelites. In spite of the local paucity of metamorphic pebbles, this unit is considered to represent the "Basal Conglomerate" (Dozy, 1933; Dozy, 1935). Upwards, the conglomerates are capped by a thin volcanic and volcaniclastic layer, which makes the transition to a several hundred metres thick arenaceous sequence (lithofacies S2). Toward the top the sandstones become finer and the beds thinner, and parallel and cross laminations, mudcracks and raindrop casts are common. This arenaceous-pelitic succession forms the highest peaks of the Orobic Alps. Locally, conglomeratic wedges, rich in quartz, metamorphic and volcanic pebbles to cobbles (lithofacies S4), are connected to synsedimentary fault scarps along the SE wall of Pizzo di Coca. These conglomerates resemble both in composition and stratigraphic location the Dosso dei Galli (Assereto & Casati, 1965) or Ponteranica formations (Casati & Gnaccolini, 1965), widely cropping out more to the east (Val Trompia) and to the west (Orobic anticline), but never reported in this sector of the Orobic Alps.

Alpine compressional events, related to southward-vergent thrusting phases, often make stratigraphic reconstruction difficult. The Alpine deformation has produced a crenulation cleavage in basement rocks and pervasive cleavage in the sedimentary cover, axial planar to EW-trending meso- and megascopic folds (D_3), regional thrust surfaces outlined by large cuspate synforms of sedimentary rocks, locally boudinaged in pieces along cataclastic zones, and sets of shear planes, gently dipping to the north, which bear qz-slickenfibres indicating a top-to-the-SSE translation (D_4). Along any shear plane the dislocation is only a few centimetres to a few metres, but the shear induces a sigmoidal distortion of the D_3 cleavage and, in finegrained layers of Collio and Verrucano Lombardo formations, a few mm to cm-spaced D_4 crenulation cleavage.

The general plunge of D_1 to D_3 structures towards the west is not sufficient to explain the lack of sedimentary cover to the east, which can be better understood by considering the effects of Permian NE-SW-trending extensional faults. These produced a structural depression to the NW (present-day coordinates) in which a thick volcanic and clastic succession accumulated. In particular, the gently westward-dipping tectonic surface exposed near the base of the vertical cliff of the Serio River waterfall and further to the west along the northern side of the Serio Valley, brings into direct tectonic superposition the Collio sedimentary sequence and the crystalline basement; this geometry and the occurrence of kinematic indicators suggesting a normal sense of movement (top to the W), preserved near the Serio waterfall, suggests the extensional kinematis of a pre-Alpine master fault. The kinematics along the extensional fault system was inverted during the Alpine compressional phase, and some segments are now represented by top-to-SSE oblique faults, with different geometries along strike.

East of the Malgina Valley, the northern tectonostratigraphic unit can be subdivided into some thrust slices underlain by local networks of Fe-carbonate veins and cataclastic zones up to tens of metres thick, which can be followed for hundreds to thousands of metres. West of the Malgina Valley, a tantalising belt of fault-bounded outcrops align near the base of the northern unit (Fig. 2); they represent slices of the formerly faulted margin that were subsequently dragged and/or tilted southward during the Alpine compression. In the sedimentary cover, west of the Malgina Valley, a set of steeply dipping, south-verging D_3 folds progressively lower the stratigraphic units to the south and follow, at the surface, the steep structural attitude of the

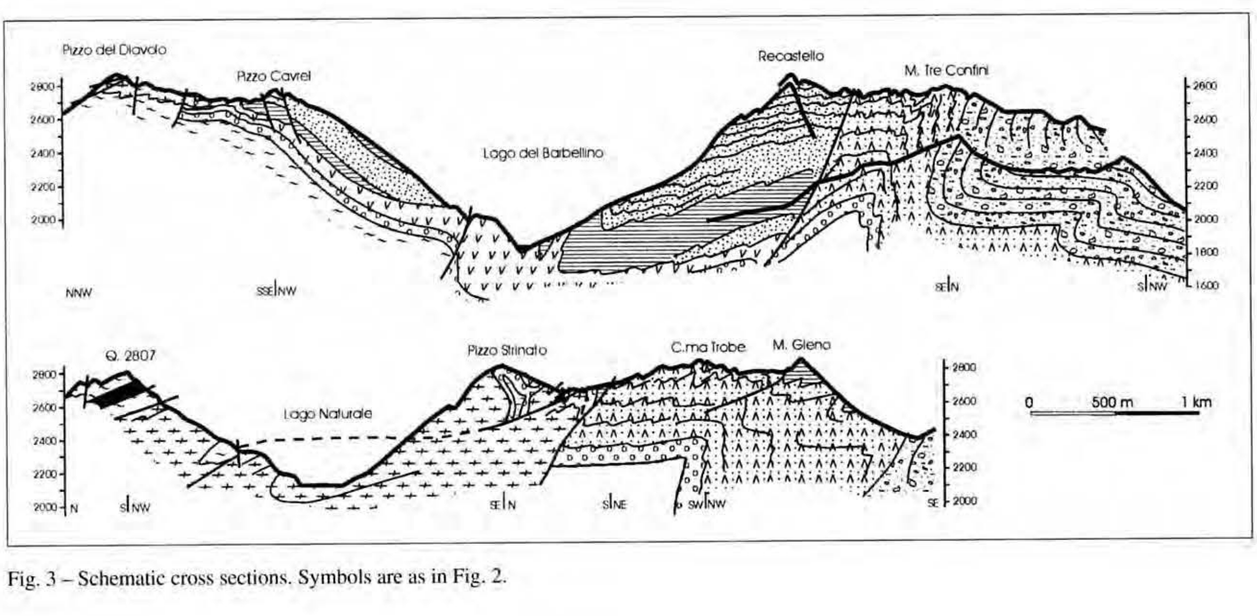


Fig. 3 – Schematic cross sections. Symbols are as in Fig. 2.

basement. The fold belt is best developed in the arenaceous-pelitic facies that form the southern slopes of Pizzo Cavrel and Pizzo Cappuccello. D_3 folds are cut by andesitic dykes related to the Adamello Tertiary intrusion, representing the main time constraint for the Alpine deformation.

Superficial shear planes, steeply dipping to the S and SW, dissect the Alpine structure, sometimes dragging the D_3-related cleavage into anomalous attitudes, and favouring deep-seated gravity-driven deformation and surficial landslides. As a whole, the entire ridge shows evidence of diffuse gravitational collapse.

THE INTERMEDIATE TECTONOSTRATIGRAPHIC UNIT

In the intermediate unit the metamorphic basement is unconformably overlain by a sedimentary succession consisting of milky quartz, metamorphic and volcanic pebbly conglomerate interbedded with purplish-red, often burrowed siltstone ("Basal Conglomerate"), very similar to that of the northern unit, followed by rhyolitic ignimbrites ("lower volcanics"). Volcaniclastic layers interbedded with grey sandstones and shales turning into well-bedded dark-grey siltstones and shales (facies S3) constitute the "lower Collio" succession. Well bedded dark greyish-greenish shales and sandstones, locally interbedded with conglomerates form the "upper Collio" succession (facies S2).

From a structural point of view this unit is characterised by a large-scale synformal-antiformal pair verging to the south, linked by a gently dipping to the north intermediate limb. Asymmetric parasitic folds, up to tens of metres in amplitude, further deform in a systematic way the limbs of the first-order folds (Fig. 3). In the northern upright limb of the main synform, large-scale "lenses" of Basal Conglomerate and Collio Fm. pelitic facies (S3) are intercalated in the intermediate volcanic and volcaniclastic layers; we interpret these "lenses" as the outcropping cores of parasitic cuspate folds that raise from the top of the Basal Conglomerate or hang from the bottom of the Collio Fm. pelitic facies. We cannot, however, exclude the presence of stratigraphic intercalations between the volcanic and sedimentary facies of the Collio Fm. The gently dipping intermediate limb crops out in the northern slope of Pizzo Recastello; it is mainly formed by the arenaceous facies deformed by a train of mesoscopic S-verging folds. In proximity to the Pizzo Recastello thrust surface, it bends into a tight antiformal structure with a vertical to overturned limb. The thrust surface fades away to the west along the western slope of Monte Cimone; to the east it merges into a NNE-SSW-trending fault that possibly acts as a lateral ramp for the intermediate thrust unit. Local complications of the structure are widespread; as an example, the upper slope of Pizzo Strinato on tight disharmonic folds and faulted folds are the consequence of a local thrust surface that intersects the ridge between the Belviso and the Serio valleys. The thrust can be followed for a few hundred metres down the western slope of the peak, from which its continuation can only be supposed to continue within the crystalline basement (dashed line on the map).

THE SOUTHERN TECTONOSTRATIGRAPHIC UNIT

The sedimentary succession of the southern thrust unit mainly consists of volcaniclastics of various grain-sizes (from coarse pebbly conglomerates to very finegrained cinerites, lithofacies V4) with locally interbedded qz-rich conglomerates and agglomerates, in places arenite-matrix supported. Grey to black siltstones and shales (facies S3; Mt. Tre Confini, Mt. Gleno) and coarse-grained arenites to conglomerates with Fe-carbonate interlayers of possible lacustrine origin (facies S5) are locally interbedded in the volcaniclastic succession, which is directly overlain by the Upper Permian Verrucano Lombardo reddish conglomerates and sandstones, and therefore ascribed to the "upper Collio". This succession could reasonably represent a marginal part of the basin, deepening toward the NW.

This structural unit is characterised by a train of south-verging mega- to mesoscopic folds, also involving the usually brittle Verrucano Lombardo Fm. A locally very pervasive D_3 cleavage flattens the volcanic pebbles of the conglomeratic layers into ellipsoidal shapes. The unit plunges to the south towards the Dezzo Valley, forming a wide antiform bending (Cedegolo Anticline *p.p.*) whose toe wedges into the carbonatic belt cropping out to the south.

CONCLUSIONS

The studied area is considered an example of the polyphase tectonics that characterise the belt of Orobic Anticlines, where the Upper Carboniferous (?) to Upper Permian stratigraphic succession of the Lombardian southern Alps extensively crops out. The late- to post-Permian extensional phase is suggested by Alpine thrust surfaces that follow abrupt discontinuities in thickness and facies of the stratigraphic record; the changes point to a northward deepening of the original basin with a step-like geometry. With reference to the northern main thrust surface, the original extensional kinematics are further suggested by a "younger over older" thrust (Serio River waterfall, and further west, outside the mapped area) and by alignments of tectonic slices, variously imbricated and/or tilted (between the Malgina Valley and the tail of Barbellino Lake), which we interpret as former horses of a main extensional boundary fault that was inverted and tilted during the Alpine compression. Minor listric normal faults dipping to the east (antithetic?) bound conglomeratic wedges comparable to the Upper Permian conglomerates; the conglomerates are still preserved with their original geometry along the eastern slopes of the Coca and Redorta peaks.

The Alpine compressional phase(s) gave rise to the main structural grain of the area, expressed by the fold-thrust sheets dealt with previously. The main phase is older than the age of the transecting andesite dykes (radiometric ages of 50-64 Ma according to Zanchi *et. al.*, 1990 and Fantoni *et al.*, 1997). A younger phase is expressed by D_4 shear planes, pervasive at the map scale, expressed both in finegrained sediment and in coarse volcaniclastic conglomerates; these structures have been described by Albini *et al.* (1994). No definite upper-age constraint is available for this event.

The late- to post-Alpine extensional phase is documented by high-angle N-S-trending faults, well expressed along the main mountain ridges, and by map-scale, near-vertical shear planes that distort the trend of the regional Alpine folds and cleavage surfaces and create huge rock pinnacles and impending rock masses ready to slide down the slopes below. Huge boulders caused by a rock-slide are now scattered in the nearby Maslana village (Valbondione) and evidence of deep-seated gravitational collapse is documented on the northern slope of Mt. Toazzo ridge (located immediately SW of Mt. Cimone).

Aknowledgement – The authors are indebted to S. Albini, C. Bigoni, D. Guizzetti, M. Pagani and G. Tucci, who shared part of the fieldwork, and to G. Cassinis for fruitful discussions and review of the draft. Data presented here were collected in the framework of the Carg mapping project.

REFERENCES

Albini S., Battaglia D., Bellini G., Bigoni C., Carminati E., Ceriani S., Forcella F., Gosso G., Guizzetti D., Oliva A., Rebay G., Siletto G. B. & Spalla M. I., 1994. Alpine deformations and pre-Alpine remnants in the north-eastern Orobic Alps, Southalpine belt. In Montrasio A. & Sciesa E. (eds): *Proc. Symp. "CROP - Alpi Centrali"*. Quad. Geodin. Alpina e Quaternaria, 2: 25-39.

Assereto R. & Casati M., 1965. Revisione della stratigrafia permo-triassica della Val Camonica meridionale (Lombardia) (with a geological map). *Riv. Ital. Paleont. Stratigr.*, 71: 999-1097.

Casati P. & Gnaccolini M., 1965. Una nuova formazione paleozoica dell'alta Val Brembana: la Formazione del Ponteranica. *Riv. Ital. Paeont. Stratigr.*, 71: 791-804.

De Sitter L.U., 1963. La structure des Alpes Lombardes. In: Livre à la mémoire du Prof. P. Fallot, *Soc.Géol.France*, 2: 245-256.

De Sitter L.U. & De Sitter-Koomans C.M., 1949. Geology of the Bergamasc Alps, Lombardia, Italy. *Leid. Geol. Meded.*, 14: 1-257.

Dozy J.J., 1933. Die Geologie der Catena Orobica zwischen Corno Stella und Pizzo del Diavolo di Tenda. *Leid. Geol. Meded.*, 6: 133-230.

Dozy J.J., 1935. Ueber das Perm der Südalpen. *Leid. Geol. Meded.*, 7 (1): 41-62.

Fantoni R., Bersezio R., Forcella F., Gorla L., Mosconi S. & Picotti V., 1997. Mesoalpine magmatism and tectonics in the western Southern Alps. 3rd *Workshop on Alpine Geological Studies*. Quad. Geodin. Alpina e Quaternaria, Abstr. vol.: 4: 47-48.

Forcella F., Sciunnach D. & Siletto G.B. (this volume). The Lower Permian in the Orobic and Cedegolo anticlines (Lombardy, Southern Alps): criteria for field mapping towards a stratigraphic revision of the Collio Formation.

Spalla M.I., Carminati E., Ceriani S., Oliva A. & Battaglia D., 1999. Influence of deformation partitioning and metamorphic reequilibration on PT-path reconstruction in the pre-Alpine basement of Central Southern Alps (Northern Italy). *J. Metam. Geol.*, 17: 319-336.

Zanchi A., Chiesa S. & Gillot P-Y., 1990. Tectonic evolution of the Southern Alps in the Orobic chain: structural and geochronological indications for pre-Tertiary compressive tectonics. *Mem. Soc. Geol. Ital.*, 45: 77-82.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 65-72

GEOLOGICAL SETTING OF THE BRESCIAN ALPS, WITH PARTICULAR REFERENCE TO THE PERMIAN OUTCROPS: AN OVERVIEW

PAOLO SCHIROLLI [1]

Key words – Brescia Province; N-S geological profile; Stratigraphy; Tectonics; Southern Alps; Northern Italy.

Abstract – Eight geological and structural zones are recognised in the Brescia Province on the basis of their prevalent lithologic pattern, different age and structural style, as due to the Alpine orogeny.
Regional tectonic lineaments or stratigraphical boundaries divide these zones, shown both in a simplified geological map of the region and in a complete N-S trending geological profile, 80 kilometres long, through the entire Brescia Province.
The profile crosses the igneous and sedimentary continental deposits of two of the major Permian basins in the region (Orobic and Collio Basins).
They corresponded to continental intramontane basins with a WSW-ENE orientation, fault-bounded by basement structural highs.

Parole chiave – provincia di Brescia; profilo geologico N-S; stratigrafia; tettonica; Sudalpino; Italia settentrionale.

Riassunto – La provincia di Brescia è stata suddivisa in otto zone geologico-strutturali, distinguibili sulla base dei litotipi prevalenti, dell'età delle formazioni e del differente stile strutturale assunto dalla successione in conseguenza degli eventi compressivi alpini. Lineamenti tettonici di importanza regionale o superfici stratigrafiche delimitano le zone geologico-strutturali, la cui estensione areale è riportata nella carta geologica semplificata della provincia, che accompagna un profilo geologico della lunghezza di circa 80 chilometri che attraversa da nord a sud l'intera provincia di Brescia. Il profilo attraversa i depositi continentali ignei e sedimentari dei due maggiori bacini deposizionali permiani della regione (Bacino orobico e Bacino di Collio). Essi rappresentano dei bacini continentali intramontani orientati in senso WSW-ENE, separati dagli alti strutturali del basamento ad opera di attivi sistemi di faglie sinsedimentarie.

INTRODUCTION

A geological profile across the entire Brescia Province, along a N-S trend, is here proposed in order to highlight the main geological features of this region. It is also supported by a concise explanation aimed at clarifying the local geological framework.

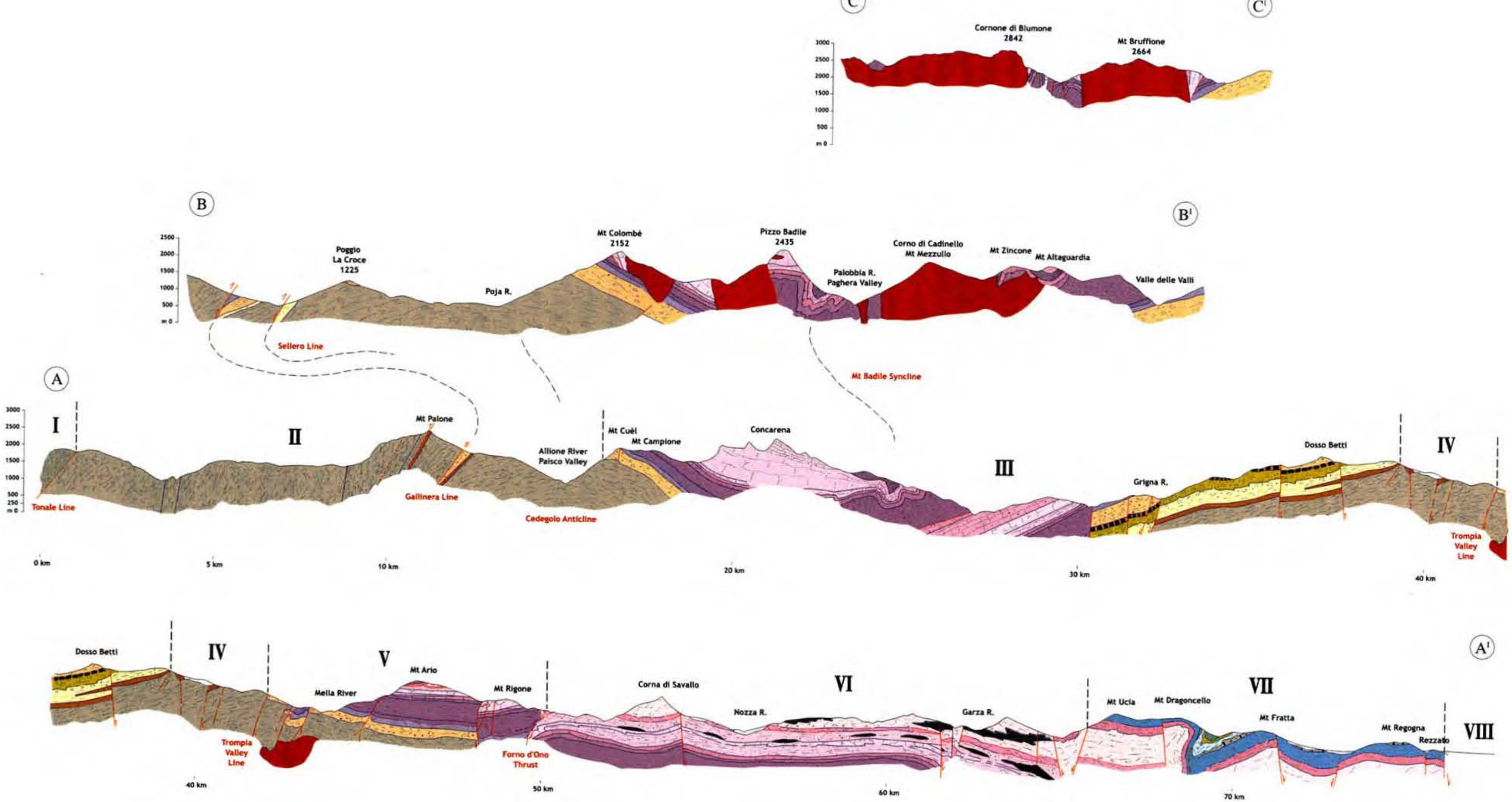
The profile (Plate 1), derived from published (Boni & Cassinis, 1973; Boni *et al.*, 1968, 1970, 1972; Bianchi *et al.*, 1971; Brack, 1984; Cassinis, 1980; Desio *et al.*, 1970; Schiavinato *et al.*, 1969; Cassinis & Castellarin, 1981; Cassinis & Forcella, 1981; Forcella, 1981; Cassinis & Castellarin, 1988) and unpublished (Brack; Schirolli) cross-sections and data on the Brescian Alps, links up a point to the north of the Tonale Line (part of the Insubric Line), near the Aprica Pass, to the last hills in front of the Po Plain, in Rezzato, a few kilometres to the east of Brescia. It allows better understanding of the geological setting of this part of Southern Alps, and the visualisation of the pellicular tectonic and stratigraphic pattern in which the Permian rocks crop out, immediately to the west of the Adamello batholith.

The most important regional faults and folds are represented along this N-S profile, which is 80 kilometres long; two other shorter cross-sections (from Brack) cut the western part of the Adamello intrusive massif, showing the structures superimposed by the magmatic Tertiary intrusion on the local stratigraphic succession of the Permian and Triassic cover.

GEOLOGICAL SETTING

A glance at the simplified geological map of the Brescia Province (Plate 1) shows the main geological features of this area. As in the whole Southern Alps, the Brescian Alps also reacted to the Tertiary Alpine compression through the imbrication of south to southeastward-verging tectonic blocks. This geological feature created the present pattern that shows older formations proceeding by degrees

[1] Sezione di Scienze della Terra, Museo Civico di Scienze Naturali, Via Ozanam 4, I-25128 Brescia, Italy.


C
C'
Cornone di Blumone
2842
Mt Bruffione
2664
3000
2500
2000
1500
1000
500
m 0
B
B'
Poggio
La Croce
1225
Poja R.
Mt Colombè
2152
Pizzo Badile
2435
Palobbia R.
Paghera Valley
Corno di Cadinello
Mt Mezzullo
Mt Zincone
Mt Altaguardia
Valle delle Valli
Sellero Line
Mt Badile Syncline
A
I
II
III
IV
Mt Palone
Allione River
Paisco Valley
Mt Cuèl
Mt Campione
Concarena
Dosso Betti
Grigna R.
Tonale Line
Gallinera Line
Cedegolo Anticline
Trompia
Valley
Line
0 km
5 km
10 km
20 km
30 km
40 km
V
VI
VII
VIII
A'
Mella River
Mt Ario
Mt Rigone
Corna di Savallo
Nozza R.
Garza R.
Mt Ucia
Mt Dragoncello
Mt Fratta
Mt Regogna
Rezzato
Forno d'Ono
Thrust
50 km
60 km
70 km

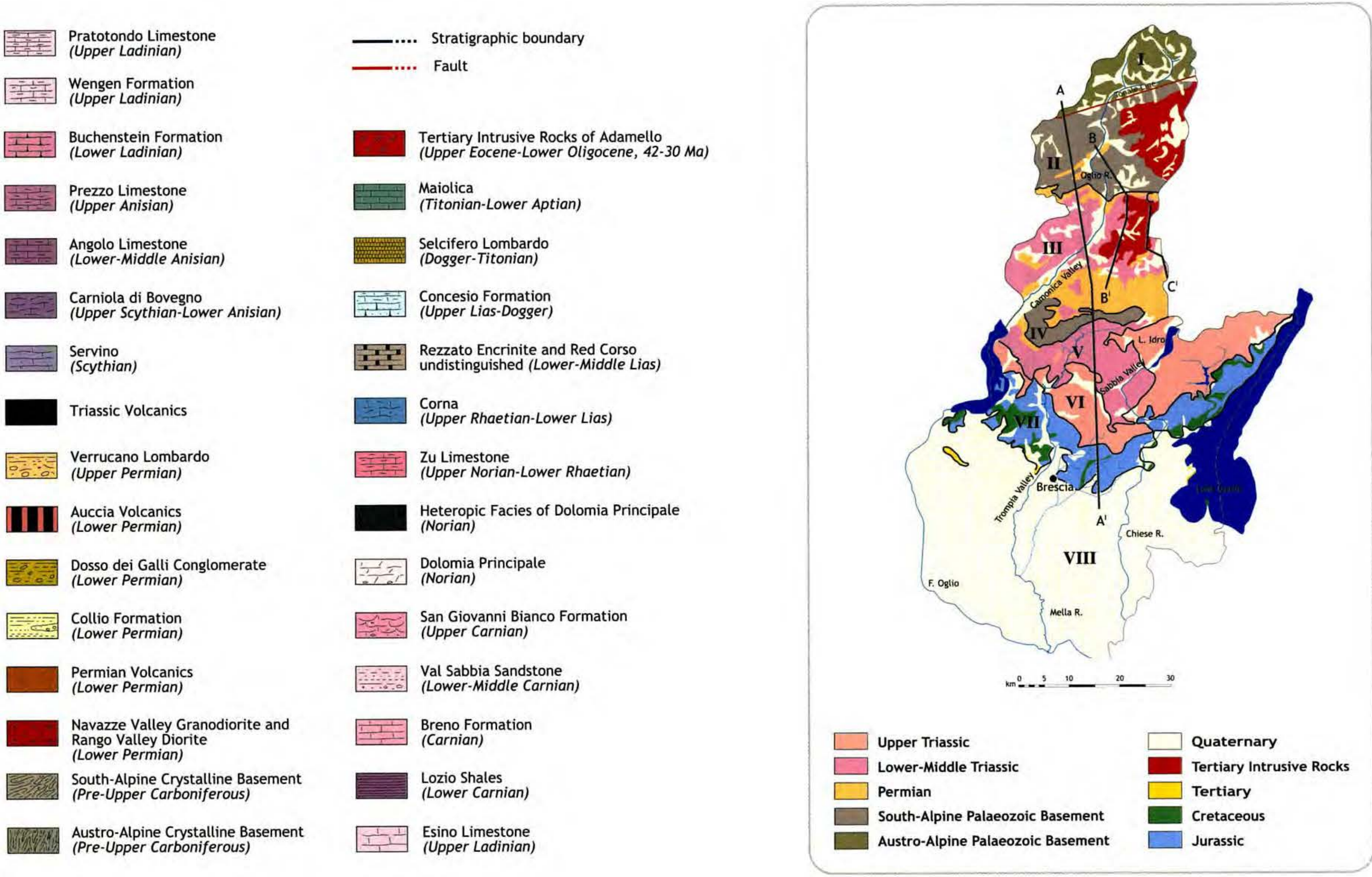


Plate I – N-S trending geological profiles across the Brescia Province. The simplified geological map of the Brescia Province shows the traces of the three profiles A-A', B-B', C-C'. Roman numbers, both in the small geological map and in the cross-section A-A', are referred to the geological and structural zones described in the text. Profiles B-B' and C-C' through the western Adamello intrusive massif derive from P. Brack unpublished data.

from the south (northern border of the Po Plain) to the north. In fact, from the south, we pass from the Quaternary alluvial deposits to the Tertiary and Mesozoic sedimentary cover of the piedmont, and from here to the first South-Alpine and then Austro-Alpine Palaeozoic metamorphic basement (Pre-Upper Carboniferous), widely cropping out to the north.

Part of South-Alpine basement, known as the "Brescia Three Valleys Massif", appears isolated between the Permian and Lower Triassic cover in the so-called "Trompia Valley Culmination".

The appearance of the Adamello batholith cuts off eastward both the South-Alpine basement and the Permian and Triassic sedimentary rocks, which crop out in the northern part of the Province. This magmatic body is represented by intrusive rocks emplaced during the Tertiary (from 42 to 30 Ma according to Del Moro *et al.*, 1986).

THE MAJOR TECTONIC DIRECTIONS

The Brescian Pre-Alps and Alps are characterised by the presence of two most important groups of tectonic lineaments. The first, with an E-W to ENE-WSW trend ("Orobic" or "Trompia" direction), is generally linked to south-verging thrust and fold Alpine structures; the second, NNE-SSW trend ("Giudicarie" direction), is connected to southeast-verging structures. These two groups of lineaments gave rise to a wide structural arc that involves both the outcropping formations of the region and the substrata below the alluvial deposits of the Po Plain (Castellarin & Sartori, 1980, 1983; Castellarin & Vai, 1986; Castellarin *et al.*, 1987; Picotti *et al.*, 1995).

The compressive regime that induced south-verging thrusts is ascribed unanimously to the structures with an Orobic trend, while the amount of transcurrent movement linked to the compression is still being defined for the Giudicarie-oriented structures (Trevisan, 1938; Laubscher, 1973, 1990; Castellarin & Sartori, 1983; Castellarin *et al.*, 1987; Doglioni & Bosellini, 1987).

The deformation of some folds with E-W trending axes, induced by the emplacement of the Adamello intrusion in the upper Camonica Valley (Cozzaglio, 1894; Brack, 1981), ascribes the Orobic direction to the first deformational phase at the origin of Brescian Pre-Alps such as the entire Southern Alps (Late Cretaceous Eo-Alpine Phase and/or Eocene Meso-Alpine Phase in age).

The Giudicarie structures were generated in a different (shortening axis rotated by about 45°) and subsequent deformational phase if compared with the above-mentioned Orobic-trending structures, *i.e.* during the Miocene Neo-Alpine Phase in the opinion of Castellarin *et al.* (1987); according to Doglioni & Bosellini (1987), they were produced by the Eo-Alpine sinistral transpressional movements along the Giudicarie Line. The southwards movement of both the Adamello crustal block and the Trompia metamorphic basement could explaine both the contemporary compression towards the south along the Trompia Valley Line and the sinistral transcurrent movement along the Giudicarie Line in the same deformation phase, following the Adamello intrusive emplacement (Middle Miocene to Messinian Neo-Alpine Phase, from Laubscher, 1990).

THE MOST IMPORTANT TECTONIC STRUCTURES

The main geological profile, N-S oriented, cuts all the major Orobic structures, firstly the Insubric Line. Under the name of the *Tonale Line*, it crosses the northern part of Brescia Province from Tonale (east) to the Aprica Pass (west), separating the northern metamorphic basements of the Austro-Alpine domain from the basement of the South-Alpine palaeogeographical-structural domain to the south.

The *Gallinera Line* (Cassinis & Castellarin, 1988) represents the eastwards termination of that important fault system (*Sellero Line* included) named the *Orobic Line*. South-verging high-angle reverse faults with north-dipping planes comprise this system. It permits the overthrust of the northern metamorphic rocks of the South-Alpine basement on to the southern Permian and Triassic cover of the north side of the Cedegolo Anticline. This structure, Orobic-oriented, formed because of the low competence of the "Carniola di Bovegno" formation.

The *Trompia Valley Line* is a complex E-W trending fault system that rose and overthrust southwards the "Brescia Three Valleys Massif" on to the Triassic cover rocks. The Trompia Line, together with the *South Giudicarie Line* (that part of the Line located to the south of its crossing with the Tonale Line), NNE-SSW oriented, give rise to a structural arc (Castellarin & Sartori, 1983; Castellarin *et al.*, 1987; Picotti *et al.*, 1995). Towards the eastern border of Adamello massif, the subvertical faults of the Giudicarie system allowed the significant uplift of the Brescia area in comparison with the eastern neighbouring sector of the Southern Alps (Castellarin & Sartori, 1980; Cassinis *et al.*, 1982).

To the south of the Trompia Line a large number of fault planes guided the thrust of the Lower-Middle Triassic rocks on to the southern Upper Triassic formations ("Dolomia Principale"). For example, the main section shows the important *Forno d'Ono Thrust*, by which the Anisian "Angolo Formation" was carried on to the younger "Sabbia Valley Sandstone", thanks to the deforming bed of the Scythian-Anisian "Carniola di Bovegno" formation.

In its turn, the wide "Dolomia Principale" plate overthrust the younger Mesozoic formations located to the south and east. Especially in evidence is the *Tremosine-*

Tignale Thrust, with a NNE-SSW orientation, running close to the western coast of Garda Lake, out of the range of the geological cross-sections presented here. The movement of this very thick dolomitic formation, favoured by the underlying Carnian evaporitic deposits, shows a south-vergence (Orobic trend) in the central-western Brescia Province, and a SSE-vergence (Giudicarie direction) in the eastern part of the Province. It forced the Jurassic and Cretaceous formations into folds of varying width, characterised by axes parallel to the regionally predominant structural directions.

GEOLOGICAL AND STRUCTURAL ZONES

With regard to its geological framework, the Brescia Province can be divided into eight geological and structural zones, bounded by regional tectonic lineaments and/or stratigraphical boundaries. The lithological pattern of the formations, their age and structural style caused by the compressional Alpine tectonic events are the major features distinguishing the eight zones below (Cassinis *et al.*, 1991).

Zone I is located to the north of the Tonale Line. It includes the metamorphic basement (generally pre-Late Carboniferous in age) of the Austro-Alpine palaeogeographical– structural domain.

Between the Tonale Line and the Cedegolo Anticline, the crystalline basement of the South-Alpine domain (locally known as the "Edolo Schists") occurs in *Zone II*. These pre-Upper Carboniferous metamorphic rocks appear as a strip immediately to the south of the Insubric Line in Lombardy. The southern boundary of Zone II is represented by the Gallinera Line. Along it, the basement thrusts southwards to cover stratigraphic units of the Cedegolo Anticline northern limb, belonging to *Zone III*. This Upper Permian to Lower-Middle Triassic sedimentary cover unconformably overlies the "Brescia Three Valleys Massif" crystalline basement of *Zone IV*. The metamorphic basement of Zone II and the Permian and Triassic sedimentary rocks of Zone III are cut by the eastern Adamello intrusion and the South Giudicarie Line (Cassinis, 1985; Brack *et al.*, 1985).

The Trompia Valley Line induced the rise and the south-verging thrust of the Zone IV crystalline basement on to the strongly deformed rocks of *Zone V*. In fact these pre-Norian Triassic formations are divided into numerous south-verging blocks by a local reverse fault system with northward-dipping planes. Both the Scythian-Anisian "Carniola di Bovegno" and the Carnian deposits aided the tectonic movements within this zone.

The Forno d'Ono overthrust is one of the most important tectonic planes that allowed the thrust of the Lower-Middle Triassic rocks on to the southern Norian "Dolomia Principale" formation of *Zone VI*. It consists of a thick and strongly rigid dolomitic plate, cut by reverse and wrench faults.

Also the Dolomia Principale generally thrust the younger Mesozoic formations of the neighbouring zone. Jurassic and Cretaceous rocks, locally unconformably overlain by Tertiary deposits, represent *Zone VII*. They reacted to the Alpine compressional movements by folding, which generated broad anticlines and synclines in the well-bedded Mesozoic limestones.

The final *Zone VIII* is characterised by the plain to the south of Brescia, where the whole stratigraphic succession described in the above-mentioned zones is buried under southward-thickening Neogene-Quaternary alluvial deposits.

PERMIAN TECTONO-SEDIMENTARY CYCLES AND PHYSIOGRAPHICAL SETTING OF THE REGION

The regional tectonic lines involved in the Alpine orogeny frequently show evidence of a long previous structural history, usually named "ancestral" character (Cassinis *et al.*, 1982; Castellarin, 1982; Castellarin & Vai, 1982; Doglioni & Bosellini, 1987; Cassinis & Castellarin, 1988; and so on). In many cases they had an active role of inversion during the Tertiary compressional regime. In fact, in former times many of these lines controlled the most intense phases of continental rifting: firstly during the Permian (Late-Hercynian event), then during the Norian and still later the Jurassic (Neo-Tethys rifting). During all these periods, the Brescia Province underwent extension.

The geological profile crosses two of the major Permian depositional basins in the region. These corresponded to continental intramontane basins with a WSW-ENE orientation, fault-bounded by basement structural highs. Only the activation of the aforementioned tectonic lines allowed the creation of these basins (Cassinis, 1982, 1985, 1988; Cassinis & Neri, 1990, 1992; Cassinis *et al.*, 1990, 1995, 1997; Perotti & Siletto, 1996).

South of the Tonale Line, the Orobic Basin is located between the Orobic Line-Gallinera Line, E-W trending system, and the southern Cedegolo Anticline. Further to the south, the sigmoidal shaped Collio Basin is bounded by the structural arc defined by the Trompia Valley Line to the south and the South Giudicarie Line to its eastern border.

Typology and areal variability of the Permian stratigraphic formations allow us to highlight the synsedimentary activity of these lines and their consequent cause and effect role in the birth and evolution of the Permian basins.

Permian formations (Cassinis, 1988) lie unconformably on the Hercynian (or Variscan) crystalline basement composed of phyllites, mica-schists and gneisses. Igneous and sedimentary continental deposits characterise the Permian succession in the Brescia Province (Cassinis, 1985; Ori *et al.*, 1988; Cassinis & Perotti, 1994). It can be divided into two major stratigraphical units, directly linked to two different tectono-sedimentary cycles (following the Hercynian orogeny) separated by a marked regional unconformity (Italian IGCP 203 Group, 1986; Cassinis *et al.*, 1988).

In the upper Trompia Valley, red-violet rhyolitic ignimbrites, lavas and tuffs of calc-alkaline geochemistry usually overlie the metamorphic basement. Only locally discontinuous outcrops of "Basal Conglomerate" (Upper Carboniferous?-Lower Permian) occur between these two units in the Brescia area. The basal volcanics appear as concordant with the overlying "Collio Formation" bodies (Peyronel-Pagliani, 1965; Origoni Giobbi *et al.*, 1979; Breitkreuz *et al.*, 1999).

Furthermore, the late Hercynian period is characterised by granodioritic and dioritic intrusives, such as the Navazze and Rango small bodies cropping out close to Collio (Upper Trompia Valley), which could be directly related to the Permian volcanic eruptions.

Continental alluvial-lacustrine well-bedded sandstones, siltstones and shales associated with interbedded volcanic rocks (Peyronel-Pagliani, 1965; Origoni Giobbi *et al.*, 1979; Breitkreuz *et al.*, 1999), characterise the "Collio Formation" (Cassinis, 1966a, 1966b; Cassinis *et al.*, 1975, 1978). This is a very thick sedimentary succession (up to 1000 m), infilling the subsiding Lower Permian basinal areas.

The reddish "Dosso dei Galli Conglomerate" (Cassinis, 1969a), rich in basement and Lower Permian volcanic fragments, lies on and laterally passes into the Collio Formation. It shows the alluvial conoid progradation from the borders to the depocentre of the basin. But the "Dosso dei Galli Conglomerate" laterally can also pass to the red-brown bioturbated fine sandstones and siltstones of the "Pietra Simona Member".

The rhyolitic-rhyodacitic ignimbrite unit of the red-violet "Auccia Volcanics" (Cassinis, 1969b; Peyronel-Pagliani & Clerici Risari, 1973; Origoni Giobbi *et al.*, 1979; Breitkreuz *et al.*, 1999) ends the Lower Permian tectono-sedimentary cycle, as well as the basin existence.

A time-gap of uncertain duration, most likely limited to the middle part of the Permian period, is associated with the regional unconformity that marks the contact between the two cycles (Cassinis & Doubinger, 1991, 1992; Cassinis & Perotti, 1997; Cassinis *et al.*, 2000 and in press).

The Upper Permian Cycle is defined by the red fluvial siliciclastic deposits ("red beds") of the "Verrucano Lombardo" and the disappearance of volcanic products. Between Camonica Valley and Giudicarie Valley, the "Verrucano Lombardo" is generally represented by fine-grained sandstones and siltstones.

The geological profile clearly shows rapid lateral facies and thickness changes in the Lower Cycle Units. In fact, the "Collio Formation" and associated volcanics disappear in the areas that were structural highs during the Early Permian. But, in the whole province, the "Verrucano Lombardo" is always present. It covers the Lower Group Units in the Permian basinal areas but directly overlies the crystalline basement on the Permian highs.

Consequently, both the cycles of the Permian succession occur where the profile crosses the Orobic and the Collio basins. In contrast, on the Camonica Valley High, which is located between the aforementioned basins, only the Verrucano lies on the metamorphic basement.

In a few kilometres, a step-by-step E-W trending fault system represents the tectonic boundary between the Collio Basin and the southern Trompia Valley High. In fact, the profile shows the Verrucano gradually overlying the basement southwards. So a thinner Permian succession crops out along an E-W oriented strip to the south of Trompia Valley Line. Moreover, the Permian granitoid intrusives within the upper Val Trompia basement are in accord with this structural pattern.

Another ridge, bounded by synsedimentary faults with a NNE-SSW orientation, earlier separated the Collio Basin from the western, smaller Boario Basin.

A large part of the above-mentioned volcanic products clearly came from the synsedimentary fault systems bounding the Permian basins. In fact, these tectonic scarp slopes were the source of strong magmatic activity following the Hercynian orogenic event.

Acknowledgements – The author is very grateful to G. Cassinis, C. Perotti and P. Brack for their careful review of the paper. A special thank to G. Cassinis, who permitted this contribution, and to P. Brack for the availability to use his unpublished data.

REFERENCES

BIANCHI A., BONI A., CALLEGARI E., CASATI P., CASSINIS G., COMIZZOLI G., DAL PIAZ GB., DESIO A., GIUSEPPETTI G., MARTINA E., PASSERI L.D., SASSI F.P., ZANETTIN B. & ZIRPOLI G., 1971. Note illustrative della Carta Geologica d'Italia, alla scala 1:100.000. Foglio 34 Breno. *Minist. Ind.,Comm., Artig., Dir. Gen. Min., Serv. Geol. d'Italia*. Nuova Tecnica Grafica, Roma: 134 pp.

BONI A. & CASSINIS G., 1973. Carta geologica delle Prealpi Bresciane a Sud dell'Adamello. Note illustrative della legenda stratigrafica. *Atti Ist. Geol. Univ. Pavia*, 23: 119-159.

BONI A., CASSINIS G., CAVALLARO E., CERRO A., FUGAZZA F., ZEZZA F., VENZO S. & MEDIOLI F., 1968. Carta Geologica d'Italia alla scala 1:100.000 - Foglio 47 Brescia (II edizione), Poligrafica & Cartevalori, Ercolano (Napoli).

BONI A., CASSINIS G. & VENZO S., 1970. Note illustrative della Carta geologica d'Italia alla scala 1:100.000. Foglio 47 Brescia. *Minist. Ind.,Comm., Artig., Dir. Gen. Min., Serv. Geol. d'Italia*. Poligrafica & Cartevalori, Ercolano (Napoli): 93 pp.

BONI A., CASSINIS G., CERRO A., ROSSETTI R., ARDIGÒ G., CAVALLARO E., FUGAZZA F. & ZEZZA F., 1972. Carta Geologica delle Prealpi bresciane a sud dell'Adamello (scala 1:50.000), edita dall'Istituto di Geologia dell'Università di Pavia, *Atti Ist. Geol. Univ. Pavia*, 22: 2 plates.

BRACK P., 1981. Structures in the southwestern border of the Adamello intrusion (Alpi Bresciane, Italy). *Schweiz. Mineral. Petrogr. Mitt.*, 61: 37-50.

BRACK P., 1984. Geologie der Intrusiva und Rahmengesteine des Suedwest-Adamello (Nord-Italien). *Diss. ETH Zuerich Nr. 7612*.

BRACK P., CALLEGARI E., CASSINIS G., CASTELLARIN A., FONTANA D., GAETANI M., ORI G., ORIGONI GIOBBI E., RIKLIN K., SARTORI R. & ULMER P., 1985. Guida all'escursione sull'Adamello meridionale. *Mem. Soc. Geol. Ital.*, 26 (1983): 391-419.

BREITKREUZ C., CHECCHIA C., CASSINIS G., CORTESOGNO L. & GAGGERO L., 1999. Dynamics of a Variscan Post-Orogenic Basin in the Southern Alps: Sublacustrine SiO_2-Rich Volcanism and Associated Mass Flows (Collio Basin, Italy). *J. Conf., EUG 10, March 28th - April 1st, Strasbourg*. Abstr. vol.: 294-295.

CASSINIS G., 1966 a. Rassegna delle formazioni permiane dell'alta Val Trompia (Brescia). *Atti Ist. Geol. Univ. Pavia*, 17: 51-66.

CASSINIS G., 1966 b. La Formazione di Collio nell'area-tipo dell'alta Val Trompia (Permiano inferiore bresciano) *Riv. Ital. Paleont. Stratigr.*, 72: 507-590.

CASSINIS G., 1969 a. Conglomerato del Dosso dei Galli. *St. Ill. Carta Geol. Italia*, Roma, n. 2: 13-22.

CASSINIS G., 1969 b. Vulcaniti di Auccia. *St. Ill. Carta Geol. Italia*, Roma, n. 2: 23-30.

CASSINIS G., 1980. Motivi strutturali emersi da un profilo condotto nelle Prealpi bresciane tra il Passo di Croce Domini e Salò. *Rend. Soc. Geol. Ital.*, 2 (1979): 13-14.

CASSINIS G., 1982. Note geologiche sull'area all'intersezione tra Linea delle Giudicarie Sud e Linea della Val Trompia. In: Castellarin A. & Vai G.B. (a cura di), *Guida alla geologia del Sudalpino centro-orientale*. Guide Geol. Reg. S.G.I., Bologna: 97-102.

CASSINIS G., 1985. Il Permiano nel Gruppo dell'Adamello, alla luce delle ricerche sui coevi terreni delle aree contermini. *Mem. Soc. Geol. Ital.*, 26 (1983): 119-132.

CASSINIS G., 1988. Carta geologica dei depositi continentali permiani a Sud dell'Adamello. *Atti Ticin. Sci. Terra*, Pavia, 31 (1987-88): tav.1.

CASSINIS G. & CASTELLARIN A., 1981. Foglio 47 Brescia. In: Castellarin A. (ed.), *Carta tettonica delle Alpi Meridionali alla scala 1:200.000*. C.N.R. Prog. Final. Geodinamica, Sottopr. 5 "Modello Strutturale", Pubbl. n. 441: 161-165.

CASSINIS G. & CASTELLARIN A., 1988. Il significato delle linee della Gallinera e delle Giudicarie Sud nella geologia dell'Adamello e zone circostanti. *Atti Ticin. Sci. Terra*, Pavia, 31 (1987/88): 446-462.

CASSINIS G. & DOUBINGER J., 1991. On the geological time of the typical Collio and Tregiovo continental beds in the Southalpine Permian (Italy), and some additional observations. *Atti Ticin. Sci. Terra*, Pavia, 34: 1-20.

CASSINIS G. & DOUBINGER J., 1992. Artinskian and Ufimian palynomorph assemblages from the central Southern Alps, Italy, and their stratigraphic regional implications. In: Nairn A.E.M. & Korotev V. (eds), *Contribution to Eurasian geology. Intern. Congr. on the Permian System of the World, Perm, Russia, 1991*. Occasional pubbl. ESRI, New Series N° 8b, Columbia University of South Carolina. part. I: 9-18.

CASSINIS G. & FORCELLA F., 1981. Foglio 34 Breno. In: Castellarin A. (ed.), *Carta tettonica delle Alpi Meridionali alla scala 1: 200.000*. C.N.R. Prog. Final. Geodinamica, Sottopr. 5 "Modello Strutturale", Pubbl. n. 441: 166-173.

CASSINIS G. & NERI C., 1990. Collio and Tregiovo Permian continental basins (Southern Alps, Italy): a general comparison. *Atti Ticin. Sci. Terra*, Pavia, Note brevi, 33: 11-15.

CASSINIS G. & NERI C., 1992. Sedimentary and palaeotectonic evolution of some Permian continental basins in the central Southern Alps, Italy. *Cuad. Geol. Iberica*, 16: 145-176.

CASSINIS G. & PEROTTI C.R., 1994. Interazione strutturale permiana tra la Linea delle Giudicarie ed i Bacini di Collio, Tione e Tregiovo (Sudalpino Centrale, N Italia). *Boll. Soc. Geol. Ital.*, 112 (1993): 1021-1036.

CASSINIS G. & PEROTTI C.R., 1997. Tectonics and sedimentation in the western sector of the Permian Continental Collio Basin, Southern Alps, Italy. In Prace Panstwowego Instytutu Geologicznego CLVII, *Proc. of the XIII Intern. Congr. on the Carboniferous and Permian, 28th August - 2nd September, 1995, Kraków, Poland*, Warszawa, Part 2: 25-32.

CASSINIS G., ORIGONI GIOBBI E. & PEYRONEL PAGLIANI G., 1975. Osservazioni geologiche e petrografiche sul Permiano della bassa Val Caffaro (Lombardia orientale) *Atti Ist. Geol. Univ. Pavia*, 25: 17-71.

CASSINIS G., MATTAVELLI L. & MORELLI G.L., 1978. Studio petrografico e mineralogico della Formazione di Collio nel Permiano inferiore dell'alta Val Trompia (Prealpi Bresciane). *Mem. Sci. Geol.*, Padova, 32: 13 pp.

CASSINIS G., CASTELLARIN A, PELOSO G.F., SARTORI R. & VERCESI P.L., 1982. Il settore della Linea delle Giudicarie Sud: evoluzione paleotettonica permo-triassica ed assetto strutturale attuale. In: Castellarin A. & Vai G.B. (eds), *Guida alla geologia del Sudalpino centro-orientale*. Guide geol. reg. S.G.I., Pitagora-Tecnoprint, Bologna: 125-130.

CASSINIS G., MASSARI F., NERI C. & VENTURINI C., 1988. The continental Permian in the Southern Alps (Italy). A review. *Z. Geol. Wiss.*, Berlin, 16: 1117-1126.

CASSINIS G., PEROTTI C.R. & VENTURINI C., 1990. Permian tectonics in the Southern Alps (Italy) In: *30th Intern. Geol. Congr., 4-14 August, Beijing, China*. Abstracts, Vol. 2 of 3: 95.

CASSINIS G., PEROTTI C.R., VERCESI L., 1991. Prealpi bresciane a sud dell'Adamello: breve sintesi delle conoscenze geologiche e ulteriori temi di ricerca. In: *Attualità dell'opera di Arturo Cozzaglio nel 40° della scomparsa. Atti del Convegno Nazionale ottobre 1990, Ateneo di Brescia*, Brescia: 35-109.

CASSINIS G., TOUTIN-MORIN N. & VIRGILI C., 1995. A General Outline of the Permian Continental Basins in Southwestern Europe.

In: Scholle P.A., Peryt T.M. & Ulmer-Scholle D.S. (eds), *The Permian of Northern Pangea, 2, Sedimentary Basins and Economic Resources*, Springer-Verlag, Berlin: 137-157.

Cassinis G., Perotti C.R. & Venturini C., 1997. Examples of late Hercynian transtensional tectonics in the Southern Alps (Italy) In: Dickins J.M. (ed.), *Late Palaeozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation*, Cambridge Univ. Press, Cambridge: 41-50.

Cassinis G., Nicosia U., Ronchi A & Santi G., 2000. Impronte di tetrapodi nel Permiano orobico e loro implicazioni stratigrafiche. Nota preliminare. *Rend. Ist. Lomb. Acc. Sci. e Lett*, B, 132 (1998): 197-217.

Cassinis G., Nicosia U. & Pittau P. & Ronchi A., in press. Palaeontologic and radiometric data from the Permian deposits of the Southern Alps (Italy), and their stratigraphic implications. *Ass. Géol. du Permien, June 1999, Paris*, abstract vol.: 6-7.

Castellarin A., 1982. Lineamenti ancestrali sudalpini. In: Castellarin A. & Vai G.B. (a cura di), *Guida alla geologia del Sudalpino centro-orientale*. S.G.I., Guide Geol. Reg., Tecnoprint, Bologna: 41-55.

Castellarin A. & Sartori R., 1980. Struttura e significato della Linea delle Giudicarie Sud. *Rend. Soc. Geol. Ital.*, 2 (1979): 29-32.

Castellarin A. & Sartori R., 1983. Il sistema tettonico delle Giudicarie, della Val Trompia e del sottosuolo dell'alta pianura lombarda. *Mem. Soc. Geol. Ital.*, 26: 31-37.

Castellarin A. & Vai G.B., 1982. Introduzione alla geologia strutturale del Sudalpino. In: Castellarin A. & Vai G.B. (a cura di), *Guida alla geologia del Sudalpino centro-orientale*. Guide geol. reg., S.G.I., Tecnoprint, Bologna: 1-22.

Castellarin A. & Vai G.B., 1986. Southalpine versus Po Plain apenninic arcs. In: Wezel F.C. (ed.), *"The Origin of Arcs". Development in Geotectonics*, Elsevier, Amsterdam, 21: 253-280.

Castellarin A., Fesce A.M., Picotti V., Pini G.A., Prosser G., Sartori R., Selli L., Cantelli L. & Ricci R., 1987. Structural and kinematic analysis of the Giudicarie deformation belt. Implications for compressional tectonics of Southern Alps. *Mineral. Petrogr. Acta*, 30 (1986-1987): 287-310.

Cozzaglio A., 1894. Note esplicative sopra alcuni rilievi geologici in Valcamonica. *Giorn. Mineral. Cristallogr. Petrogr.*, 5: 21-43.

Del Moro A., Pardini G., Quercioli C., Villa I. & Callegari E., 1986. Rb/Sr and K/Ar chronology of Adamello granitoids, Southern Alps. *Mem. Soc. Geol. Ital.*, 26 (1983, Parte prima): 285-299.

Desio A., Boni A., Dal Piaz Gb., Bianchi A., Casati P., Assereto R., Comizzoli G., Passeri L.D., Cassinis G., Cerro A., Rossetti R., Accordi B., Dieni I., Malaroda R., Cevales G. & Morgante S. (1970) - Carta Geologica d'Italia alla scala 1:100.000 - Foglio 34 Breno, E.I.R.A., Firenze.

Doglioni C. & Bosellini A., 1987. Eoalpine and mesoalpine tectonics in the Southern Alps. *Geol. Rdsch.*, 76: 735-754.

Forcella F., 1981. Foglio 19 Tirano. In: Castellarin A. (ed.), *Carta tettonica delle Alpi Meridionali alla scala 1: 200000*. C.N.R. Prog. Final. Geodinamica, Sottopr. 5 "Modello Strutturale", Pubbl. n. 441: 166-173.

Italian IGCP 203 Group (Ed.), 1986. Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys. Field Guidebook. *Field Conf. SGI-IGCP Project 203, July 1986, Brescia (Italy)*, Tipolit. Comm. Pavese, Pavia: 180 pp.

Laubscher H.P., 1973. Alpen und Plattentektonik: das Problem der Bewegungsdiffusion und kompressiven Plattengrenzen. *Z. Deutsch. Geol. Ges.*, 124: 295-308.

Laubscher H. P., 1990. The problem of the deep structure of the Southern Alps: 3-D material balance considerations and regional consequences. *Tectonophysics*, 176: 103-121.

Ori G.G., Dalla S. & Cassinis G., 1988. Depositional history of the Permian continental sequence in the Val Trompia-Passo Croce Domini area (Brescian Alps, Italy) In: Cassinis G. (ed.), *Proceedings of the Field Conference on "Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys, and additional regional reports". (Brescia, 4-12 July 1986), Soc. Geol. It. - IGCP Proj. no 203*. Mem. Soc. Geol. It., 34 (1986): 141-154.

Origoni Giobbi E., Peyronel Pagliani G. & Zanchini Camerini R.M, 1979. Contributo alla conoscenza chimico-petrografica delle vulcaniti permiane affioranti tra la Val Trompia e le Valli Giudicarie. *Rend. Ital. Mineral. Petrol.*, 35: 277-298.

Perotti C.R. & Siletto G.B., 1996. Le caratteristiche geometriche dei bacini permiani tra la Val Camonica e la Val Giudicarie (Sudalpino Centrale). *Atti Ticin. Sci. Terra*, Pavia, ser. spec., 4: 77-86.

Peyronel-Pagliani G., 1965. Studio petrografico delle valcaniti della "Formazione di Collio" in alta V. Trompia (Brescia). *Rend. Ist. Lomb. Sci. Lett., Cl. Mat. Fis. Chim. Geol.*, 99: 148-174.

Peyronel-Pagliani G. & Clerici Risari E., 1973. Le ignimbriti paleozoiche costituenti la formazione "Vulcaniti di Auccia" (Permico bresciano) *Atti Ist. Geol. Univ. Pavia*, 23: 160-169.

Picotti V., Prosser G. & Castellarin A., 1995. Structures and Kinematics of the Giudicarie - Val Trompia Fold and Thrust Belt (Central Southern Alps, Northern Italy). *Mem. Sci. Geol.*, Padova, 47: 95-109.

Schiavinato G., Desio A., Bianchi A., Dal Piaz Gb., Montrasio A., Crespi R., Boriani A., Bonsignore G., Ragni U., Mottana A., Borgo A., Liborio G., Campiglio C., Comizzoli G., Passeri L.D., Dieni I., Pollini A., Proto Decima F., Sassi F., Zanettin B., Accordi B., De Vecchi Gp. & Morgante S., 1969. Carta Geologica d'Italia alla scala 1:100.000 - Foglio 19 Tirano, E.I.R.A., Firenze.

Trevisan L., 1938. Il fascio di fratture tra l'Adige e la Linea delle Giudicarie e i suoi rapporti col massiccio intrusivo dell'Adamello. Studi Trent. Sci. Nat., 29: 177-187.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 73-81

VOLCANISM AND ASSOCIATED SUB-LACUSTRINE CRYSTAL-RICH MASS-FLOW DEPOSITS IN THE EARLY PERMIAN COLLIO BASIN (ITALIAN ALPS)

Christoph BREITKREUZ [1-2], Giuseppe CASSINIS [3], Claudio CHECCHIA [2], Luciano CORTESOGNO [4] and Laura GAGGERO [4]

Key words – rhyodacite dome; phreatomagmatic explosion; turbidite; Permo-Carboniferous magmatism; post-Variscan.

Abstract – The Collio Basin is an intramontane continental basin developed as a consequence of post-Variscan orogenic collapse in southern Europe. Its evolution was controlled by extensional tectonics associated with calc-alkaline, intermediate and acidic magmatism.

Two episodes of ignimbrite-forming eruptions bracketed the development of the Collio Basin. During the intervening period, alluvial to lacustrine sedimentation was accompanied by episodic volcanism, recorded as fragments within sedimentary deposits, by syndepositional sills and dykes, massive acid laccoliths and domes with brecciated bases, and lastly, as volcaniclastic mass-flow deposits.

Immediately above the lower Collio Fm., several of these volcaniclastic mass-flows crop out in the central and eastern part of the basin; the most prominent are the Dasdana I Beds between the Trompia and the Caffaro valleys. These 10-20 m thick beds consist of: (1) amalgamated coarse-sandy to gravelly crystal-rich turbidites; and (2) a well-bedded sandy-pelitic unit rich in whitish lava fragments.

The volcaniclastic mass flows originated at the eastern margin of the basin from a porphyritic acid dome, presumably fragmented by phreatomagmatic explosions and/or seismic liquefaction. The metamorphic basement clastics and the high proportion of lacustrine pelitic fragments in the lower subunit indicate a (partially) intrusive position for the dome.

The sub-lacustrine/subaerial eruption column generated dense, crystal-rich turbidity currents.

Later, in a second phase, the foamy lava fragments sedimented from dilute turbidity currents, together with sandy-pelitic detritus, and from fall-out.

Parole chiave – duomo riodacitico; esplosione freatomagmatica; torbiditi; magmatismo permo-carbonifero; post-varisico.

Riassunto – Il Bacino di Collio in Val Trompia è un bacino continentale intramontano creatosi a seguito del collasso post-orogenico varisico nell'Europa meridionale. La sua evoluzione è controllata da una tettonica estensionale associata ad un magmatismo calc-alcalino intermedio e acido. Lo sviluppo del Bacino di Collio è scandito da due eventi ignimbritici basale e sommitale, ed è caratterizzato da una sedimentazione alluvio-lacustre alternata ai prodotti di un' attività vulcanica, che include clasti di questa natura all'interno di depositi sedimentari, *sill* e filoni sin-deposizionali, laccoliti e duomi acidi con basi brecciate, e torbiditi vulcanoclastiche. Quest'ultimi depositi si stagliano in un certo numero al di sopra della porzione inferiore della Formazione di Collio, che è di origine alluvio-lacustre, nella zona centro-orientale del bacino; il più significativo tra essi è quello affiorante sul M.te Dasdana ("Dasdana I Beds"), che dall'alta Val Trompia giunge fino in Val Caffaro. I "Dasdana I Beds" presentano in genere spessore tra 10 e 20 metri e sono formati da (1) una sotto-unità inferiore di torbiditi ricche in cristalli di taglia da grossolana a media, e (2) da una sotto-unità superiore arenaceo-pelitica ben stratificata, ricca in frammenti lavici di colore biancastro. Le torbiditi vulcanoclastiche si sono originate al margine est del bacino a seguito dell'esplosione freato-magmatica di un duomo acido di lava porfirica, unita possibilmente ad un fenomeno di liquefazione di origine sismica. I clasti di basamento metamorfico e l'alta percentuale di frammenti neri pelitici nella prima sotto-unità suggeriscono una posizione parzialmente intrusiva del duomo. La colonna di eruzione sub-lacustre/sub-aerea diede origine a correnti di torbidità dense (sotto-unità inferiore). Successivamente, i frammenti di pomici e di lave, anche a tessitura bollosa, furono sedimentati all'interno di correnti di torbidità più diluite, o si depositarono a seguito della precipitazione del "*fall-out*" (sotto-unità superiore).

INTRODUCTION

The Collio Basin in the Brescian Alps is one of the best-preserved intra-Variscan post-orogenic basins of southern Europe. The evolution of the Collio Basin occurred between 283±1 and 281±2 Ma (Schaltegger & Brack, 1999), *i.e.* during the Early Permian, and its dynamics included tectonism, sedimentation and volcanism (Cassinis, 1966;

[1] GeoForschungsZentrum Potsdam, Germany.
[2] Institut für Geologie, Geophysik und Geoinformatik, Freie Universität Berlin, Germany.
[3] Dipartimento di Scienze della Terra, Via Ferrata 1, I-27100, Pavia, Italy.
[4] Dipartimento per lo Studio del Territorio e delle sue Risorse, Università di Genova, Corso Europa 26, I-16132, Genova, Italy.

Ori *et al.*, 1988; Cassinis & Perotti, 1997). The Collio Basin presumably formed as a half-graben pull-apart structure within the framework of Late Paleozoic dextral transcurrent tectonics (Fig. 1).

The succession of volcanic events within the Collio Basin can be correlated with many intramontane troughs in southern Europe, such as those in Sardinia (Perdasdefogu, Escalaplano and Seui) and in the Ligurian Briançonnais. The timing of volcanism in relation to regional transtensional tectonics points to a Variscan post-collisional setting (Cortesogno *et al.*, 1998). The volcano-sedimentary deposition in the Collio Basin was bracketed in time by two episodes of ignimbrite-forming eruptions. The present contribution summarises recent research carried out in the (sub)volcanic units and major volcano-sedimentary mass-flow deposits intercalated within the alluvial-to-lacustrine sediments of the Collio Formation.

VOLCANIC ACTIVITY AND DEPOSITIONAL DEVELOPMENT IN THE COLLIO BASIN

The earliest volcanic activity is represented by subaerial emplacement of rhyolite ignimbrites directly on the Variscan basement, which in places was affected by pedogenic alteration. Volcaniclastic deposits are locally separated by decimetric tuffs with accretionary lapilli, indicating intermittent phreatomagmatic activity, and sandy to gravelly alluvial sediments. Grey to reddish-grey ignimbrite layers are homogeneous in composition, rich in pumice clasts and poorly welded; they extend far to the east, with a progressive increase in thickness (up to100 and more metres) westwards of the basin. This suggests a relatively flat paleotopography and probably a distal deposition from an extrabasinal source zone. The occurrence of andesite lava clasts within the ignimbrite indicates an earlier, intermediate volcanic activity.

Deposition of conglomeratic and arenitic alluvial fans intermittently followed, indicating progressive subsidence of the basin, triggering erosion along the margins. The common occurrence of rounded andesite clasts in the conglomerates suggests that the volcanic centres were localised at and near the eroded border of the Collio Basin. The subsequent depositional phase is represented by alluvial plain to lacustrine finer-grained clastics, and probably indicates a period of relative tectonic stability.

Rhyolite and rhyodacite laccoliths and domes were essentially emplaced along the southeastern margin of the basin (Malga Fontana, Dosso del Bue), probably related to basin-controlling fault activity.

Repeated phreatomagmatic explosions are indicated by: (i) breccias with rhyodacite clasts up to one metre in size underlying the dome structure; (ii) dome portions with subintrusive microtextures directly covered by tuffs, vesicular hyaloclastites and sediments; (iii) occurrence of thick tuffs with accretionary lapilli that probably represent surge deposits. Explosion of some porphyritic lava domes led to the formation of widespread sub-lacustrine mass-flow deposits (see below).

Towards the western development of the basin, distal deposits of the volcanic activity comprise green-blackish, highly fine silicified deposits (cinerites ?), characterised by laminar and convolute structures, locally interbedded with pelites rich in plants. Also, in places, late intermediate magmatic activity is recorded in the form of rare dykes.

The peak of the volcanic activity was followed by the second sedimentary cycle (upper Collio Fm.) characterised by prevailing arenitic layers, with frequent reworked, intermediate-to-acid volcanic clasts. Sedimentation within the basin ended with the deposition of con-

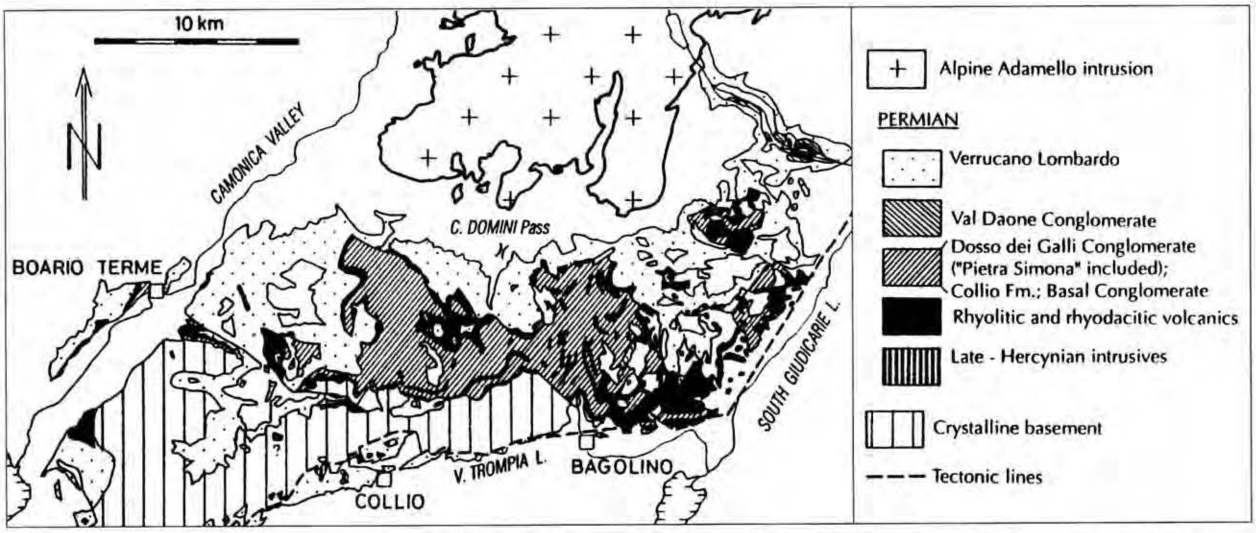


Fig. 1 – Location of the Early Permian continental Collio Basin between the Camonica and South Giudicarie Valleys, central Southern Alps.

glomerates rich in a hematite matrix (Dosso dei Galli Fm.).

Extended and thick (>100 m) subaerial ignimbrites (Auccia ignimbrite), characterised by a prevailing violet colour, abundant phenoclasts and eutaxitic *fiammae* and a strongly welded glassy matrix, covered the whole basin. Locally, a thin hydroxide-rich paleosol separates the top of the ignimbrite from the overlying Verrucano Lombardo fluvial clastics.

CHEMICAL FEATURES OF (SUB)VOLCANIC ROCKS AND OF THE DASDANA VOLCANICLASTIC MASS-FLOW

Chemical data on the magmatic rocks of the Collio Basin can be found in Peyronel-Pagliani (1965), Peyronel-Pagliani & Fagnani (1965), Peyronel-Pagliani & Clerici Risari (1973), Cassinis *et al.* (1975), Origoni *et al.* (1979), and Cortesogno *et al.* (1998).

The present data are addressed in order to compare the volcaniclastic mass-flows with the massive acid volcanic rocks in the basin. Samples of the volcaniclastic mass-flows were selected in order to avoid any sedimentary or basement components. The subvolcanic bodies occurring eastwards of the basin are dacitic to rhyolitic in composition. The analysed lithologies (Fig. 2A) included: (1) high-K dacite (possibly a complex laccolith) intruding pyroclastic deposits (Malga Fontana); (2) high-K dacite clasts in an explosive magmatic breccia covered by a rhyolite flow (Malga Scaie, east of the Dorizzo valley); and (3) five samples from rhyolite domes (Dosso dei Lupi, Rio Secco). The Malga Fontana intrusion and the Malga Scaie breccia are interpreted as dacite on the basis of mineral modes in the phenocryst assemblage, although they fall in the tra-

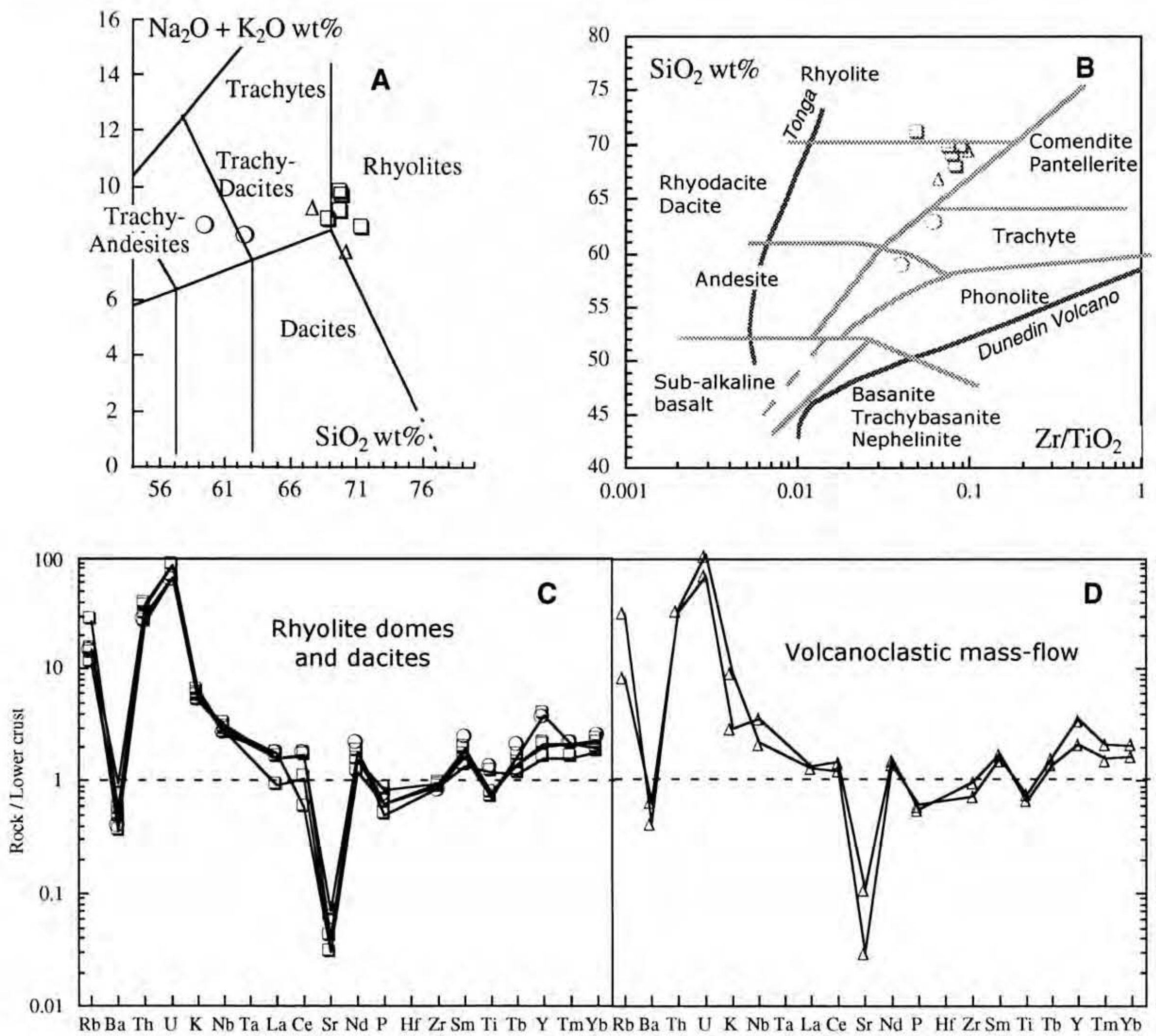


Fig. 2 – Chemical features of the volcaniclastic mass-flows in comparison with the dacites and rhyolites. A) Total alkali–silica classification (Le Maitre *et al.*, 1989) for dacites (○) rhyolites (□), and the Dasdana I Beds (△). B) $Zr/TiO_2 - SiO_2$ (Winchester & Floyd, 1977). Symbols as in A). C) Rock/lower crust normalised spidergrams (Weaver & Tarney, 1984) for dacites (○) rhyolites (□) and the Dasdana I Beds (△).

chyandesite-trachydacite field in Fig. 2A. They also differ from the probably younger dacite domes in having higher modal biotite. The marked differences between dacite samples, mostly in SiO_2 and Na_2O/K_2O ratio, are controlled by high porphyricity ($20 < P.I. < 35$) and by the irregular distribution of phenocrysts.

All lithologies show relatively high alkali contents ($Na_2O + K_2O$ in the range of 8-10 wt%). Affinity with the high-K transitional series is also consistent with the Zr/TiO_2 ratios (Fig. 2B). The relatively high CaO content in one of the mass flows (1.56 wt%) is related to the presence of carbonates in the matrix. Also, REE patterns (not reported) are homogeneous, with significant fractionation of LREEs, almost flat HREEs, and a weak negative Eu anomaly.

Lower-crust normalised spidergrams (Weaver & Tarney, 1984) for the dacites, rhyolites and volcaniclastic mass-flows (Fig. 2 C, D) are highly homogeneous, showing evident positive anomalies for LILEs except for Ba_N, being close to unity or slightly lower, and a marked negative anomaly for Sr_N. HFSEs show normalised values near to unity, with weak negative anomalies for Sm, Tm, Y and Yb. The volcaniclastic mass-flows strongly resemble the rhyolitic domes for major, trace and rare earth elements, pointing to a common origin. The slightly lower average silica and alkali contents could correspond to secondary enrichment in early crystallised phenocrysts, as a consequence of loss of floating glassy material.

THE SUB-LACUSTRINE VOLCANICLASTIC MASS-FLOW DEPOSITS: OCCURRENCE AND SEDIMENTOLOGY

The alluvial to lacustrine sequences of the Collio Fm. contain repeated intercalations of volcaniclastic mass-flow deposits, some of which cover a large part of the homonymous basin (Cassinis, 1988; Cassinis & Perotti, 1997). The slopes of the Val Caffaro, in the east of the Collio Basin, expose at least three of these crystal-rich competent units.

For its massive look and thickness, one of the most prominent is represented by the Dasdana I Beds, cropping out in the upper part of the lower Collio Fm. from Val Caffaro to M. Colombine (Fig. 3). The 10-20 m thick Dasdana I Beds consist of two subunits: (1) amalgamated coarse-sandy to gravelly crystal-rich turbidites; and (2) a well-bedded sandy-pelitic unit rich in whitish, frequently large, lava fragments (Plate 1, A-C). Both these units correspond to the old informal members "D" and "E" , respectively, which were introduced by Cassinis in 1966.

Detailed sedimentological sections, a representative selection of which is shown in Fig. 4, document the geometry and granulometric features of the Dasdana I Beds: the thickness of the lower subunit (1) increases from Mt. Colombine in the west to Val Caffaro in the east. The thickness of subunit (2) is almost constant; conversely, apparent changes occur in clast nature and in the clast/matrix ratio (see below). At the base of the Dasdana I Beds, soft sediment deformation results in decimetre to metre-scale load casts and balls of volcaniclastic material sunk into the substrate. In places, roughly E-W oriented channels occur at the base.

At Mt. Dasdana, mineralised danburite, tourmaline, ankerite, and trace gold-bearing layers in alternating millimetre to centimetre-scale laminae have been discovered in pelites a few metres just below the Dasdana I Beds. Generally, borate and boron silicates can form in evaporitic environments, and precipitation of less soluble boron

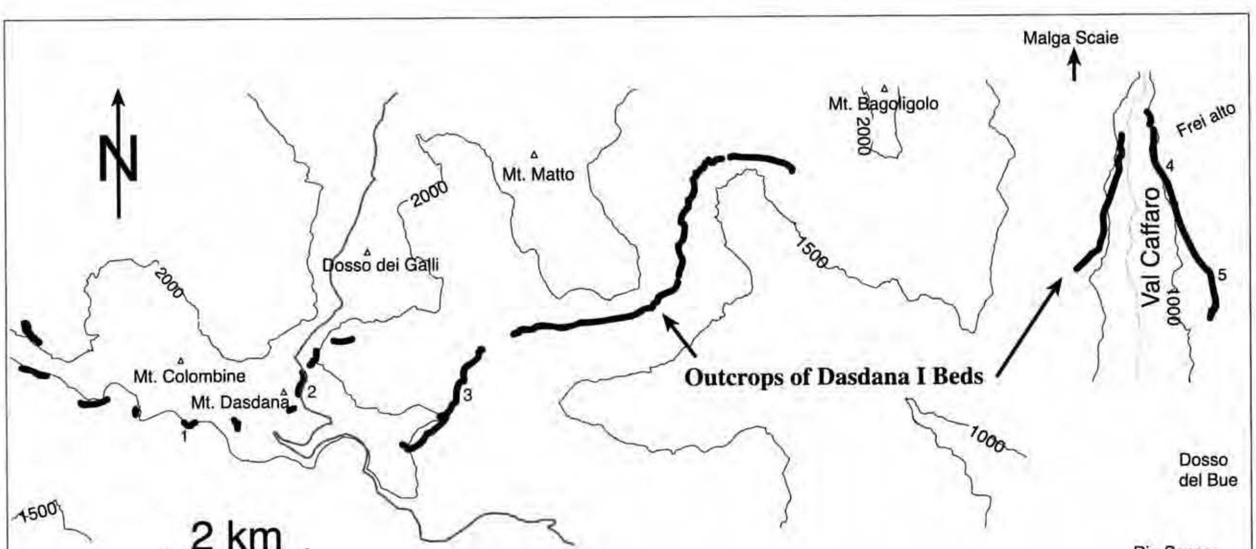


Fig. 3 – Outcrops of the Dasdana I Beds in the Collio Basin. Numbers indicate the sites of measured sections.

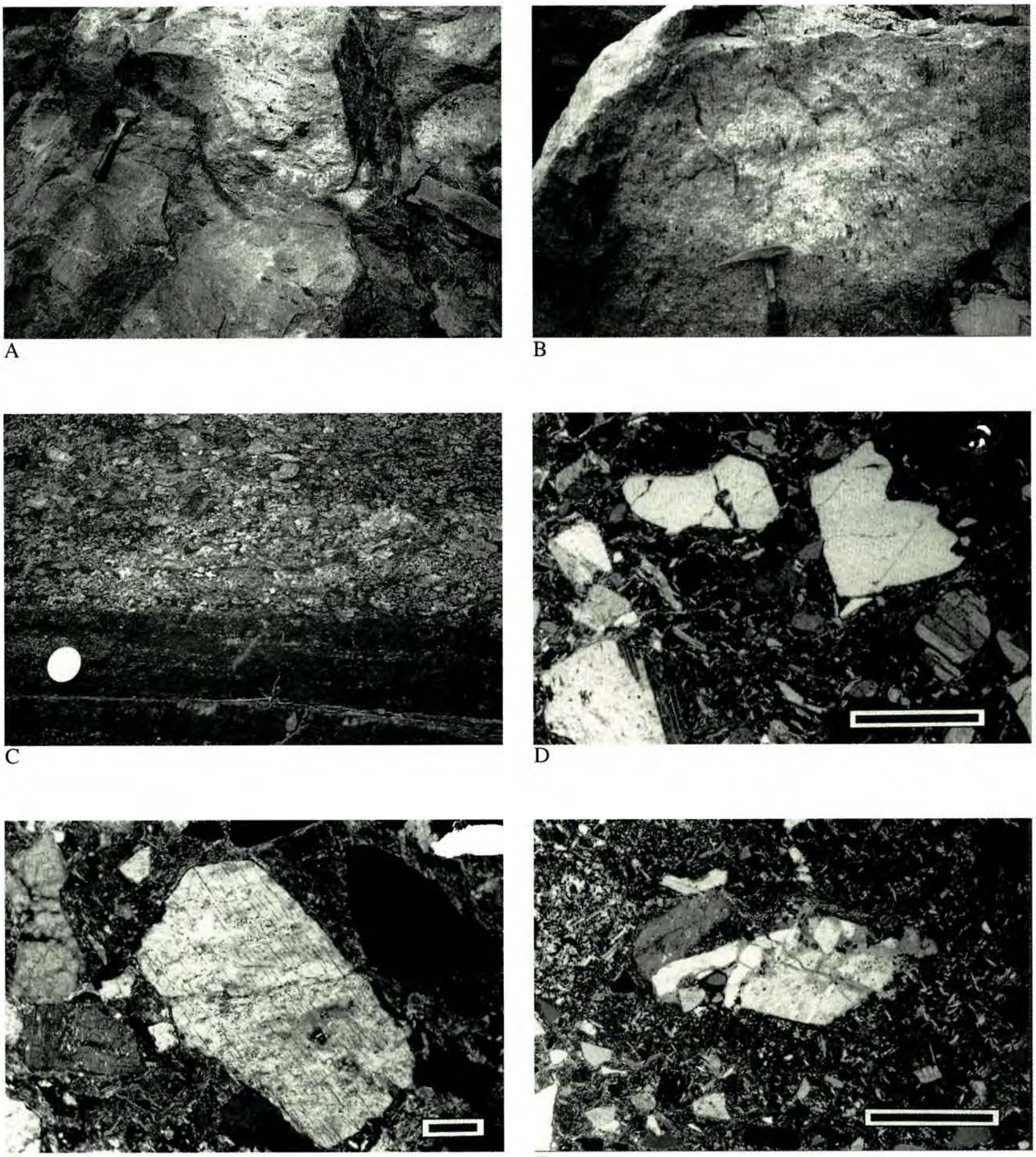


Plate 1

A. Field features of the Dasdana I Beds: erosional contact between the lower and upper subunits.

B. Lower subunit of the Dasdana I Beds including centimetre-scale clasts of prevailing andesitic and subordinate acidic volcanic rocks and metamorphic basement.

C. Upper subunit of the Dasdana I Beds: layer rich in porphyritic lava clasts.

D. Dasdana I Beds: microphotograph from the upper subunit, showing phenoclasts of volcanic quartz and plagioclase. Crossed polars, scale bar = 1 mm.

E. Dasdana I Beds: microphotograph from the upper subunit, showing a volcanic K-feldspar. The inner deformation of the phenoclast precedes its inclusion in the fine-grained matrix. Crossed polars, scale bar = 1 mm.

F. Dasdana I Beds: microphotograph from the upper subunit, showing a lava clast of felsitic dacite and a K-feldspar phenoclast in a matrix of neoblastic quartz. Crossed polars, scale bar = 1 mm.

silicates (danburite and tourmaline) instead of borate is favoured by high alkalinity. In most cases, occurrences of danburite are associated with volcanism, and the related hydrothermal activity provides the source for boron (Harder, 1959). Traces of danburite and tourmaline in the sediments exclude any post-diagenetic origin.

Subunit (1) of the Dasdana I Beds comprises light grey, amalgamated gravelly Bouma A (B) divisions. Faintly stratified Bouma B sequences occur in the form of discontinuous erosional remnants. Some of the 1-2 m thick Bouma A divisions start with darker grey matrix-rich deposits and have distinct bases showing erosional W-E oriented channels (Plate 1A). Black pelite (lacustrine Collio rip-ups) and various volcanic and metamorphic rocks occur as outsized clasts (up to metre-sized), isolated or concentrated in lenses. The modal composition of the lower subunit comprises fragments of plagioclase (20-30%), K-feldspar (7%), quartz (20%), biotite (3-10%), and por-

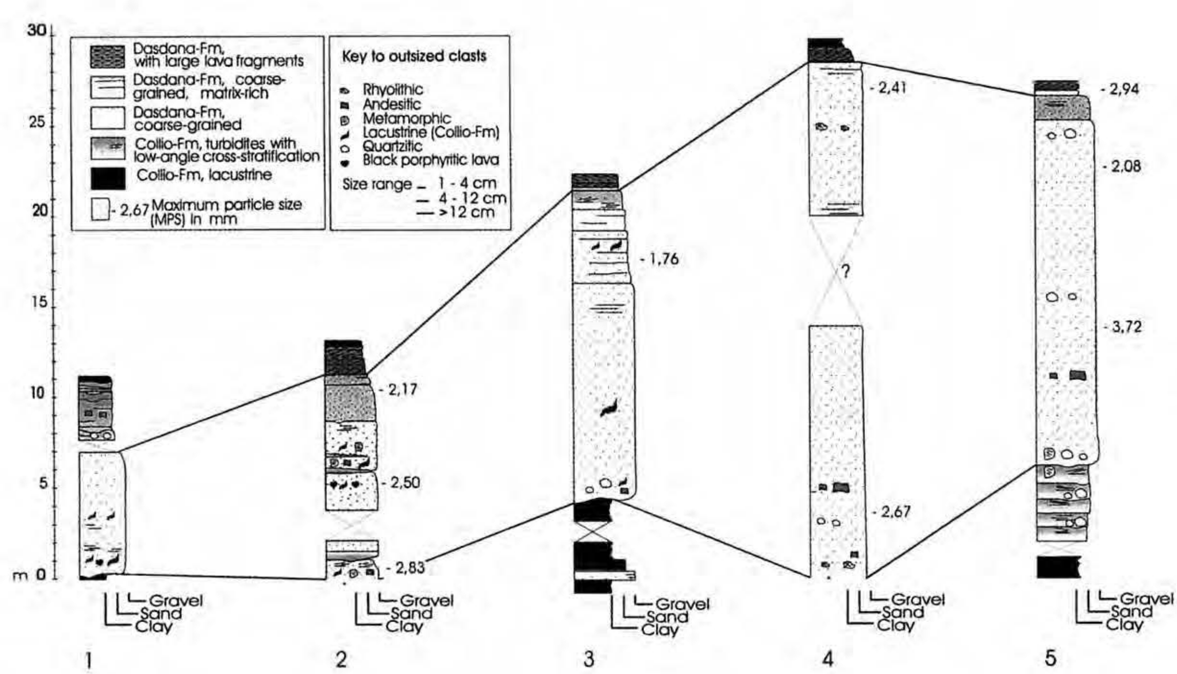


Fig. 4 – Representative sedimentological sections for the Dasdana I Beds.

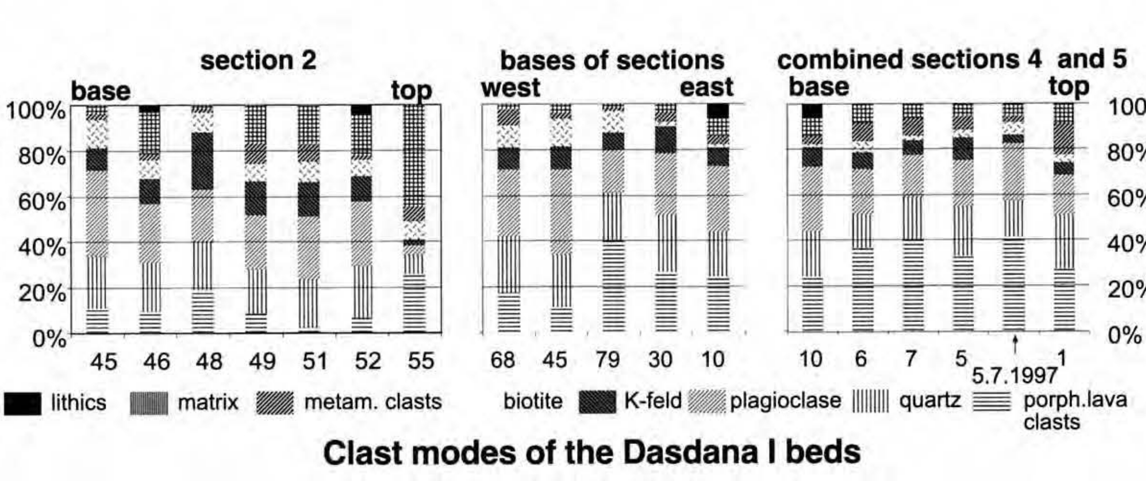


Fig. 5 – Modal composition of the Dasdana I Beds from thin-section point-counting.

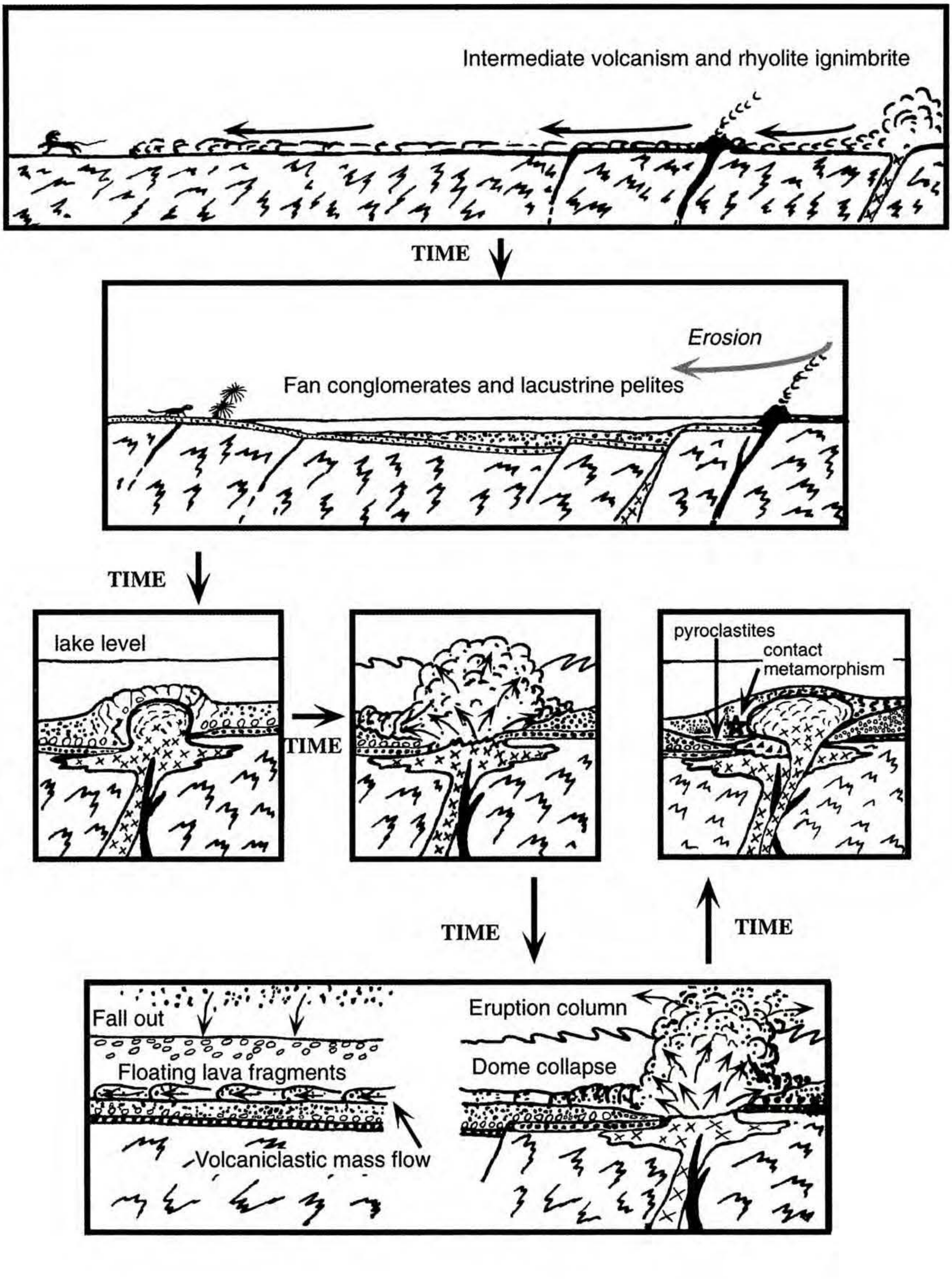


Fig. 6 – Highly idealised tectonic, sedimentary and magmatic evolution for the Collio Basin, inferred from local relationships.

phyritic rhyodacitic/rhyolitic lava (20-30%) as well as metamorphic basement clasts (5%, biotite, muscovite, garnet-bearing quartz mica-schist) and pelite clasts (Fig. 5). The lower Dasdana I Beds revealed some systematic proximal-distal trends such as a higher plagioclase and biotite content together with a diminishing unit thickness, maximum particle size and proportion of porhyritic lava fragments towards the W (Fig. 4).

The rhyodacitic-rhyolitic porphyritic lava clasts (Fig. 5) of the Dasdana I Beds resemble a single population displaying the same phenocryst assemblage (quartz, plagioclase, K-feldspar, biotite; Plate 1D, F) that is present as crystal fragments (in the mass-flow deposits). Predominantly the groundmass of the lava clasts consists of a micrographic mosaic of quartz and feldspar; subordinately, illite-chlorite groundmass occurs, produced by *in situ* alteration of glass. Uncompacted lava clasts with micrographic groundmass show irregular ragged to cauliflower shapes typical of the phreatomagmatic fragmentation of viscous magma. From these textures we infer that the lava fragments originated from a lava dome that was already cooling down, forming an outer glassy carapace and an inner crystallised core. Computer-aided image analyses indicate that the phenocryst content of the fragmented dome was of the order of 20%.

The upper subunit (2) of the Dasdana I Beds consists of well-bedded, partly turbiditic, sandy to pelitic deposits (Figs 4, 5), which contain varying amounts of gravel-sized, porphyritic, acidic lava fragments. The phenocryst assemblage within the lava fragments is similar to that present in the lower subunit; however, spindle to cauliflower shapes are dominant (Plate 1C). Where illite and/or chlorite replaced the groundmass of the fragments, strong compaction took place. In addition to clay minerals, quartz, albite and carbonate formed. These strongly compacted lava fragments presumably had a glassy groundmass during transport and deposition.

POSSIBLE SCENARIO FOR THE FORMATION OF THE LACUSTRINE VOLCANICLASTIC MASS-FLOW DEPOSITS

Striking features of the Dasdana I Beds and similar units of the Collio Fm. include the compositional homogeneity within a given unit, and the strong concentration of crystals in the thick, gravelly lower subunit. Comparing the content of crystals originating from the lava dome (in places more than 60%, Fig. 5) with the estimated crystallinity of the lava fragments (about 20%), strong fractionation between lava and crystal fragments during eruption and transport has to be considered. The groundmass textures found in the porphyritic lava fragments (from granophyric to (glomero)porphyritic, with felsitic poikilomosaic and spherulitic up to glassy mesostasis) indicate that the source for the mass flows was a texturally zoned lava dome, and not an erupting magma chamber. Thus we propose that the Dasdana I Beds and similar sub-lacustrine deposits of the Collio Basin formed as a consequence of phreatomagmatic explosions and/or seismic liquefaction of rhyodacite domes, which had already developed a textural zonation upon cooling. The common occurrence of fine to large fragments of metamorphic basement and of lacustrine pelite clasts suggests, at least for the Dasdana I Beds, an intrusive position for the cryptodome, presumably at the transition between the Variscan basement and the overlying Collio Fm. As a consequence of the liquefaction of the cryptodome, a sub-lacustrine/subaerial eruption column formed, from which pulses of dense, crystal-rich mass-flows originated, leading to the deposition of the Bouma A (B) units. In the first instance, much of the foamy lava remained in the column and sedimented later in a second phase, from dilute turbidity currents together with sandy-pelitic detritus, and from fall-out, forming the upper sandy-pelitic subunit rich in large lava fragments.

CONCLUSIONS

The subsiding half-graben of the Collio Basin was controlled by approximately N-S and E-W oriented faults that represented the main conduits for the ascent of magmas at its eastern marginal areas (Fig. 6). The magmas produced minor andesite effusions and rhyodacite laccoliths and domes, mostly emplaced at the basement-cover contact. Upon emplacement some of these lava domes and laccoliths were affected by fluidisation, perhaps triggered by earthquakes, which led to strong phreatomagmatic eruptions and to the formation of crystal-rich volcaniclastic mass-flow deposits. Similar crystal-rich volcaniclastic deposits have been reported from other Permo-Carboniferous basins in Europe, such as in the Pyrenees (Marti, 1996).

Acknowledgements – This work was carried out with CNR-Gruppo Alpi funds to L. Cortesogno, and with the Vigoni CRUI-DAAD 1999-2000 funds to C. Breitkreuz and L. Cortesogno. The fieldwork of G. Cassinis was supported by CNR and MURST (co-fin. 1998) grants. The authors are grateful to B. Bonin for his helpful comments on this paper.

REFERENCES

CASSINIS G., 1966. La Formazione di Collio nell'area tipo dell'alta Val Trompia (Permiano Inferiore bresciano). *Riv. Ital. Paleont. Stratigr.*, 72: 507-590.

CASSINIS G., 1988. Carta geologica dei depositi continentali permiani a Sud dell'Adamello. *Atti Ticin. Sci. Terra*, Pavia, 31 (1987-88): Tavola 1.

CASSINIS G. & PEROTTI C., 1997. Tectonics and sedimentation in the western sector of the Permian Continental Collio Basin, Southern Alps, Italy. In: *Proc. XIII Intern. Congr. on the Carboniferous and Permian*, 1995, Krakow, Poland, Part 2, Warszawa: 25-32.

CASSINIS G., ORIGONI G. & PEYRONEL-PAGLIANI G., 1975. Osservazioni geologiche e petrografiche sul Permiano della bassa Val Caffaro (Lombardia orientale). *Atti Ist. Geol. Univ. Pavia*, 25: 17-71.

CORTESOGNO L., CASSINIS G., DALLAGIOVANNA G., GAGGERO L., OGGIANO G., RONCHI A., SENO S. & VANOSSI M., 1998. The Variscan post-collisional volcanism in Late Carboniferous-Permian sequences of Ligurian Alps, Southern Alps and Sardinia: a synthesis. *Lithos*, 45 (1-4): 305-328.

HARDER H., 1959. Beitrag zur Geochemie des Bors. Teil I: Bor in Mineralen und magmatischen Gesteinen. Teil II: Bor in Sedimenten. *Nachdr. Akad. Wiss. Göttingen, II, Math.-Phys.*, I, 5: 67 pp.; II, 6: 123 pp.

LE MAITRE R.W., BATEMAN P., DUDEK A., KELLER J., LAMEYRE, J., LE BAS M.J., SABINE P.A., SCHMID R., SORENSEN H., STRECKEISEN A., WOLLEY A.R. & ZANETTIN B., 1989. *A classification of igneous rocks and glossary of terms*. Blackwell, Oxford: 193 pp.

MARTI J., 1996. Genesis of crystal-rich volcaniclastic facies in the Permian red Beds of the Central Pyrenees (NE Spain). *Sediment. Geol.*, 106: 1-19.

ORI G.G., DALLA S. & CASSINIS G., 1988. Depositional history of the Permian continental sequence in the Val Trompia – Passo Croce Domini area (Brescian Alps, Italy). In: Cassinis G. (ed.), *Proc. Field Conf. on "Permian and Permian Triassic boundary in the South Alpine segment of the Western Tethys, and additional regional reports"*. IGCP Proj. No. 203, Mem. Soc. Geol. Ital., 34 (1986): 141-154.

ORIGONI GIOBBI E., PEYRONEL-PAGLIANI G. & ZANCHINI-CAMERINI R.M., 1979. Contributo alla conoscenza chimico-petrografica delle vulcaniti permiane affioranti tra la Val Trompia e le Valli Giudicarie. *Rend. Ital. Mineral. Petrol.*, 35: 277-298.

PEYRONEL-PAGLIANI G., 1965. Studio petrografico delle vulcaniti della "Formazione del Collio" in alta Val Trompia (Brescia). *Rend. Ist. Lomb. Sci. Lett.*, Cl. Mat. Fis. Chim. Geol., 99: 148-174.

PEYRONEL-PAGLIANI G. & CLERICI RISARI E., 1973. Le ignimbriti paleozoiche costituenti la formazione "Vulcaniti di Auccia" (Permico Bresciano). *Atti Ist. Geol. Univ. Pavia*, 23: 160-169.

PEYRONEL-PAGLIANI G. & FAGNANI G., 1965. Tufi con glauconite nell'Alta Val Trompia (Brescia). *Rend. Soc. Mineral. Ital.*, a. 21: 247-255.

SCHALTEGGER U. & BRACK P., 1999. Short lived events of extension and volcanism in the Lower Permian of the Southern Alps (Northern Italy, Southern Switzerland). *EUG '99*, DO2:4A/02:F1: 296-297.

WEAVER B & TARNEY J., 1984. Empirical approach to estimating the composition of the continental crust. *Nature*, 310: 575-657.

WINCHESTER J.A. & FLOYD P.A., 1977. Geochemical differentiation of different magma series and their differentiation products using immobile elements. *Chem. Geol.*, 20: 325-343.

NEW PALAEONTOLOGICAL DATA FOR THE VAL GARDENA SANDSTONE

UMBERTO NICOSIA [1], EVA SACCHI [2] and MARCO SPEZZAMONTE [3]

Key words – ichnology; northern Italy; Permian; tetrapod footprints; biochronology.

Abstract – A new find of tetrapod footprints – *Rhynchosauroides* sp. cfr. *R. palmatus* (Lull, 1942) – from the lowermost portion of the Val Gardena Sandstone allowed us to improve our knowledge of the stratigraphy of this formation.
The section, from which the new material comes, was studied at various times from both the sedimentological and the paleontological point of view. It was subdivided into five (and a lower part of a sixth) third-order depositional cycles. The very rich paleontological data (ichnofossils and sporomorphs) and some peculiar depositional characteristics (interfingering and overlying marine layers, a clearly exposed P/T boundary) made the section optimal for stratigraphical purposes. Unfortunately botanical and ichnological data allowed good results only for the upper cycles, while the data from the first cycle were not completely satisfactory.
The new find, from within 20 m of the underlying volcanics, ultimately solved that problem, allowing us to ascribe the whole sequence to a very short depositional time interval.

Parole chiave – icnologia; Italia settentrionale; Permiano; impronte di tetrapodi; biocromologia.

Riassunto – Viene segnalato il ritrovamento di una icnofauna con *Rhynchosauroides* sp. cfr. *R. palmatus* (Lull, 1942) nella parte inferiore delle Arenarie di Val Gardena, nella sezione del Bletterbach (Bolzano). Il nuovo ritrovamento ha permesso di chiarire la stratigrafia di questa formazione.
La sezione da cui proviene il nuovo materiale è stata studiata a più riprese sia dal punto di vista sedimentologico che paleontologico. I dati paleontologici (icnofossili e sporomorfi) e le caratteristiche deposizionali (livelli marini intercalati e a copertura, ottimo affioramento del limite P/Tr) ne fanno una splendida sezione per la stratigrafia del Permiano superiore. La sezione comprende cinque cicli deposizionali di terzo ordine e la parte inferiore di un sesto ciclo; sfortunatamente i dati icnologici e paleobotanici davano buoni risultati soltanto per i cicli superiori mentre non erano soddisfacenti per il I ciclo. La nuova faunula, proveniente da un livello posto a meno di venti metri dalle vulcaniti del substrato e proprio da sedimenti del I ciclo, permette di risolvere il problema e di attribuire l'intera sequenza ad un breve intervallo di tempo.

GEOLOGICAL SETTING

A new find of tetrapod footprints from the lowermost portion of the Val Gardena Sandstone has allowed us to improve the biochronological calibration of that formation and to eliminate a large degree of uncertainty from previously known data on stratigraphy of Permian deposits in the alpine region. The Permian rocks cropping out in the central and eastern Alps are traditionally subdivided into two major tectonostratigraphic complexes or cycles (Italian IGCP 206 Group, 1986), the first (pre-Permian-Lower Permian) composed of a complex of volcanic, sedimentary and volcano-sedimentary rocks, the second (Upper Permian) of clastics and calcareous rocks. The two complexes are separated by a regional unconformity.

The Upper Permian cycle is in its turn mainly composed of siliciclastic sediments deposited in environments related to braided river plains and deltas, and by carbonate limestone laid down in a clearly marine environment. The former are ascribed to the Val Gardena Sandstone (VGS), and the latter the Bellerophon Fm. The upper boundary of the Bellerophon Fm. Finds is the sharp contact with the Tesero Mb., the first member of the overlying Lower Triassic Werfen Fm.; at that contact is traditionally located the P/T boundary (Assereto *et al.*, 1973).

As a whole the Permian deposits form a transgressive sequence. They were subdivided into minor cycles: originally into three third-order sedimentary cycles (Massari *et al.*, 1988), and then subsequently into five and a lower part of a sixth (Massari *et al.*, 1994). Moreover, the VGS was dated using scattered marine elements in its upper part (Neri *et al.*, 1994), and by means of sporomorph assem-

[1] Dipartimento di Scienze della Terra, Università "La Sapienza", P.le A.Moro 5, 00185 Roma, Italy.
[2] Via Trevi 163, 05100 Terni, Italy.
[3] San Polo 2018, 30125 Venezia, Italy.

blages and tetrapod footprints (Conti *et al.*, 1977; Ceoloni *et al.*, 1988; Massari *et al.*, 1988, 1994). The presence of a magnetic reversal recognised as the Illawarra Reversal Event (Mauritsch & Becke, 1983) constrained the lower boundary.

The outcrop from which the new find comes is the most famous Permian track-site of northern Italy; the section is located along the Bletterbach near Redagno (Aldein, Bozen, Italy) (Fig. 1). It was studied at various times both from the sedimentological (Massari *et al.*, 1988, 1994) and the palaeontological point of view (for a historical review, see Blieck *et al.*, 1995, 1997). Subsequently, footprints from the same outcrop have been used as a database to establish a faunal unit and the corresponding faunal age (Conti *et al.*, 1997), obviously named after the section as the Bletterbach Faunal Unit and the Bletterbach Faunal Age. The chronostratigraphic boundaries of the faunal unit were constrained, by the assumed Illawarra Reversal Event at the base, and by the Fungi Blooming Event at the top, to an interval ranging from the Midian (*p.p.*) to Late Djulfian (Conti *et al.*, 1997).

The very rich paleontological data (ichnofossils and sporomorphs) and some peculiar depositional characteristics (interfingering and overlying marine layers, and the clearly exposed P/T boundary) make the section optimal for the stratigraphical purposes. Only the paleontological data from the sediments pertaining to the first third-order cycle were not completely satisfactory. Footprints were lacking from the first 60 m of the section, and sporomorphs were too poorly preserved within the same interval. The new find, from within 20 m of meters the underlying volcanics, has solved that problem, allowing us to progress with the stratigraphy.

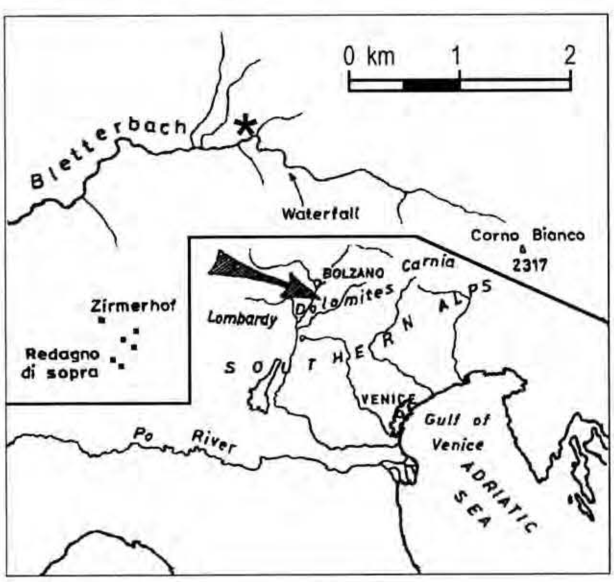


Fig. 1 – Location of the Bletterbach section; the asterisk shows the exact location of the new find.

TETRAPOD FOOTPRINTS

The VGS and the Bellerophon Fm. were subdivided into cycles, and the same cycles were recognised along other sections over the whole southern Alpine region. All the examined sections show the same vertical organisation (Massari *et al.*, 1988, 1994). In the Bletterbach Gorge the upper boundary of the first cycle was set at around 74 m from the base in Massari *et al.* (1988), and at 29 m in Massari *et al.* (1994). Up to that time, no footprints had been found within the first 60 m of the succession. The new footprints were found along a lateral channel of the Bletterbach, imprinted on a small surface 13 m above the lower boundary between sandstone and the underlying volcanics (Fig. 2).

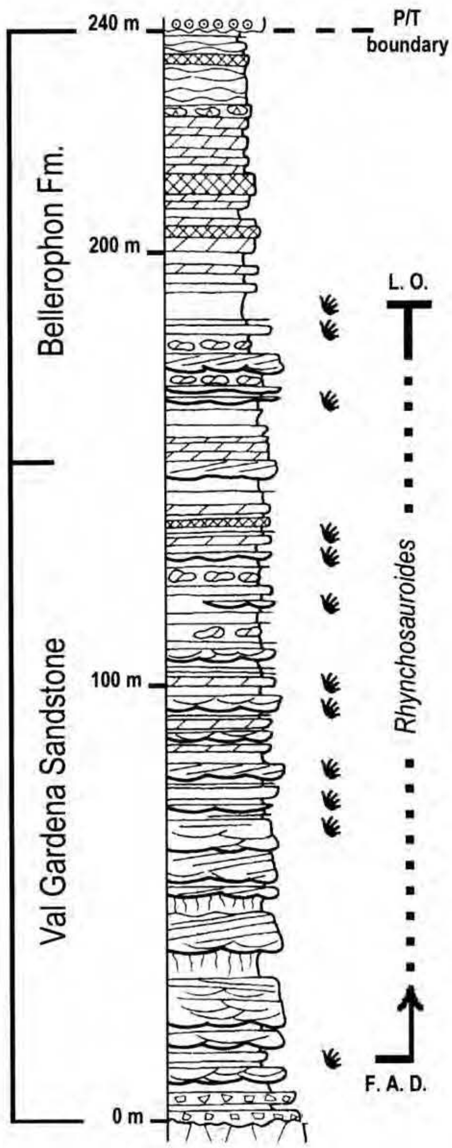


Fig. 2 – Simplified stratigraphic column of the section; the *Rhynchosauroides* F. A. D. arrow points to the new ichnological level.

The first part of the formation is composed of coarse to medium sandstone, reddish-purple in colour, poorly cemented, poorly sorted and rich in porphyric pebble. Deposits are upward-fining, passing to medium-grained arenites, structureless and poorly cemented. The imprinted surface, about 160 by 80 cm in size, was found within a better cemented medium-grained arenitic body, with some small subspherical cavitie, probably due to the dissolution of gypsum nodules. The rock unit containing the new find is less than one metre thick and extends laterally only for some tens of metres. Below and above there are numerous levels with gypsum nodules, and others with pedogenetic structures like calcrete, colour mottling and deep dessication cracks.

At 15 m from the base the situation changes abruptly, thanks to the presence of a cross-laminated, coarse-grained arenitic body with an erosional base. This is the first of the frequent channelised bodies that one can find going up-section.

According to Massari *et al.* (1988), such parts of the section "may represent the distal part of a semiarid alluvial fan, locally merging into an inland sabkha where high evaporation rates may have caused precipitation of sulphates in the capillary fringe above the water table". The same depositional environment is confirmed by Massari *et al.* (1994): "the deposits may record sedimentation on "flashy alluvial" fans typical of semi-arid areas".

Surface analysis

The poor condition of the exposure (the surface is periodically flooded and covered by large amounts of debris) and the risk of destruction of the specimen by weathering, compelled us to make a plastercast. The first time we moulded the natural casts, they were subsequently lost be-

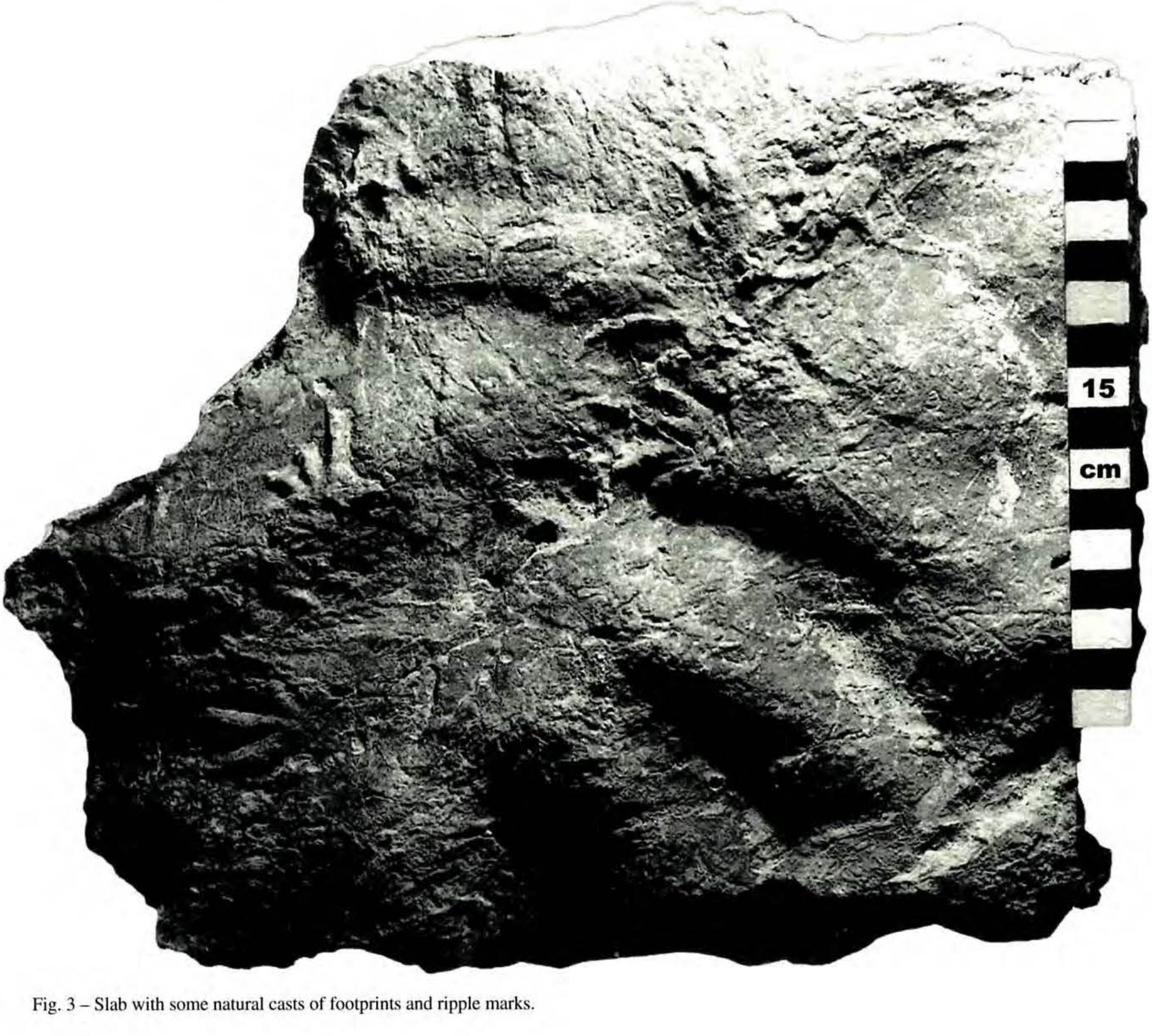


Fig. 3 – Slab with some natural casts of footprints and ripple marks.

cause they were imprinted on a thin, uncemented clay cover. A few months later, with a more specific technique, it was possible to mould the corresponding underprints, still in place. In both cases we moulded the most footprint-rich portion of the surface, about 80 by 60 cm in size. Thus we have studied the original surface and some isolated natural casts (Fig. 3), a plastercast of the prints and another of the underprints.

The track-bearing surface is subdivided into two parts, the first flat and the second covered by ripple marks. The ripples are asymmetric and irregular, showing discontinuous and sinuous crests. The distance between crests ranges between 5 and 8 cm and their maximum height varies between 1,5 and 3 cm. Such bottom structures were probably made by unidirectional, low-intensity currents in very shallow waters.

The ripple crests are marked by some slight impressed and discontinuous groove marks, probably made by drifting plant fragments. Neither the footprint bearing bed, nor the few overlying layers show any internal structures.

Systematics

The material consists of nearly 30 footprints, ascribed to the ichnogenus *Rhynchosauroides* Maidwell, 1911. Some of them are preserved as natural casts, others as prints and underprints. Sometimes we have prints and reverse moulds of the same footprints. The material includes impressions of somewhat unclear trackways, as well as well-preserved isolated footprints and sets (Fig. 4). Because of the rich sample the analysis of extramorphologies has yielded clear results. As already mentioned, the footprints are quite irregular but, in some cases, extremely well-preserved. The greater irregularities seem to involve digit divergences. This extramorphology is more characteristic of lacertoid reptile footprints, and is frequently recognised when footprints were impressed on very plastic ground. It seems connected to be related to the greater equilibrium and stability of the track-maker.

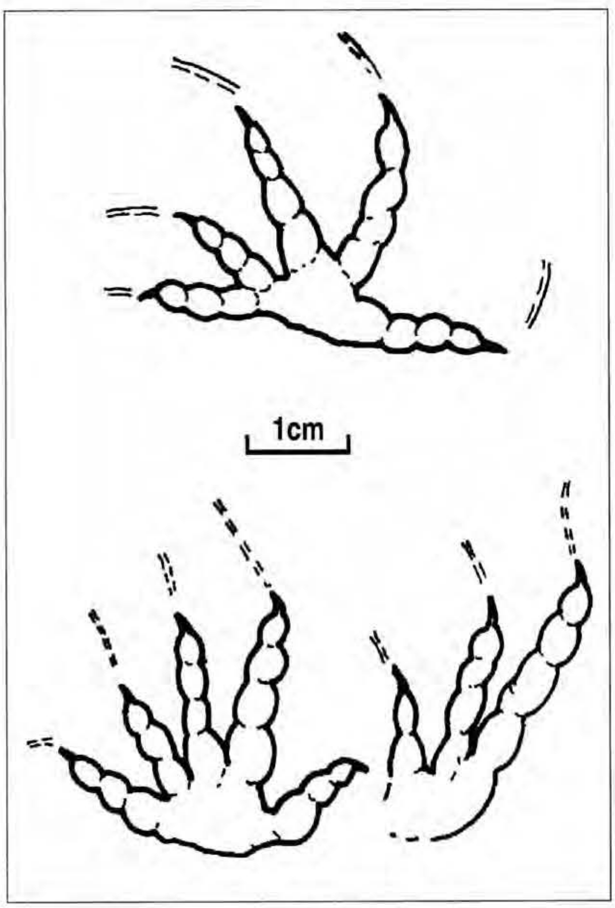


Fig. 4 – Drawing of a single manus and of a set of footprints from the new surface.

Ichnogenus *Rhynchosauroides* Maidwell, 1911
(type species: *R. palmatus* (Lull, 1942))

DESCRIPTION: quadruped lacertoid footprints, ectaxonic, asymmetric. Digit length increases from I to IV, V is strongly abducted and is as long as the I digit. Digits of *manus* are more or less curved inward, with the exception of digit V which forms an angle of about 60° with digit IV. The *pes* is slightly larger than the *manus* and shows a less rounded outline; *pes* digits are less curved. *Manus* often superimposing *pes* and sometimes surpassing it.

Even if showing functional prevalence especially on digits III and IV, it can be defined as semi-plantigrad showing the consistently clear proximal attachment of the metapodial-phalangeal pads and often the posterior edge of the sole.

OCCURRENCE: the genus is characteristic of the European Lower Triassic but was already used for some forms present in Permian VGS, from levels well above the one presently described (Conti *et al.*, 1977). The new finding can thus be considered as the first appearance datum level of the ichnogenus.

Rhynchosauroides cfr. *R. palmatus* (Lull, 1942)

MATERIAL: Seventeen isolated natural casts and two surface plaster casts, one with prints and another with underprints. On the plasters are preserved two trackways and some isolated footprints.

DEPOSITORY: footprints will be preserved in the Geological Section of the Museumsverein Aldein, at the school of Radein/Redagno (Bozen/Bolzano, South Tirol, Italy). Plaster casts of the surface are preserved at the same depository and at the Museum of Palaeontology of the Dipartimento di Scienze della Terra of the University "La Sapienza" of Rome.

DESCRIPTION: Trackway: Trackways are irregular due to environmental conditions and to the footprint-bearing bed geometry. In fact the surface shows a series of irregular ripples, and the footprints are imprinted both on the crests and within the troughs. The track-maker digits, quite vertically mobile, left footprints of similar shape while the dimensions, the relative distances and the digit divergences are very variable, depending on the ground characteristics. In the troughs, footprints are more deeply impressed, even if expulsion borders and displaced mud render the impression less clear; moreover *manus* and *pes* are often overprinted.

REMARKS: footprints closely similar to the new find were previously collected from some layers up-section. Apart from small differences in preservation, the new find shows the same size interval and the same evolutionary level as the previously discovered material and can be ascribed to the same ichnotaxon (compare specimen with collection number 75/10 in Conti *et al.* (1977, p.31).

Biochronological meaning

The new find, showing a very characteristic ichnospecies, also present in the upper portion of the sequence, enables us to ascribe the new footprints to the same faunal unit established for the higher layers (Bletterbach Faunal Unit in Conti *et al.*, 1997). It allows inclusion of the whole sediment thickness to a consistent biochronological unit (Bletterbach Faunal Age in Conti *et al.*, 1997).

CONCLUSIONS

The new finds can be ascribed to the very particular faunal association present in the upper levels of the section, on this basis we can ascribe the VGS cropping out in the Bletterbach section to a very short time interval. Such an interval can be coarsely calibrated on the basis of the rate of evolution of reptiles and the age of the last volcanics, at the base, and Late Permian marine fossils and sporomorphs at the top; it ranges between 260 and 251 Ma BP (Cassinis *et al.*, in press). This datum also brings forward to the age of the base of the VGS in the section, thus enlarging the time gap corresponding to the basal unconformity (Cassinis *et al.*, in press).

Previous studies on the same outcrop showed the presence of third-order sedimentary cycles. All but the first of them were ascribed to the same faunal unit, characterised by Late Permian ichnotaxa (Bletterbach Faunal Unit in Conti *et al.*, 1997). The lowermost cycle age remained a mystery, due to the lack of tetrapod footprints and to the presence of a sporomorph association with low stratigraphical meaning. Moreover, correlation among the third-order cycles shows the presence of the same first cycle in all the sections examined by Massari *et al.* (1994), and allows us to extend the conclusions valid for the Bletterbach section to the whole southern Alpine region. Consequently the age of the VGS can be limited to the same short time interval over the whole Alpine region. This raises strong doubts over the coincidence between the Illawarra Reversal Event and the magnetic reversal recognised by Mauritsch & Becke (1983) at the Paularo section in the Carnic Alps (Venturini, 1986).

Acknowledgments – We wish to thank Profs. Francesco Massari and Giuseppe Cassinis for their helpful comments.

REFERENCES

ASSERETO R., BOSELLINI A., FANTINI SESTINI N. & SWEET W. C., 1973. The Permian-Triassic boundary in the Southern Alps (Italy). *Mem. Canad. Soc. Petroleum Geol.*, 2: 176-199.

BLIECK A. with contributions of CONTI M. A., FLÜGEL H. W., GAND G., LELIEVRE H., MARIOTTI N., NICOSIA U., POPLIN C., SCHNEIDER J. W. & WERNEBURG R., 1995. The Alps, a quasi-desert in Palaeozoic vertebrate database, and the Gondwana-Laureuropa palaeogeographic relationships. *Ichth. Iss.*, Brisbane, 15: 8-13.

BLIECK A., CONTI M. A., DALLA VECCHIA F. M., FLÜGEL H. W., GAND G., HUBMANN B., LELIEVRE H., MARIOTTI N., NICOSIA U., POPLIN C., SCHNEIDER J. W. & WERNEBURG R., 1997. Palaeozoic vertebrates of the Alps: a review. *Bull. Soc. Géol. France*, 168 (3): 343-350.

CASSINIS G., NICOSIA U., PITTAU P. & RONCHI A., in press. Palaeontologic and radiometric data from the Permian deposits of the Southern Alps (Italy) and their stratigraphic implications. *14th thematic day of the AGP, June18, 1999, Paris.*

CEOLONI P., CONTI M.A., MARIOTTI N. & NICOSIA U., 1988. New Late Permian tetrapod footprints from the Southern Alps. In: Cassinis G. (ed.), Proc. Field Conf. on: *Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys, and additional regional reports*. Brescia, 4-12 July 1986. Mem. Soc. Geol. Ital., 34 (1986): 45-65.

CONTI M. A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1977. Tetrapod footprints of the "Val Gardena Sandstone" (North Italy). Their paleontological, stratigraphic and paleoenvironmental meaning. *Palaeontographia Ital.*, N.S., 40: 1-91.

CONTI M. A., MARIOTTI N., NICOSIA U. & PITTAU P., 1997. Selected bioevents succession in the continental Permian of the Southern Alps (Italy): improvements of intrabasinal and interregional correlations. In: Dickins J. M., Yang Z.Y., Yin H.F., Lucas S. G. & Acharyya S. J. (eds), *Late Palaeozoic and Early Mesozoic circum-Pacific events and their global correlation*. Cambridge Univ. Press: 51-65.

ITALIAN IGCP 203 GROUP, 1986 (ed.). Field Conf on: *Permian and Permian-Triassic Boundary in the South-Alpine Segment of the Western Tethys. Field Guide-Book. Brescia, July 1986*. Tipolitogr. Comm. Pavese, Pavia, 180 pp.

MASSARI F., CONTI M.A., FONTANA D., HELMOLD K., MARIOTTI N.,

NERI C., NICOSIA U., ORI G.G., PASINI M. & PITTAU P., 1988. The Val Gardena Sandstone and *Bellerophon* Formation in the Bletterbach Gorge (Alto Adige, Italy): biostratigraphy and sedimentology. *Mem. Sci. Geol.*, Padova, 40: 229-273.

MASSARI F., NERI C., PITTAU P., FONTANA D. & STEFANI C., 1994. Sedimentology, palynostratigraphy and sequence stratigraphy of a continental to shallow-marine rift-related succession: Upper Permian of the eastern Southern Alps (Italy). *Mem. Sci. Geol.*, Padova, 46: 119-243.

MAURITSCH H. J. & BECKE M., 1983. A magnetostratigraphic profile in the Permian (Gröden beds, Val Gardena Formation) of the Southern Alps near Paularo. *Newsletter*: 80-86.

NERI C., MASSARI F., CONTI M. A., MARIOTTI N., NICOSIA U. & PITTAU P., 1994. Permian stratigraphy in the Southern Alps (Italy): new contributions. *Permophiles*, 25: 25-33.

VENTURINI C., 1986. Permian red beds of the Val Gardena Sandstone in the Carnic Alps. In: Italian IGCP 203 Group (ed.), *Field Guide-Book of Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys. Brescia, July 1986.* Tipolit. Comm. Pavese, Pavia: 59-65.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 89-107

PERMIAN AND TRIASSIC TETRAPOD ICHNOFAUNAL UNITS OF NORTHERN ITALY: THEIR POTENTIAL CONTRIBUTION TO CONTINENTAL BIOCHRONOLOGY

MARCO AVANZINI [1], PAOLA CEOLONI [2], MARIA ALESSANDRA CONTI [3], GIUSEPPE LEONARDI [4], RICCARDO MANNI [3], NINO MARIOTTI [3], PAOLO MIETTO [5], CRISTINA MURARO [6], UMBERTO NICOSIA [3], EVA SACCHI [7], GIUSEPPE SANTI [8] and MARCO SPEZZAMONTE [9]

Key words – stratigraphy; biochronology; ichnology; reptiles; Permian; Triassic; Northern Italy.

Abstract – After theoretical analyses on the application of the main stratigraphic methods to continental deposits, we carried out a feasibility analysis to assess the ages of Permian and Triassic continental sediments by means of tetrapod footprints.
The data mainly originate from the Central and Southern Alps. The paleogeography of the Alpine region during Permian and Triassic times gave rise to a unique geological situation and well-exposed sections in which marine sediments, continental deposits rich in footprints and volcanic rocks are interfingered. The resulting mixed sections enable us to build a framework of biostratigraphical and chronological data in which tetrapod footprint-based evolutionary groups can be considered as biochronological units.
Such units (*Land Ichnofaunal Units*) and the corresponding biochronological units (*Land Ichnofaunal Ages*), still to be formalised, seem to reveal some advantages with respect to other dating systems.

Parole chiave – stratigrafia; biocronologia; icnologia; rettili; Permiano; Triassico, Italia Settentrionale.

Riassunto – L'applicabilità dei più diffusi e tradizionali metodi stratigrafici ai depositi continentali lascia molto dubbiosi. Di conseguenza è stata portata a termine l'analisi di fattibilità sulla possibilità di utilizzare le orme di tetrapodi per definire le età dei sedimenti continentali del Permiano e del Triassico. La base-dati utilizzata è stata raccolta dalle Alpi Centrali e Meridionali.
La paleogeografia del Permiano e del Triassico in tali regioni determinò una situazione geologica particolare e sezioni, ben esposte, nelle quali si intercalano sedimenti continentali a impronte di tetrapodi, vulcaniti e livelli marini. Le sezioni miste che risultano da questa situazione ci hanno permesso di costruire una maglia di dati cronologici e biostratigrafici nella quale insiemi evolutivi basati sulle orme di tetrapodi (*Land Ichnofaunal Units*) possono essere considerati come unità biocronologiche (*Land Ichnofaunal Ages*). Tali unità, ancora da formalizzare, sembrano rivelare parecchi vantaggi rispetto agli altri sistemi di scansione dei fenomeni geologici nei sedimenti continentali.

INDEX

[1] Museo Tridentino di Scienze Naturali, v. Calepina 14, 38100 Trento, Italy.
[2] V. Pestalozzi 24, 00168 Roma, Italy.
[3] Dipartimento di Scienze della Terra, Università "La Sapienza", P.le A. Moro 5, 00185, Roma, Italy.
[4] V. A. Modigliani 2, 80070 Monterusciello, Italy.
[5] Dipartimento di Geologia, Paleontologia e Geofisica, Università degli Studi, v. Giotto 1, 35137 Padova, Italy.
[6] V. Ninfa 15, 04100 Latina, Italy.
[7] V. Trevi 163, 05100 Terni, Italy.
[8] Dipartimento di Scienze della Terra, Università degli Studi, v. Ferrata 1, 27100 Pavia, Italy.
[9] San Polo 2018, 30125 Venezia, Italy.

INTRODUCTION

Over the last 30 years the authors have studied Permian and Triassic tetrapod footprints in the Southern and Central Alps (see bibliography). After the first, mainly systematic studies (Leonardi & Nicosia, 1973; Conti *et al.*, 1977, 1991, 2000; Ceoloni *et al.*, 1988b; Mietto, 1981, 1987; Santi, 1992 and in press; Avanzini & Neri, 1998; Leonardi, 2000; Avanzini, in press), some attempts were made to assess the age of track-bearing continental dep osits using different methods. Some of us (Conti *et al.*, 1979, 1989; Neri *et al.*, 1994) tried to assess the ages of continental deposits by studying them using classical biostratigraphical methods. Another attempt (Ceoloni *et al.*, 1988b) examined the possibility of correlation of our deposits with bone-based Bakker's "Dynasties" (Bakker, 1977) or with the "Empires" of Anderson & Cruikshank (1978). An attempt was also made, in the same paper, to use variation of the degree of biodiversity for the Permian interval (Ceoloni *et al.*, 1988b).

In a different approach tetrapod footprint-bearing levels were used as markers of transgressive or high-stand events (De Zanche *et al.*, 1993; Gianolla *et al.*, 1998) for Triassic sequence-stratigraphy in the Dolomites.

Each attempt, even if improving the subdivision and correlation of Permian and Triassic sediments, was quite unsatisfactory with respect to our efforts, and showed a variety of problems and uncertainties. At first we hypothesised that such negative aspects were linked either to the particular paleogeography/geology of the Alpine region, or to an incomplete ichnological literature. Subsequently we recognised the same problem in widespread geological domains (Lucas, 1996, 1998a, 1998b, 1999).

Indeed, the problems, large enough in marine stratigraphy and complicated by different codes and philosophies (Harland, 1992) seem to be enhanced during subdivision and correlation of continental deposits. Thus we began a feasibility study of a different stratigraphical tool, which is the use of tetrapod footprints for stratigraphical purposes using a biochronological approach. In this paper, after having analysed theoretical and practical problems, we will show the results of this analysis.

MAIN THEORETICAL PROBLEMS

The stratigraphical subdivision of continental deposits is characterised by enormous problems which depend on their intrinsic characteristics such as:

- the sharply changing depositional environments;
- the shape and dimensions of basins;
- the laterally and vertically discontinuous geometry of sedimentary bodies;
- the discontinuous fossil record: the frequent occurrence of non-fossiliferous units as well as units in which one does not find body fossils but just the less diagnostic footprints.

Problems also arise because of the kind of study, and because of real theoretical difficulties in applying classical stratigraphy. These last can depend on the systematics of land animals or, last but not least, can be due to the traditions of the discipline and to the conservative approach of many researchers to the argument. Moreover, most researchers work in this field after having been trained in marine sediment stratigraphy.

Problems in chronostratigraphy and geochronology

The lack of a specific standard reference scale for geological time is the first peculiarity that a "marine-trained" stratigrapher notices when attempting time subdivision and correlation in the continental deposits. Such a lack of standard reference units is not devoid of meaning, but corresponds to the actual situation with continental deposits.

Indeed, a conflict exists between the situations as recognised in continental deposits and the basic stratigraphic rules (mainly derived from the study of marine sediments). This conflict is well illustrated by sentences of this kind: - "*... Boundary-stratotypes of a stage should be within sequence of* ***continuous*** *deposition preferably marine ...*" (Hedberg, 1976, p. 71). - "*... Boundary-stratotypes should be chosen in sequences of essentially* ***continuous*** *deposition ...*" (Hedberg, 1976, p. 84). - "*... the correlation potential of any boundary level should be tested through a detailed study of several* ***continuous*** *successions covering the critical interval ... The most suitable of these sections can then be selected for definition of the GSSP.*" (Remane *et al.*, 1996). – "*... The boundary-stratotypes of a stage should be within sequences of essentially continuous deposition, preferably marine (except in cases such as the stages based on mammalian faunas in regions of nonmarine Tertiary sequences or the Quaternary glacial stages.*" and next "*... If major events in the geological development of the Earth can be identified at specific points in sequences of continuous deposition, these may constitute desirable points for the boundary-stratotypes of stages.*" (Salvador, 1994).

It is not by chance that the recommendation to use continuous sequences (*e.g.* marine pelagic) to establish unit-stratotypes or boundary-stratotypes (GSSPs) is present within the stratigraphic codes (Hedberg, 1976; Salvador, 1994) and within IUGS Guidelines (Remane *et al.*, 1996). We believe that "continuous" in that sense means not only and simply "without gaps" but mostly "constant" in every sense. This need is based on the theoretical constraint of the maximum continuity in type and rate of sedimentation and in the constancy of the deposition environment, "*... Absence of vertical facies changes at or near the boundary. A change of* *litho- or biofacies reflects a change of ecologic conditions which may have controlled the appearance of a given species at the boundary level. ...*" (Remane *et al.*, 1996). Continuity and constancy are needed for full confidence in the recognition of both faunal changes and all other events.

These characteristics contrast sharply with the evident characteristics of continental deposits. Indeed, the continental environment is known for discontinuities and sharp variations in the rate and type of sedimentation. Moreover basins are laterally discontinuous and the geometry of rock bodies is irregular; thus direct correlation, superposition and continuity are almost always impossible in practice and incorrect from a conceptual point of view.

From the above we recognised the theoretical impossibility of establishing "continental stages" and the use of special chronostratigraphical units. Also the selection of continental sections as assumed auxiliary type-sections seems unworkable. It is well known that the only geochronological units that we can use are based on standard marine stages, but also that correlational elements between continental and marine sequences are usually few or completely absent. Thus chronostratigraphy and geochronology are both extremely difficult to use for assessing the age of continental sediments.

Problems in lithostratigraphy

Problems also arise if one limits oneself to the use of lithostratigraphy; strong similarities in composition of sediments and the repetition of their depositional environments show the substantial inadequacy of the lithostratigraphic method, as demonstrated by the frequent diachronic correlation present in the old literature. One exemplar in this field is the widespread use of the names Rotliegendes or Buntsandstein (both actually lithostratigraphic units at a group level; Menning, 2000a) with chronostratigraphical meaning. The same is true for the term "Weald", originating in England but used the world over. A recent example of the low degree of confidence of the lithostratigraphic criteria is the systematic attribution of Cretaceous rocks to Palaeozoic units and ages in the several intracratonic basins of NE Brasil, because of misleading lithostratigraphic similarity, until the recent systematic discovery of dinosaur footprints within the units (Leonardi & Avanzini, 1994, p. 54; Carvalho *et al.*, 1994).

The U.B.S.U.s

The institution of the unconformity-bounded stratigraphic units (*e.g.* allostratigraphic units, synthems – see Salvador, 1987; 1994) although partially solving the above-mentioned problem, within an intrabasinal lithostratigraphical framework and for sequence-stratigraphy, seems useless for continental chronostratigraphy and geochronology.

"*...The worst possible boundary (for chronological units) is an unconformity ...*" this sentence (Hedberg, 1976, p. 84) finds its theoretical basis in the evidently diachronus nature of the first sediments onlapping the unconformity surfaces. This agrees with the opinion of Cowie *et al.* (1986) *"An obvious boundary should be suspect"*. Even if the isochrony of each cycle of higher orders (global cycles after Haq *et al.* (1987, 1988) may be stated, the exact age of the onlapping sediments seems to depend strongly on the morphology of the basin and on the physical location of each examined section.

Problems in continental biostratigraphy

The use of biostratigraphy in continental sequences presents in its turn various types of problems. Within such sediments fossils are not usually rock-forming elements, as is true for most marine sediments. Fossils are usually scattered, and mainly as for the large land vertebrates only partially preserved and displaced within sedimentary traps. Very rare but not impossible (see the case of Passo Palade section in the Southern Alps: Avanzini & Neri, 1998), are the cases in which fossils of different ages or evolutionary levels are superimposed in the same sections. This presents a major difficulty to the needs of stratigraphy; a GSSP definition starts with a marker event that may be the first appearance or last occurrence of a fossil species. "*... First appearances are generally more reliable than extinction events, especially if the gradual transition between the marker and its ancestor can be observed. ...*" (Remane *et al.*, 1996).

One of the requirements for a GSSP which is proper and pertinent to our situation, is: "*Favourable facies for long-range biostratigraphic correlations; this will normally correspond to an open marine environment where species with wide geographic range will be more common than in coastal and continental settings. The latter should therefore be avoided*". (Remane *et al.*, 1996).

Moreover many types of biozones (obviously, except the chronobiozones) need to be bounded by isochronous surfaces; thus these types of subdivision also partially run into the above-mentioned problems.

The most frequently used biozones for continental sediments are a kind of Oppel's zone; a type of biozone that last that will disappear from the international codes, because it can be assimilated with the Assemblage-zone or the Multi-taxon-concurrent-range zone (Salvador, 1994). Actually the biostratographic approach uses the Interval-zone for preference, instead of the Oppel's zone. Also discarding these theoretical problems we know that a practical, reliable solution is a long way off. Indeed, in recent decades some attempts have been made to use biostratigraphy for solving such problems; reptile-based biozones or associations were repeatedly proposed by many authors (*e.g.* Bonaparte, 1973; Bakker, 1977; Anderson & Cruikshank, 1978; Lucas, 1999) (see also Lucas, 1996 for a synthesis of Permian biostratigraphy). All these attempts must be considered difficult to apply, and only suitable for a few exceptional and isolated basins, in confined regions. This may be due to:

1. the characteristics of land vertebrates, which are more provincial with respect to marine animals;
2. the continental deposits which have little potential for fossil preservation;
3. the fact that, within such deposits, fossil finds are scattered and punctuated events, mainly restricted to certain layers (Lucas, 1998 b).

The same considerations also seem to apply for the biostratigraphy based on tetrapod footprints. Ichnostratigraphic schemes or ichnozones were proposed by Holub & Kozur (1981), Ellemberger (1983 a, b, 1984) and Boy & Fichter (1988 a, b), while Gand (1987) and Gand & Haubold (1988) suggested the use of ichnoassociations for the Permian. Demathieu & Haubold (1974) and Haubold (1986) suggested the use of ichnostratigraphy for Triassic time.

However the discontinuous record, the incorrect theoretical approach and very "provincial" systematics made these attempts unsatisfactory, putting aside the different opinions on ichnotaxa and the resultant over-splitting that makes correlation difficult.

In conclusion, we must emphasise that in continental deposits the basal principles informing the stratigraphy (superimposition and continuity) are almost impossible to apply. The practical and theoretical impossibility of recognising boundary stratotypes, establishing stages and, frequently, setting biozones for fossils with discontinuous distribution are huge obstacles to the correct and useful time subdivision of continental sediments. All the above makes the use of lithostratigraphy, chronostratigraphy and geochronology unreliable and inhibits the use of biostratigraphy. To these general problems we have to add some particular difficulties related to the stratigraphic nomenclature of the Permian and Triassic continental deposits.

Problems in Permian and Triassic stratigraphic nomenclature

Inconsistencies in stratigraphy of continental deposits of the European Permo-Triassic interval have also stemmed from a number of nomenclature problems that depend with several causes. Perhaps the main one is the traditional use, with geochronological or chronostratigraphical meaning, of units that are only lithostratigraphical in nature. For instance, Rotliegendes-Zechstein and Buntsandstein-Muschelkalk-Keuper are historical names from German stratigraphy, respectively originating from the bipartite lithostratigraphic subdivision of Central European Permian sediments (Dyas) and from the traditional tripartite Triassic (Menning, 2000 b). Their use as chronostratigraphical units poisoned the literature. In this way many important data previously published are today unusable and so it is impossible to recognise the exact position of many fossil-bearing levels.

In the same way, the frequently continued use of traditional names such as Autunian, Saxonian and Thuringian, corresponding neither with true stratotypes nor with valid biostratigraphical calibrations, gives rise to further confusion. Moreover, we do not agree with the aim of establishing auxiliary stratotype points in continental deposits (Broutin *et al.*, 1999) when GSSP are obviously in marine sequences (Remane *et al.*, 1996).

In conclusion, the landscape is bleak: lithostratigraphy seems useless, biostratigraphical and chronostratigraphical units are impossible to establish and difficult to use. We must again remember that the only available correlation units are the geochronological standard units. These are not only based on marine sediments, and thus often lacking in elements of direct correlation with continental units, but in their turn are frequently poorly-defined and confused. Moreover, the long-running and unresolved debates on these topics, frequently repeated in a cyclic way, seem to indicate that one abandons the correlation of sections, levels, fossils and events because one is too busy correlating names.

With such a desolate general view, the only possibility seems to be a change of approach and trying to utilise a system less related to the standards and which does not require all the theoretical and practical formal necessities of the other branches of stratigraphy. Then instead of repeatedly trying again direct correlation among taxa or the use of biozones, we chose to test the possibility of using tetrapod footprints as faunal elements within evolutionary units (Faunal Units). These last seem easier to use; being less formally constrained than the other stratigraphic units.

Importance of vertebrate ichnology in Permian and Triassic red beds

It is soon evident that tetrapod footprints are an important component of Permian and Triassic faunal elements. They are well known in the literature and frequently are recorded when other fossils are lacking. Now we need to consider whether they have the necessary characteristics to be used for stratigraphy (rate of evolution, dispersion, confidence, etc.).

The first condition requires that different forms show the consequences of evolution, that is to say, that they changed in an irreversible way as time passed, that changes occurred with a rate convenient to the time period, and that it is possible to recognise ancestor-descendant relationships. Clearly, footprint and trackway changes are related to the evolution of the foot, the gait and other features of reptilian behaviour.

During Permian and Triassic times, reptiles underwent major diversification and gave rise to most of the groups (Benton, 1993), so that by the end of the Triassic almost all the main patterns were already distinguishable. Consequently, in the same interval reptilian feet show the greatest variability, going from the stem-reptile foot to a mammalian foot, and from basal crocodilomorph till to the true dinosaurian foot (avian pes).

During the transition "advanced ornithosuchids-primitive dinosaurs", the foot evolved rapidly towards bipedality and the functional tridactylity of the pes. It had already reached the "avian" pattern by earliest Carnian. After that, the dinosaurian pes pattern remained substantially unchanged, at least for the theropod (non-avian and avian), for the stem-ornithischians [or basal ornithischians] and for basal prosauropods. This situation changed in the Early Jurassic, with the appearance of the quadrupedal or semi quadrupedal herbivores, like large prosauropods, sauropods and relatively large ornithopods, with their quite new and different feet. As a consequence, in Upper Triassic terrains there exists the first difficulty in subdividing footprints: the absolute domain of the dinosaurian footprints makes their use in stratigraphy less attractive, and their systematics less simple.

Thus at present we can easily recognise different associations only for Permian-Triassic time, associations in which stem-reptiles, mammal-like reptiles and thecodonts absolutely prevail over basal dinosaurs.

In conclusion, within the Permian and Triassic interval, so rich in continental sediments (geocratic), the use of ichnoassociations might be very useful for stratigraphy, even if preserving some intrinsic problems.

Problems in the philosophy of tetrapod-ichnology

The first theoretical problem is related to the two-fold philosophical interpretation that forms the basis of ichnology. Many researchers prefer a simple behavioural interpretation of traces, mainly those that come from the study of invertebrate ichnology ("ichnology mainstream", Bromley, oral comm., Halle Workshop, March 1997). They consider it almost impossible that an ichnofossil could be linked to a low-level zoological category. Such generalisation also implies that the same behaviours could repeat through time, and consequently give a very low degree of confidence in the stratigraphic use of ichnofossils.

Theoretically that concept does not fit within the concept of expanded phenotype, in which the behaviour is included and has to be considered like any other characteristic, realised on the basis of the dynamic and metabolic characteristics of an organism, pertaining to the genetics of a defined population or species.

In practice, if the behavioural interpretation could be consistent for a worm trace, it seems almost less and less valid for tetrapod trackways, frequently showing the traces of variable osteological and behavioural characteristics.

A completely different interpretation admits in principle the possibility for a paleontologist to be able to recognise a direct correspondence between footprint and trackmaker taxonomic group. It is clear to ichnologists that an ichnospecies does not correspond to a species, but it is also clear that careful taxonomic analysis and correct classification would correspond to a well-defined, if higher, taxon like a genus or a family.

If the latter interpretation is accepted, one should be able to use ichnofossils in stratigraphy with the same dignity and confidence of body fossils. This possibility was recognised by Haubold (1971 a, b) and Conti *et al.* (1977) and is implicit and clearly demonstrated by the different footprint associations already listed on a time scale by various authors (*i.e.* Haubold, 1971 a, b, 1986; Gand, 1987). Consequently we believe to be possible the use of reptile footprints for time subdivision, in contrast to the opinions expressed by Lucas (1996). This author, in analysing Permian reptile distribution, suggested a three-fold subdivision for the continental Permian similar to Romer (1973), and subsequently (Lucas, 1998 b) excluded the practical possibility of using footprints for correlation. Lucas, maintaining the impossibility of recognising the correspondence between ichnogenera and taxa below the family level, stated that "... *orders, superfamilies and families of body-fossil taxa* (of Permian reptile) *have stratigraphic ranges on the magnitude of series, so ichnobiostratigraphy based on the ichnotaxa can only discriminate correlations at the series level. ...*" (Lucas, 1998 b, p. 21).

Such an approach to the problem shows an evident weakness, misinterpreting our caution in limiting zoological attribution to family level as an actual uniformity within families. If one finds a cat-trackway and a tiger-trackway and classifies both ichnotaxa just as Felidae that does not mean that a tiger and a cat are the same animal and share the same vertical and geographical distribution. Moreover, the practical impossibility of reaching a well-defined classification, as in common for paleontologists when fossils are incomplete or poorly preserved, cannot be set as a principle, since the continual and progressive refinement of our knowledge might change this situation completely.

Lucas' way of thinking also leads to a strange interpretation. According to that system we must ascribe an ichnofossil to a family of the bone-based systematics and then use the recorded temporal distribution of families for correlation. However, stratigraphy is a practical tool, always based on the recognition of a sequence of events or forms (or of unknown objects) which repeats with the same order in different sections (homotaxy). After this process and that of calibration, correlation is possible. That also excludes consideration of the zoological attribution of the utilised taxa (*e. g.* the stratigraphy based on *incertae sedis* fossils).

We will now examine the characteristics of biochronology. We believe that the biochronological value of a fossil group is determined by the succession of its different evolutionary stages. Once the succession of different forms is verified, their evolutionary status can be determined on the grounds of eco-evolutionary valuations or of ancestor-descendant relationships within lineages.

Since our aim is to establish ichnofaunal units, we must also consider the relationships of the taxa within an association. The consistency of each taxon within an association depends not only on the evolutionary stages but also on ecological and paleogeographical characteristics. Evolutionary equivalent associations can have partially or totally different compositions because of varying environments or due to the paleogeographycal positions of depositional basins in which track-bearing sediments were laid down.

Only after having established a sequence of consecutive evolutionary steps can we try to correlate to standards, although the biochronological value of the sequences is valid even if correlation is still doubtful. The chronometric value of the evolutionary stages can be assured by calibrations with external data, and only by correlation with Ages (based on marine standard Stages).

Moreover, by the study of the associations it is possible to recognise one or more index forms whose lifetime corresponds with that of the whole association. If recognised such forms share the same biochronological value as the whole association. We must keep in mind that this kind of marker can be useful but is not necessary. Also first and last appearance datum (FAD, LAD), first and last occurrence (FO, LO) and other boundary events can be useful but are not necessary.

All that considered, the remaining obstacles to the use of ichnofossils consist of the difficult taxonomy, the resulting confused systematics, and (only marginally) the uncertain zoological value of ascribing ichnogenera and ichnospecies. In fact, these are practical and temporary problems and not theoretical obstacles to the use of ichnofossils in stratigraphy.

Problems in ichnological taxonomy

Once stated that, from the theoretical point of view, tetrapod ichnofossils can be used for stratigraphy, we will briefly examine the present position of ichnotaxonomy. Tetrapod footprint taxonomy has many problems, already largely debated but also possible to overcome with the present state of the art. The Workshop on Ichnofacies and Ichnotaxonomy of the Terrestrial Permian, held at the Martin Luther University in Halle (Germany) in spring 1997, helped to change and reinforce some ideas on ichnotaxonomy and ichnosystematics. Moreover, discussions underlined the influence of extramorphologies and pushed towards an ever-increasing caution in establishing new taxa. As a result of that meeting, we can consider that taxonomy in vertebrate ichnology has reached a greater degree of maturity. The ensuing simplification of the enormous number of names present in the literature concerned with Permian vertebrate ichnology is in progress (Haubold, 1996; Conti *et al.*, 2000). The same simplification is also in progress today for inflationary nomenclature on small dinosaurian Triassic footprints (Olsen & Galton, 1984; Leonardi & Lockley, 1995; Leonardi, 2000).

It is time to discuss another point, before passing to the actual study of footprint-based chronology; this is the problem of the relationship between ichnological and zoological systematics.

Problems in ichnosystematics

Today footprints enjoy a sufficiently mature taxonomy while the ichnological systematics and nomenclature are still influenced by their well-known historical problems. Depending on the different philosophies and sometimes on the enthusiasm and inexperience of the classifiers; as well as *"systematic obstinacy"* (the classification at all hazards and at any rate; *"accanimento sistematico" sensu* Conti *et al.*, 2000), we can have:

1. taxa absolutely split, in which different names correspond simply to different attitudes (behaviour and gait) of the track-makers (see Ellemberger, 1970, 1972, 1974) or to a type of gait or to any characteristic producing repetitive extramorphologies. In fact, in simply recognising the sliding of a pes or a particular type of impression in a normal trackway, all similar footprints among those in a trackway are automatically considered normal footprints of a different animal [see Haubold (1996) for the concept of "phantom" taxa]. An absolutely demonstrative case is that of *Chelichnus* (or *Laoporus*) in which a regularly-placed sand-sliding, in a dune environment, distinguished all the footprints and was considered as a taxonomical feature (Haubold, 1996);
2. huge ichnogenera, which consist of the sum of many previously existing taxa. This case is often a kind of surrender, when one realises our inability to subdivide footprints, either because of an overlap of characteristics, or because of the coherent (even if incorrect) knowledge that some kinds of footprints are not sufficient to define a track-maker. Sometimes, after a taxon is correctly established, with its variability, further data are added to the original variability. They lead the taxon variability range to overlap to ranges of other taxa that were well separated when originally established. In this case, a too cautious re-

vision can create some problems because the different names converge to create enormous synonymic lists and equally enormous variability. Such resulting variability is able in practice able to include many different forms. A good example of this case is *Grallator* (*i.e.* Olsen & Galton, 1984) now inclusive of the three old genera *Grallator*, *Anchisauripus* and *Eubrontes*, and probably most of the species previously ascribed to the invalid name *Coelurosaurichnus* (Leonardi & Lockley, 1995);

3. some rarer cases represented by ichnogenera including more species, in this case one may perceive a correspondence between ichnospecies and fossil species (or populations characterised by particular behaviours), *e.g.* the case of ichnogenus *Rhynchosauroides*;

4. ichnogenera, usually monotypic, for which there exists wide sampling and a well-described dimensional and gait variability; in conclusion, taxa well known and rather reliable as in the case of *Ichniotherium*. These last represent solid and reliable bases for stratigraphy, and it is desirable that after in-depth and up-to-date studies, all the taxa will reach this condition.

PERMIAN AND TRIASSIC FOOTPRINT-BASED BIOCHRONOLOGY

After examination of the problems, we believe that all the above-mentioned theoretical difficulties will be overcome. Consequently, tetrapod footprints appear available for assessing the age of continental deposits, if using a biochronological approach. We concluded that to be sure of such an assumption, we only needed a complete practical test on this topic.

We tested the possibility of recognising evolutionary stages, setting them in a sequence of evolutionary units, and using these as chronological tools. In applying this method, we will follow a path closely parallel to mainstream land vertebrate stratigraphy (Walsh, 1998).

Permian and Triassic paleogeography and the geological setting of the Southern Alps

We believe that examples of all the aforementioned problems in continental stratigraphy are present in the Permian and Triassic geology of the Southern Alps.

The Upper Carboniferous-Upper Permian succession of the Southern Alps is separated into two major tectonosedimentary cycles by a regional unconformity:

- a lower cycle represented by calcalkaline acidic to intermediate volcanic and alluvial-lacustrine continental deposits (Collio Fm.; Dosso dei Galli Cgl.; Auccia Volcanites; Ponteranica Cgl.; Tregiovo Fm.; and ignimbrites and lavas of the Atesino Volcanic District);
- an upper cycle represented by fluvial red clastics of Verrucano Lombardo and Val Gardena Sandstone, laterally and vertically replaced in part by sulphate evaporites and shallow-marine carbonate sequences (Bellerophon Fm.).

The regional unconformity between the two cycles is well documented by extensive erosional surfaces and paleosoil horizons. The stratigraphic break is different in different outcrops, with a time-gap ranging 14 to 27 Ma (Italian IGCP 203 Group, 1986; Cassinis *et al.*, 1988, 1999).

The continental Permian units from which we collected the fauna were the Collio Fm., the Dosso dei Galli Cgl., and the Tregiovo Fm. from the first cycle. In second cycle, in the Dolomites area, the fossiliferous units were the Val Gardena Sandstone and the Bellerophon Fm.

The Triassic stratigraphy in the Dolomites and the interpretation in terms of sequence stratigraphy have been made possible by a highly resolved ammonite standard scale (Mietto & Manfrin, 1995 a, b). This standard scale is based on the definition of a zone succession characterised by genera; in turn each zone is subdivided into a number of subzones defined by species. Within the Middle Triassic these subzones allow a biochronostratigraphic resolution which can be extended throughout the Tethyan region.

The Triassic succession in the Dolomites and surrounding areas can be schematised as follows:

on the whole the Lower Triassic consists of terrigenous and terrigenous-carbonate units essentially deposited in shallow marine to tidal flat environments (Werfen Fm.). The Scythian–Anisian boundary seems to occur at a peritidal carbonate platform which extended throughout the Southern Alps (Lower Serla Dolomite, Lusnizza Fm.). Several terrigenous and terrigenous carbonate units follow, essentially Anisian in age (Braies Group, Upper Serla Fm. and Contrin Fm. - Pisa *et al.*, 1979; De Zanche & Farabegoli, 1982), including a number of rock units deposited in basinal, lagoonal, peritidal and continental environments. The Ladinian interval is represented in the Dolomites by basinal units (Buchenstein and Wengen Fms) and carbonate platforms (Sciliar Dolomite). In the Carnian, carbonate platforms, marls, shales and volcanic siltstones and sandstones are recognisable (San Cassiano Fm., Dürrenstein Fm.). An interval of vari-coloured terrigenous-carbonate rocks of Late Carnian age (Raibl Fm.) is covered by the carbonate tidal-flat deposits of the Dolomia Principale Fm. (uppermost Carnian to Rhaetian).

The continental units, interbedded with marine units, from which we collected the ichnofauna, were the Werfen Fm., the Braies Group, the Dürrenstein Fm., the Dolomia Principale Fm.

Tetrapod footprint database

A first attempt in using biochronology was proposed by

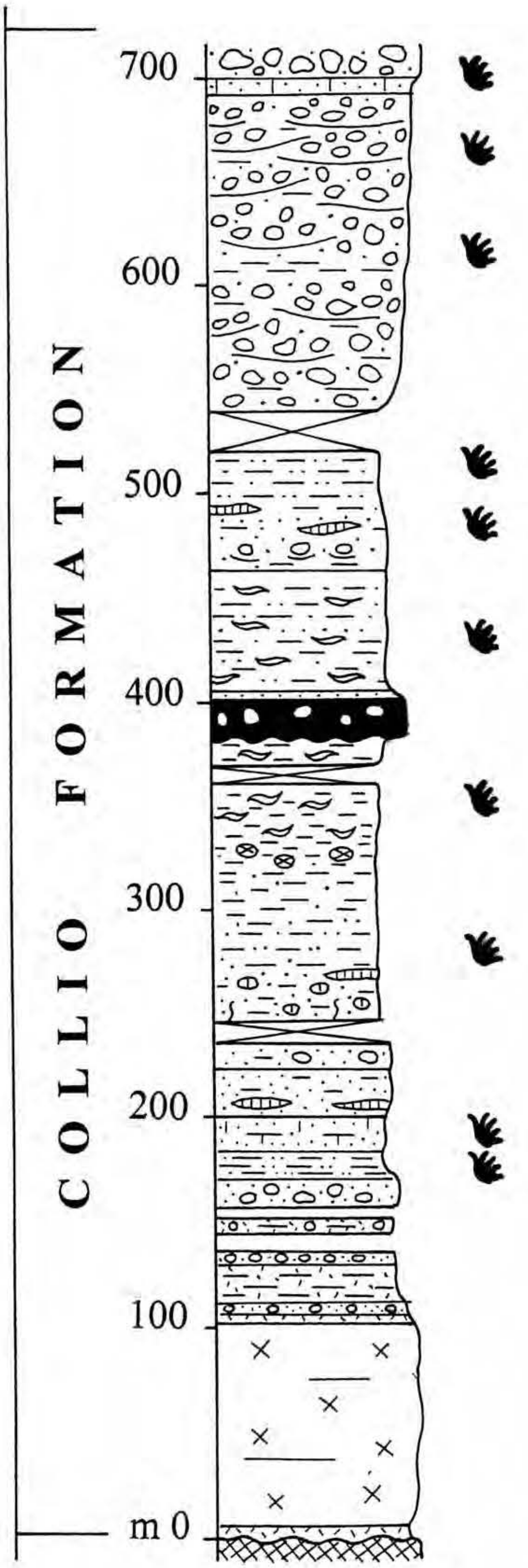


Fig. 1 - Schematic columnar section of the Collio Fm. (Early Permian) at the Dasdana Valley (Brescia, northern Italy). Footprint outlines indicate footprint levels (Modified from Italian IGCP 203 Group, 1986 and Ceoloni *et al.*, 1987).

Conti *et al.*, (1997) for the Permian; this second attempt, for the Permian and Triassic interval, is based on an updated and very much richer ichnological database. In the last few years, the ichnological literature on northern Italy has increased enormously due to the fact that many new tetrapod footprint-bearing outcrops have been found and studied. In the same way, the number of researchers partly or totally devoted to this type of fossils has increased. The recent developments in ichnology are linked both to increasing knowledge of the stratigraphical, paleoecological and paleogeographical importance of footprints and to the ever increasing number of new finds. The development is also demonstrated by the quasi-exponential growth in the number of papers on tetrapod ichnology.

All together in Italy, up to summer 1999, 35 tetrapod footprint-rich outcrops were detected, 32 of them present in the southern Alpine belt. Such outcrops obviously differ in the types of footprints (amphibians, stem-reptiles, "thecodonts", phytosaurs, dinosaurs), in the frequency of finds (single levels or multiple levels inside the same section), in dimensions of the outcrop (from a few square decimetre-sized slabs to kilometre-scale track-sites), and in degree of ichnodiversity.

After a coarse stratigraphical calibration, we selected all the data from Permian, Triassic and Lower Jurassic outcrops to check the stratigraphical value of the footprints. In many cases the systematics are still in progress, and frequently the names given to the trackway still have an uncertain systematic position. Nevertheless all the data falling in the Permian-Triassic interval were used. In order to escape temporary systematic problems, in this analysis of feasibility we used widely inclusive names, aware that many of these names represent taxa that will eventually be given a well-defined meaning. The only rule was that the names had to correspond to different objects, so that they were easy to recognise and easy to use.

Calibration data

Ichnological results were calibrated with all the other available data at our disposal from the quite rich literature (see Cassinis *et al.*, 1999, for a bibliographic review). Data under consideration were different depending on the different paleogeographical and environmental framework. In our case the tetrapod footprints are recorded from different paleoenvironments: Lower and Upper Permian outcrops are mainly within continental deposits and marine events are recorded only at the very top of the Upper Permian sections; in contrast, Triassic footprint-bearing levels crop out mainly within marine sequences.

For calibration we used data on:

a. sporomorphs, megaplants, isotopic dating, sequence stratigraphy for Lower Permian outcrops;

b. sporomorphs, megaplants, foraminifers, algae, bra-

chiopods, nautiloids, conodonts, sequence stratigraphy for Upper Permian tracksites;
c. ammonites, conodonts, sporomorphs, sequence stratigraphy for Triassic tracksites. Only in the last case was possible to use ammonite standard biozonation and then a calibration with marine standard chronostratigraphical and geochronological units.

Intrabasinal correlation and association analysis

In the most outcrops footprints were present in isolated layers, but we had the good fortune to be able to use, as main reference outcrops, three sections in which thick sequences of track-bearing sediments were superimposed.

Within these outcrops ichnofaunas are well represented and widespread, and have mostly been previously studied (see below). We compared all the recognised levels and the isolated findings with the associations recorded from the main sections. The results, all consistent, are summarised below.

Lower Permian Ichnoassociation

This association includes all the ichnotaxa recognised within the first cycle sediments of the Alpine Permian-Triassic sequence. In the past this was tentatively considered as a faunal unit under the name of Collio Faunal Unit, further subdivided into two faunal subunits named as the Pulpito Faunal Subunit and the Tregiovo Faunal Subunit (Conti *et al.*, 1997). To each of them was also ascribed a biochronological value with the names of the Collio Faunal Age (Rabejac Faunal Subage and Tregiovo Faunal Subage).

The ichnoassociation is based on data from the Dasdana Valley section (Collio Fm.; Cassinis, 1966), in which ten footprint-bearing layers were recognised through a nearly 700 m thick section (Geinitz, 1869; Curioni, 1870; Berruti, 1969; Ceoloni *et al.*, 1987; Conti *et al.*, 1991, 2000).

After a partial revision, the ichnoassociation includes reptile footprints (?*Camunipes cassinisi, Varanopus curvidactylus, Amphisauropus latus, Ichniotherium cottae, Dromopus lacertoides, D. didactylus*) and less frequent amphibian footprints (*Batrachichnus* sp.) (Fig. 1).

This set of data was successfully compared with data coming from sediments cropping out in other parts of the Orobic Basin (Gümbel, 1880; Dozy, 1935; Casati, 1969; Casati & Forcella, 1988; Nicosia *et al.*, 1999 a, 2000; Cassinis *et al.*, 2000; Santi, in press; Santi & Krieger, in press) and in the Tregiovo Basin (Conti *et al.*, 1997).

Correlational elements with marine deposits are not possible, but we can use floristic data (Cassinis & Doubinger, 1991 a, b) for correlation, and we can constrain the ages of the base and the top by using radiometric data (Cassinis *et al.*, in press). Actually, the time interval in which this fauna is widespread in northern Italy is limited to between 286/283 Ma BP, at the base, and 278/273 Ma BP at the top (Cassinis *et al.*, 1999 and in press).

Upper Permian Ichnoassociation

This ichnoassociation includes all the taxa recognised within the second cycle sediments. In Conti *et al.* (1997) this association was also considered to be a faunal unit under the name of Bletterbach FU, with a faunal age named Bletterbach FA.

The ichnoassociation is based on data from the Bletterbach section in which 12 layers were recognised in a thickness of nearly 180 m (Ceoloni *et al.*, 1988 a, b; Conti *et al.*, 1975, 1977, 1980 a, b, 1987; Leonardi & Nicosia, 1973; Leonardi *et al.*, 1975; Nicosia *et al.*, 1999 b).

The ichnoassociation is composed of footprints ascribed to reptiles (mammal-like, prolacertiforms, pareiasaurids) characterised by a very advanced evolutionary stage. Among them only some taxa were selected to have a more confident database (*e.g. Pachypes dolomiticus, Ichniotherium accordii, Rhynchosauroides pallinii, Dicynodontipus* sp.) (Fig. 2). The other outcrops bearing the same fauna were the following: SS. 48, Monte Cislon (Kittl, 1891; Abel, 1929); S. Pellegrino Pass, Seceda (Conti *et al.*, 1977), Nova Ponente (Wopfner, 1999) in the Dolomites, Ligosullo in the Carnia region (Mietto & Muscio, 1987), Recoaro near Vicenza (Mietto, 1975, 1981, 1995), the San Genesio-Meltina Plateau in the Adige Basin, and Mt. Luco in the Tregiovo Basin (Avanzini, unpublished).

The only elements that allow correlation are the Late Permian marine events at the top and the sporomorphs at the base. Nevertheless we were able to constrain the association to an interval ranging from nearly 259 to 255 Ma BP (Cassinis *et al.*, in press).

The two Permian associations still present a big problem; their evolutionary stages are very different, and between the Lower Permian and Upper Permian ichnofaunas there seems to be an evolutionary jump. From that point of view we can suppose that the lack of an ichnofaunal record for such a long interval is related to a lack of sediment. Indeed, in the Alpine region, sediments must have been lacking between the first-cycle and second-cycle sediments, because of the enormous gap, lasting 14 to 27 million years (Cassinis *et al.*, 1999, p. 10). So different chronometric ages of track-bearing sediments validate the gap between evolutionary stages. We can also observe that the same gap and the resulting change in evolutionary stage seems widespread all over the world.

Lowermost Triassic Ichnoassociation

Few footprints are recorded from the Lower Triassic sediments, Recoaro, Val Gardena (Bulla/Pufels) and Val Tra-

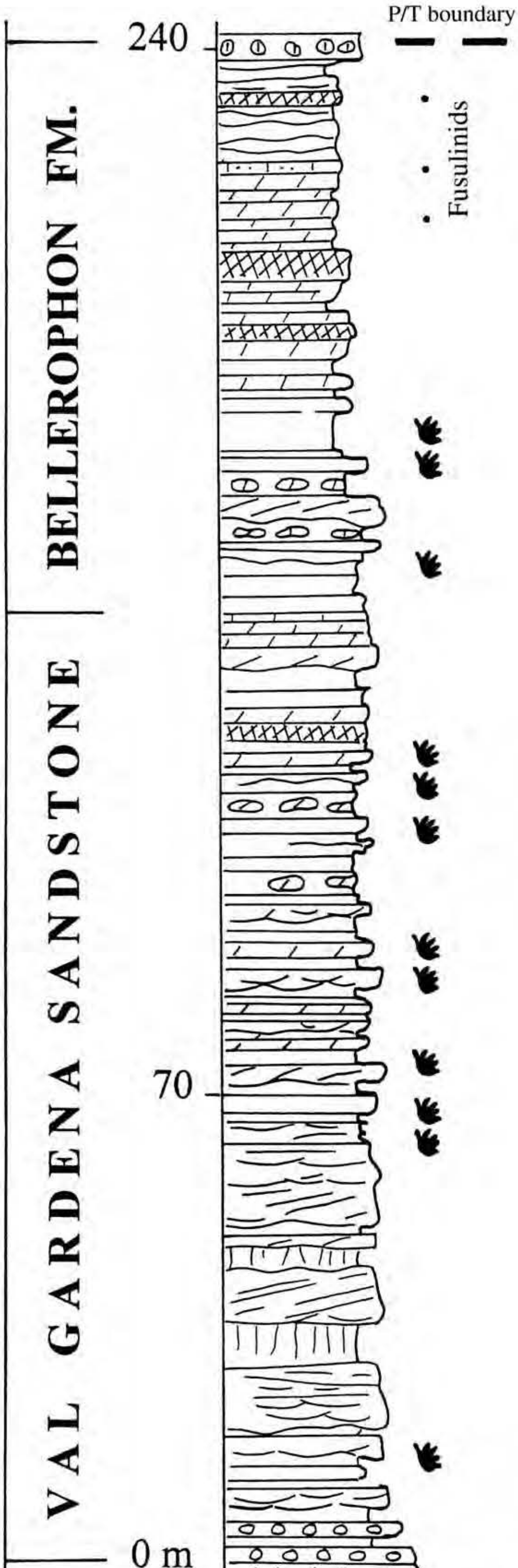


Fig. 2 – Schematic columnar section of the Val Gardena Sandstone and Bellerophon Fm. (Late Permian) at the Bletterbach Gorge (Bozen, northern Italy). Footprint outlines indicate footprint levels. (Modified from Massari *et al.*, 1988).

vignolo (Dolomites) and also in Carnia (Conti *et al.*, 2000). Some forms, ascribable to *Rhynchosauroides* sp. cfr. *R. schochardti*, were collected from the terrigenous layers of the Werfen Formation (Mietto, 1986). Other taxa, termed "Pseudosuchians" by Leonardi (1967), are to date poorly documented and represented only by incomplete specimens. The upper part of this interval is calibrated to Olenekian (Spathian) age by ammonites (*Tirolites* zone).

Mid-Triassic Ichnoassociation

Several ichnoassociations, some of which are still under study, have been discovered in the Dolomites and surrounding areas (Abel, 1926; Brandner, 1973; Mietto, 1987, 1995, 2000, and unpublished data; Sirna *et al.*, 1994).

Tracksites are located in the Braies Dolomites (northern Dolomites) (Abel, 1926; Brandner, 1973), in the eastern Dolomites (Conti *et al.*, 2000; Mietto, 2000), in the upper Val di Non and Val d'Adige, (Avanzini & Neri, 1998, Avanzini, in press) and in the Recoaro area (Mietto, 1987, 1995).

Most of the tracks pertain to Lepidosauria of the *Rhynchosauroides* ichnogenus with the typical *Rhynchosauroides tirolicus* (Abel, 1926). Subordinately Archosauria tracks have been recognised (*Synaptichnium priscum, Synaptichnium pseudosuchoides, ?Synaptichnium cameronense, Parasynaptichnium gracilis, Chirotherium rex, Chirotherium barthii, Brachychiroterium parvum, Brachychirotherium* aff. *parvum, Isochirotherium delicatum*). The sites also yielded tracks that may be ascribed to amphibians, chelonians and therapsids.

The track-bearing units of the eastern Southern Alps identify a transitional, continental-to-marine environment, characterised by terrigenous and carbonate platforms and coastal delta mouth bars deposited under relatively arid conditions. These deposits can be calibrated, using ammonites and other marine faunas, to the whole Anisian time interval.

Upper Triassic Ichnoassociations

Tracks of terrestrial reptiles were found in Upper Triassic units (Dürrenstein Fm., Dolomia Principale Fm. and equivalent units) of the Dolomites (Mietto, 1988, 1990, 1992; Leonardi & Avanzini, 1994; Avanzini *et al.*, in press) and the Carnic Pre-Alps (Dalla Vecchia & Mietto, 1998; Dalla Vecchia, 1996; Roghi & Dalla Vecchia, 1997).

The first ichnoassociation includes tracks made by "thecodonts" (chirotheroid tracks), phitosaurs, mammal-like reptiles and probable basal dinosaurs. The age of the sequence has not yet been well defined. Data from outside the Dolomites (eastern Southern Alps) seem to indicate a Carnian age (Latest Julian-Early Tuvalian) using ammonites (*Austriacum-Dilleri* zone).

A higher association is made by footprints ascribed to medium-to-large theropod dinosaurs (*Eubrontes, An-*

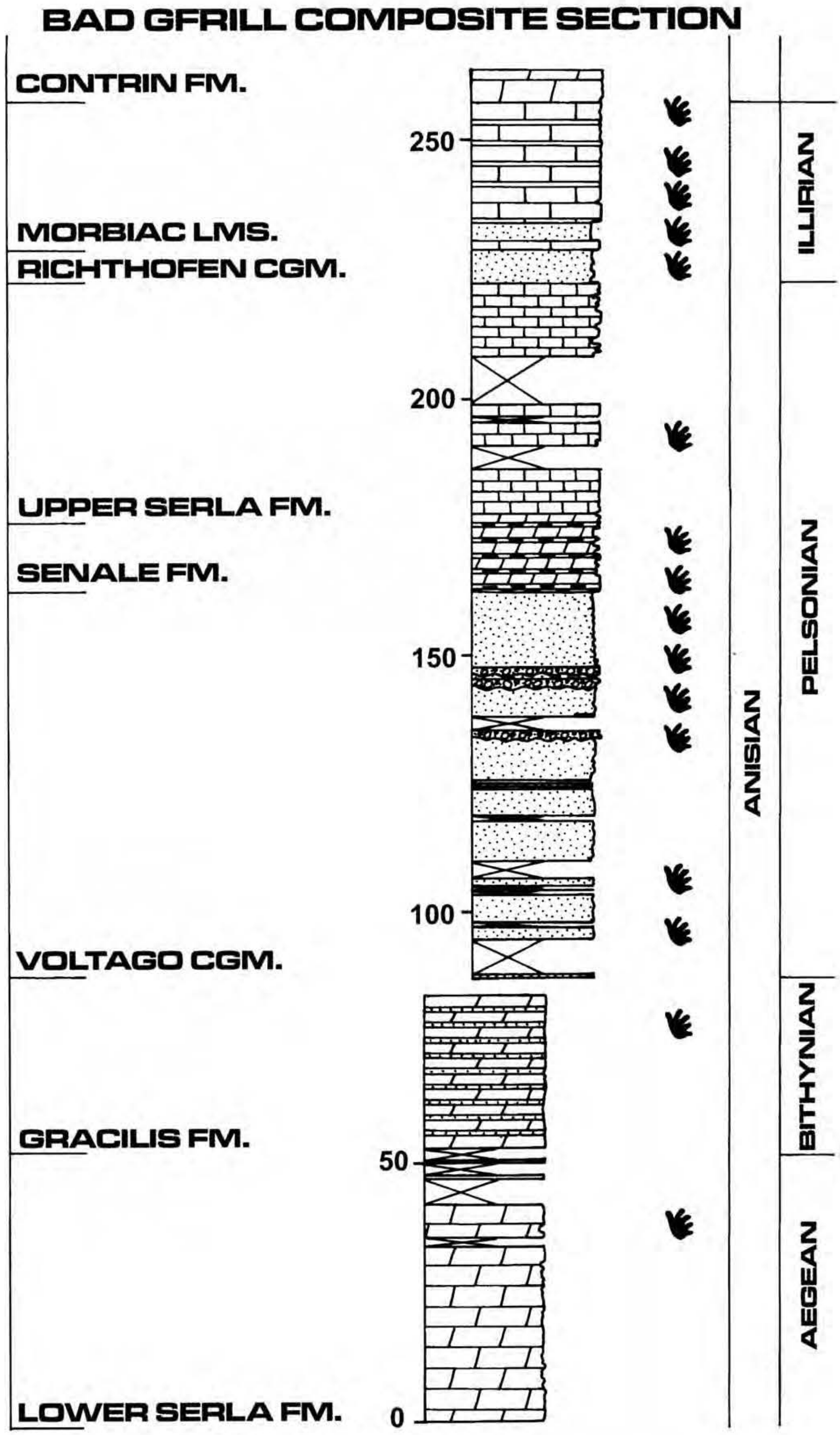


Fig. 3 - Schematic columnar section of the Mid-Triassic mainly marine sequence at the Bad Gfrill section (Bozen, northern Italy). Footprint outlines indicate footprint levels. Only for this type of sequence is it possible to use marine standard ages.

chisauripus), "thecodonts", and basal Ornithischia. The presence of prosauropods is also probable. This association is Late Carnian (Late Tuvalian) to Early Norian in age due to the presence of ammonites in the Carnic equivalent basal sequences (*Anatropites* zone).

The Triassic faunal assemblage of the Southern Alps is very interesting because track-bearing layers are interbedded with marine layers (Fig. 3). It was found possible to use ammonite standard biozonation and the resulting calibration with marine standard chronostratigraphical units.

The most recent data on the Anisian levels, the interval in which we find the most complex and rich ichnoassociations, lead us to hypothesise that it will be possible to use tetrapod footprint associations with the same resolution as ammonite biozones.

We also believe it is possible that the calibration we are performing in the Southern Alps could yield decisive results in dating sedimentary sequences still lacking in chronostratigraphical calibration.

Extrabasinal correlations

The final step, still to be accomplished, is a coarse correlation of our results with data listed from outcrops all over the world.

1. We can consider our Lower Permian Ichnoassociation as at the same evolutionary stage as the ichnoassociations from:

a. Cape John Formation, Nova Scotia, Canada (Hunt, oral com.);

b. the De Chelly Sandstone (Haubold *et al.*, 1995 b; Morales & Haubold, 1995); the Robledo Mountains Member of the Hueco Fm. (Hunt *et al.*, 1995 a; Lucas *et al.*, 1995 b); the Abo Fm. (Lucas *et al.*, 1995 a), the Earp Fm., the Sangre de Cristo Fm., New Mexico, (Lucas & Hunt, 1995); and many other formations from U.S.A. (Haubold *et al.*, 1995 a; Hunt *et al.*, 1995 b);

c. the Clear Fork Group from Castle Peak, Texas , U.S.A. (Sarjeant, 1971);

d. the Keele and Enville beds of the Birmingham region, UK (Haubold & Sarjeant, 1974);

e. the whole Nahe-Gruppe in SW Germany (Boy & Fichter, 1988 a, b);

f. all the formations of the Thuringian Forest Rotliegend up to the Tambach Fm. (Lützner, 1987; Sumida *et al.*, 1996);

g. all the formations of the Lodève, Saint-Affrique and Provençal (Demathieu & Gand, 1992) basins listed in Gand (1987) and Gand *et al.* (1995) and, generally, from all the French basins;

h. from the Aksautskian and Kinyrtchdskian formations of the northern Caucasus, Russia (few and poorly preserved specimens, Lucas *et al.*, 1999).

2. Possibly the same evolutionary stage, as shown by our Upper Permian Ichnoassociation, can be ascribed to the specimen of *Paradoxichnium problematicum* Müller, 1959 from the "Zechstein bei Gera" (Müller, 1959).

3. The same evolutionary stage, as shown by our Lower Triassic Ichnoassociation, could be ascribed to:

a. the Solling and Kronach ichnofaunas from the Buntsandstein Fm. (Germany) (Demathieu & Leitz, 1982; Demathieu, 1984);

b. the Solliès – Ville and Sanary ichnofaunas from the Buntsandstein Fm. (Provence, France) (Charles, 1949) and the "Werfénien" Fm. (Ellemberger, 1965);

c. the Lodève and Dio ichnofaunas from the Buntsandstein Fm. (Massif Central – France) (Gervais, 1857; Orszag-Sperber, 1966);

d. the Jaegerthal (Schimper, 1850), Saint-Valbert (Daubrée, 1857) and Granges la Ville (Buffard, 1966) ichnofaunas from the Buntsandstein Fm. of Vosges (Germany-Belgium-France);

e. the Roberts Fm. Ichnoassociation (Spathian in age) from the Alpes Maritimes of France (Demathieu, 1977).

4. We can consider the basal Middle Triassic (Lower and Middle Anisian) Ichnoassociation of the Southern Alps as at the same evolutionary stage as the ichnoassociations from:

a. Trémonzey/Vosge (France) from the Upper Buntsandstein Fm. (Demathieu & Durand, 1975);

b. Winterswijk (Holland) (Demathieu & Oosterink, 1983)

c. Lodève (France) (Demathieu, 1984);

d. the Holbrook Mb. of the Moenkopi Fm. (Peabody, 1948, Hunt & Lucas, 1993);

e. Fm. de Rimplas (Grès de Gonfaron) and Fromagine Fm. from the Alpes Maritimes of France (Demathieu, 1977).

5. The Middle Triassic (Upper Anisian) Ichnoassociation was at the same evolutionary stage as the ichnoassociations from the Muschelkalk of the Massif Central, Vosges (Granges la Ville), and Provence (Sanary) (Ellemberger, 1965; Buffard, 1966; Courel *et al.*, 1968; Courel & Demathieu, 1973).

6. We can consider our Upper Triassic (Carnian – Norian) Ichnoassociation as at the same evolutionary stage of the ichnoassociations coming from:

a. the Dokum, Lockatong, Stockton, Passaic (= Lower Brunswick) and Wolfville formations of the Newark Supergroup (North America) (Olsen, 1980, 1983);

b. the Middle Keuper formations of Valaise, Languedoc and Germany (Europe) (Haubold, 1984, 1986);

c. the Trias of Vieux Emosson in Switzerland (Demathieu & Weidmann, 1982);

d. the Molteno Formation, Zones A/1-4 of Lesotho (South Africa) (Ellenberger, 1972, 1974);

e. the Ipswich Coal of Queensland (Australia);

f. the Mercia Mudstone Group of South Wales (England) (Lockley *et al.*, 1996).

At this time the analysis is still in progress, but it seems that our results could usefully be applied to most of the published material.

FAUNAL UNITS AND ICHNOFAUNAL UNITS

In Fig. 4 the data for northern Italian ichnofaunas are plotted on a geochronological scheme. According to our analyses and all the available calibration data, it seems well proven that six groups of footprints can distinguish six discrete intervals in the Permian-Triassic periods. Each interval is characterised by different taxa, showing different and successive evolutionary levels.

At this point we have only to discuss:

1. with which type of unit these intervals can be associated;
2. their validity for correlation to basin and extrabasin level;
3. if they are suitable for defining the ages of the deposits.

It seems clear that reptile footprints can be used to distinguish more or less different associations, characterised by different evolutionary stages. As they, more or less correspond to Oppel's zones, and correspond to evolutionary units, they can be established as faunal units.

The evolutionary units or faunal units (FUs) are characterised by taxa, in general unique to the unit; moreover additional taxa may occur in more than one unit. The FUs can be named on the basis of characterising taxa or better by the most representative localities.

The FUs thus represent a co-evolved association of a variable number of coeval taxa. We know that within an association (and in light of the "Red Queen" theory), species change in co-evolutionary equilibrium, and thus the presence of one or a few of them could be sufficient to mark a well-defined evolutionary stage.

The FUs present optimal tools for continental deposits because they are based on associations and do not need markers, and because, from a theoretical point of view, they represent units that avoid all the problems of continuity and superimposition. They can be used in cases of single or punctuated finds. In practice they represent defining moments in biological evolution, and so, as associations, they are unrepeatable moments in time. The definition of FUs, even if requering experience and knowledge of the faunas, is possible and relatively simple, being based on sets of taxa borne of co-evolutionary processes and in ecologically characterised associations.

Thus each FU also represents the time interval of existence of the selected members of the association and thus the interval of persistence of such biological equilibria. Consequently a FU can easily be transformed into a faunal age (FA), or biochronological unit; each FA being typified by a find locality. A sequence of successive steps in evolution is so transformed into a sequence of FAs. It is obvious that without a well-fixed calibration a sequence of FAs just represents a sequence of time intervals, but after calibration they change into useful tools in the subdivision of sedimentary sequences and in correlation of non-superimposed deposits.

In the study of Tertiary-Quaternary continental deposits, which present similar problems, time subdivisions based on the concept of faunal ages are used, in their turn tied to evolutionary mammal associations (Walsh, 1998). This method is well-enough established (Wyss *et al.*, 1996; Pajak *et al.*, 1996; Walsh, 1998) that scales were organised into NALMAs (North American Land Mammals Ages) and SALMAs (South American Land Mammals Ages). The same use of evolutionary units was already implicit, although more or less hidden, within the concepts of "Ages-Reptiles" of Bonaparte (1973), "Reptiles Dynasties" of Bakker (1977) and within the "Empires" of Anderson & Cruikshank (1978). On each occasion these subdivisions were based on large collections of bone remains from sediments that did not have superimposed sections. Also the very recent Triassic stratigraphy (Lucas, 1999) is a suite of temporally successive bone-based assemblage zones.

From the analysis of the ichnological database it seems demonstrated that, on the same principles, it is possible that ichnoassociations (frequently classified just at ichnogenus level) can be used as FUs or FAs over the time scales of geological phenomena.

At the moment our ichnoassociations are still lacking in boundary events, but are well differentiated from an evolutionary point of view and well constrained from the chronometric point of view. We believe that, in the future, Land Ichnofaunal Units (LIUs) and the consistent Land Ichnofaunal Ages (LIAs) could be the most useful tools for subdividing and correlating Permian-Triassic continental sediments.

CONCLUSIONS

The present situation shows a general lack of stratigraphic markers, and the difficulty of using the traditional systems for assessing the age of Upper Paleozoic and Lower Mesozoic continental deposits. The only real alternative seems to be the use of non-formalised associations of fossils, each of them with a biochronological value and thus independent of the need for direct superposition and continuity.

For the Permian and Triassic continental deposits of the Alpine region, tetrapod footprints seem the best fossils for this purpose. They can be used to establish evolutionary units, once problems in the philosophy, systematics and nomenclature of the ichnofossils are overcome.

ICHNOTAXA	A	S	A	K	K	T	I	O	A	L	C	N/R	H	S	P
***Anomoepus* sp.**													□		
Ornitischia ind.												□	□		
***Parabrontopodus* sp.**													□		
Sauropoda ind.													□	□	
Prosauropoda ind.												□			
***Eubrontes* sp.**												□	□	□	
***Anchisauripus* sp.**											□				
***Grallator* sp.**												□	□		
Ceratosauria ind.											□	□	□	□	
"Phytosauria" ind.											□				
Therapsida ind.									□		□				
Procolophonida ind.									□						
Chelonomorpha ind.									□						
Isochir. delicatum									□						
***Isochirotheriun* sp.**									□						
Brachichir.* aff. *parvum									□						
***Brachichirotherium* sp.**									□		□				
Chirotherium rex									□						
Chirotherium barthi									□						
***Chirotherium* sp.**									□		□				
***Parasynaptichnium* sp.**									□						
***Synaptichnium* sp.**									□						
Chirotherida ind.						□	□		□		□				
Rhynch. tirolicus									□						
Rhynch. schochardti							□								
***Rhynchosauroides* sp.**						□	□		□						
Rhynch.* aff. *palmatus						□									
Rhynchosauroides pallinii						□									
***Dicynodontipus* sp.**						□									
Ichnioth.* aff. *cottae						□									
Ichniotherium accordii						□									
Pachypes dolomiticus						□									
Dromopus didactylus				□											
Dromopus lacertoides				□											
Amphisauropus latus				□											
Ichniotherium cottae				□											
Varanopus curvidactylus				□											
?Camunipes cassinisi				□											
***Batrachichnus* sp.**				□											

Fig. 4 – Stratigraphical distribution of the main groups of footprints for the Permo-Triassic sediments of northern Italy. Some clusters representing evolutionary levels can be distinguished. PERMIAN: A - Asselian; S - Sakmarian; A - Artinskian; K - Kungurian; K - Kazanian; T - Tatarian. TRIASSIC: I - Induan; O - Olenekian; A - Anisian; L - Ladinian; C - Carnian; N - Norian; R - Raethian. JURASSIC: H - Hettangian; S - Sinemurian; P - Pliensbachian.

The use of a sequence of footprint-based evolutionary units (LIUs) seems at the moment the most suitable system for timing and correlation of the continental sediments. A sequence of LIUs and the corresponding LIAs, still to be established after calibration, could be a powerful tool to apply to the problem of continental stratigraphy.

Taking into consideration the still general zoological meaning of the ichnogenera, it is obvious that the sensitivity of such units will be poor with respect to the units used in marine stratigraphy, since those biozones related to body fossils will carry greater confidence and will be considered more suitable where they can be used.

REFERENCES

ABEL O., 1926. Der erste Fund einer Tetrapodenfährte in den unteren alpinen Trias. *Paläont. Z.*, 7 f1: 22-24.

ABEL O., 1929. Eine Reptilfährte aus dem Oberen Perm (Grödener Sandstein) der Gegend von Bozen, Südtirol. *Palaeobiology*, Leipzig, 2: 1-14.

ANDERSON J.M. & CRUICKSHANK A.R.I., 1978. The biostratigraphy of the Permian and the Triassic: part 5. A review of the classification and distribution of Permo-Triassic tetrapods. *Palaeont. Africana*, 12: 15-44.

AVANZINI M., in press. *Synaptichnium* tracks with skin impressions from the Anisian (middle Triassic) of the Southern Alps (Val di Non-Italy). *Ichnos*, Amsterdam.

AVANZINI M. & NERI C., 1998. Impronte di tetrapodi da sedimenti anisici della Valle di Non (Trentino occidentale - Italia): nota preliminare. *Ann. Mus. Civ. St. Nat. Ferrara*, 1: 5-19.

AVANZINI M., DALLA VECCHIA F.M., DE ZANCHE V., GIANOLLA P., MIETTO P., PRETO N. & ROGHI G., in press. Aspetti stratigrafici relativi alla presenza di tetrapodi nelle piattaforme carbonatiche mesozoiche del Sudalpino. *Collana Studi Acc. Naz. SS.LL.AA.*, Modena.

BAKKER R.T., 1977. Tetrapod mass extinction - a model of the regulation and speciation rates and immigration by cycles of topographic diversity. In: Hallam A. (ed.), *Patterns of evolution as illustrated by the fossil record*. Elsevier Publ. Comp., Amsterdam: 439-468.

BENTON M. J., 1993. *The Fossil Record 2*. Chapmann & Hall, London: 845 pp.

BERRUTI G., 1969. Osservazioni biostratigrafiche sulle formazioni continentali pre-quaternarie delle valli Trompia e Sabbia. II. Sulla fauna fossile della Formazione di Collio (alta Val Trompia). *Natura Bresciana*, Ann. Mus. Civ. Sc. Nat., Brescia, 6: 3-32.

BONAPARTE J.F., 1973. Edades/Réptil para el Triásico de Argentina y Brasil. *Actas 5° Congr. Geol. Argentino*, Buenos Aires, 3: 93-129.

BOY J.A. & FICHTER J., 1988 a. Zur Stratigraphie des Höheren Rotliegend im Saar-Nahe-Becken (Unter-Perm; SW-Deutschland) und seiner Korrelation mit anderen Gebieten. *N. Jb. Geol. Paläont. Abh.*, Stuttgart, 176 (3): 331-394.

BOY J.A. & FICHTER J., 1988 b. Ist die Stratigraphische Verbreitung der Tetrapodenfährten im Rotliegenden ökologisch beeinflußt?. *Z. geol. Wiss.*, Berlin, 16 (9): 877-883.

BRANDNER R., 1973. Tetrapodenfährten aus der unteren Mitteltrias der Südalpen. *Festschrift Heissel, Veröffentlichungen*, Univ. Innsbruck, 86: 57-71.

BROMLEY R.G., 1997. *Oral communication at the Workshop: Ichnofacies and ichnotaxonomy of the terrestrial Permian*. March 8-11, 1997, Halle/Saale: 13 pp.

BROUTIN J., CHÂTEAUNEUF J.J., GALTIER J. & RONCHI A., 1999. L'Autunien d'Autun reste-t-il une référence pour les depôts continentaux du Permien inférieur d'Europe? Apport des données paléobotaniques. *Géologie de France*, Paris, 2: 17-31.

BUFFARD R., 1968. Le Muschelkalk de la région de Villersexel (Haute Saône) et du massif de la Serre (Jura). *Thèse 3e cycle*, Dijon: 188 pp.

CARVALHO I. DE S., VIANA M.S.S. & LIMA F.M.F., 1994. Dinossauros do Siluriano: un anacronismo crono-geológico nas bacias interiores do Nordeste? *Atad 48° Congr. Brasil. de Geologia*, Rio de Janeiro, Boletim de resumos expandidos, 3: 213-214.

CASATI P., 1969. Strutture della Formazione di Collio (Permiano Inferiore) nelle Alpi Orobie. *Natura. Soc. It. Sc. Nat., Museo Civ. St. Nat. e Acquario Civ.*, Milano, 60 (4): 301-312.

CASATI P. & FORCELLA F., 1988. Alpi Orobie. In: *"Il Bollettino", CAI - Annuario Comitato scientifico centrale*, Torino, 87: 81-86.

CASSINIS G., 1966. La Formazione di Collio nell'area tipo dell'alta Val Trompia (Permiano inferiore bresciano). *Riv. Ital. Paleont. Stratigr.*, 72: 507-588.

CASSINIS G. & DOUBINGER J., 1991 a. On the geological time of the typical Collio and Tregiovo continental beds in the Southalpine Permian (Italy), and some additional observations. *Atti Ticin. Sci. Terra*, Pavia, 34: 1-20.

CASSINIS G. & DOUBINGER J., 1991 b. Artinskian to Ufimian palynomorph assemblages from the Central Southern Alps, Italy and their regional stratigraphic implications. In: Nairn A.E.M. & Koroteev V. (eds), *Contribution to Eurasian geology*, Intern. Congr. Permian System of the World, Perm, Russia, 5-10 August 1991. Occasional pubbl. ESRI New Series No 8b, Columbia, University of South Carolina, part I: 9-18.

CASSINIS G., MASSARI F., NERI C. & VENTURINI C., 1988. The continental Permian in the Southern Alps (Italy). A review. *Z. geol. Wiss.*, Berlin, 16 (11/12): 1117-1126.

CASSINIS G., CORTESOGNO L., GAGGERO L., MASSARI F., NERI C., NICOSIA U. & PITTAU P. (coordinators), 1999. *Stratigraphy and facies of the Permian deposits between Eastern Lombardy and the Western Dolomites. Field Trip Guidebook*. Intern. Field Conf. on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations". 23-25 September 1999, Brescia. Earth Sci. Dept., Pavia University, Pavia: 157 pp.

CASSINIS G., NICOSIA U., RONCHI A. & SANTI G., 2000. Impronte di tetrapodi nel Permiano orobico e loro implicazioni stratigrafiche. Nota preliminare. *Rend. Ist. Lomb. Acc. Sc. e Lett.*, B., 132 (1998): 197-217.

CASSINIS G., NICOSIA U., PITTAU P. & RONCHI A., in press. Palaeontological and radiometric data from the Permian deposits of the Southern Alps (Italy), and their stratigraphic implications. *Ass. Géol. du Permien*, June 1999, Paris.

CEOLONI P., CONTI M.A., MARIOTTI N., MIETTO P. & NICOSIA U., 1987. Tetrapod footprints from Collio Fm. (Lombardy, Northern Italy). *Mem. Sci. Geol.*, Padova, 39: 213-233.

CEOLONI P., CONTI M.A., MARIOTTI N. & MIETTO P. & NICOSIA U., 1988 a. Tetrapod footprint faunas from Southern and Central Europe. *Z. geol. Wiss.*, Berlin, 16 (9): 895-906.

CEOLONI P., CONTI M.A., MARIOTTI N. & NICOSIA U., 1988 b. New Late Permian tetrapod footprints from the Southern Alps. *Mem. Soc. Geol. Ital.*, 34 (1986): 45-65.

CHARLES H., 1949. Note sur la présence de *Chirotherium* près de Solliès - Ville (Var). *C.R. Seance Et. Paléthn. - Provence*, 2: 10-12.

CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1975. Tetrapod footprints, fishes and molluscs from the Middle Permian of the Dolomites (N. Italy). *Mem. Geopaleont. Univ. Ferrara*, 3 (2): 141-150.

CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1977. Tetrapod footprints of the "Val Gardena Sandstone" (North Italy). Their paleontological, stratigraphic and paleoenvironmental meaning. *Palaeontographia Ital.*, Pisa, N.S., 40: 1-91.

CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1979. Nuovo contributo alla stratigrafia delle "Arenarie di Val Gardena". *Mem. Soc. Geol. Ital.*, 20: 357-363.

CONTI M.A., LEONARDI G., MARIOTTI N., NICOSIA U., 1980 a. A review of a group of Permian tetrapod footprints from Northern Italy. *Mem. Sci. Geol.*, Padova, 34: 143-152.

CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1980 b. Tetrapodi e pesci della Val Gardena. *In:* Autori Vari: *I vertebrati fossili italiani - Catalogo della Mostra.* Verona: 51-60.

CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1987. Sobre una nova localidade com icnofauna de repteis do Permiano Superior na formacao Arenarie di Val Gardena nos arredores de Redagno (Bolzano, Italia). *1040 Anais do Xesimo Congr. Brasil. Pal.*, Rio de Janeiro: 319-332.

CONTI M.A., MARIOTTI N., MIETTO P. & NICOSIA U., 1989. Correlation elements in the central western Southalpine Permian. *Ass. Géol. du Permien I° Réun.*, 16-17 Juin 1988, Paris, Abstr. Vol.: 26-28.

CONTI M.A., MARIOTTI N., MIETTO P. & NICOSIA U., 1991. Nuove ricerche sugli icnofossili della Formazione di Collio in Val Trompia (Brescia). *Natura Bresciana.* Ann. Mus. Civ. Sc. Nat., Brescia, 26 (1989): 109-119.

CONTI M.A., MARIOTTI N., NICOSIA U. & PITTAU P., 1997. Selected bioevents succession in the continental Permian of the Southern Alps (Italy): improvements of intrabasinal and interregional correlations. In: Dickins J.M. (ed.), *Late Palaeozoic and Early Mesozoic circum-pacific events and their global correlation.* Cambridge University Press, Cambridge: 51-65.

CONTI M.A., LEONARDI G., MIETTO P. & NICOSIA U., 2000. Orme di tetrapodi non dinosauriani del Paleozoico e Mesozoico in Italia. In: Leonardi G. & Mietto P. (eds), *Dinosauri in Italia. Le orme giurassiche dei Lavini di Marco (Trentino) e gli altri resti fossili italiani.* Accademia Editoriale, Pisa: 297-320.

COUREL L. & DEMATHIEU G., 1973. Données récentes sur le Trias du Mont d'Or Lyonnais dans les domaines de la stratigraphie et de l'ichnologie. *Geobios*, 6 (1): 5-26.

COUREL L., DEMATHIEU G. & BUFFARD R., 1968. Empreintes de pas de vertébrés et stratigraphie du Trias. *Bull. Soc. Géol. France*, 7 (X): 275-281.

COWIE J.W., ZIEGLER W., BOUCOT A.J., BASSET M.G. & REMANE J., 1986. Guideline and Statutes of the International Commission on Stratigraphy. *Cour. Forsch.-Inst. Senck.*, Frankfurt/M., 83: 1-14.

CURIONI G., 1870. Osservazioni geologiche sulla Val Trompia. *Rend. Ist. Lomb. Sc. Lett. Arti, Mem.*, Milano, Ser. 3, 2: 1-60.

DALLA VECCHIA F.M., 1996. Archosaurian trackways in the Upper Carnian of Dogna Valley (Udine, Friuli, NE Italy). *Natura Nascosta*, Monfalcone, 12: 5-17.

DALLA VECCHIA F.M. & MIETTO P., 1998. Impronte di rettili terrestri nella Dolomia Principale (Triassico superiore) delle Prealpi carniche (Pordenone, Friuli). *Atti Ticin. Sci. Terra*, Pavia, ser. spec., 7: 87-107.

DAUBRÉE A., 1857. Notes sur la découverte de traces de pattes de quadrupède dans les grès bigarrés de Saint Valbert près Luxeuil (Haute-Saône). *Bull. Soc. Géol. France*, 2 (XV): 218-221.

DE ZANCHE V. & FARABEGOLI E., 1982. Scythian-Anisian lithostratigraphic units in the Southern Alps. *Geol.-Paläont. Mitt.*, Innsbruck, 11: 299-308.

DE ZANCHE V., GIANOLLA P., MIETTO P., SIORPAES C. & VAIL P.R., 1993. Triassic sequence stratigraphy in the Dolomites (Italy). *Mem. Sci. Geol.*, Padova, 45: 1-27.

DEMATHIEU G., 1977. La palichnologie des vertébrés. Développement récent et rôle dans la stratigraphie du Trias. *Bull. du B.R.G.M.*, IV (3): 269-278.

DEMATHIEU G., 1984. Une ichnofaune du Trias moyen du basin de Lodève (Hérault, France). *Ann. Paléont. (Vert.-Invert.)*, Paris, 70 (4): 247-273.

DEMATHIEU G. & DURAND M., 1975. A propos de quelques traces de pas et figures sedimentaires dans le Buntsandstein supérieur du sud-ouest des Vosges. *Bull. Acad. et Soc. Lor. des Sci.*, 54 (1): 23-36.

DEMATHIEU G. & GAND G., 1992. La palichnofaune des bassins permiens provençaux. *Geobios*, 25 (1): 19-54.

DEMATHIEU G. & HAUBOLD H., 1974. Evolution und Lebensgemeinschaft Terrestrischer Tetrapoden nach ihren Faehrten in der Trias. *Freiberger Forschh.*, Leipzig, C 298: 51-72.

DEMATHIEU G. & LEITZ F., 1982. Wirbeltierfährten aus dem Röt von Kronach (Trias Nordost - Bayern). *Mitt. bayer. Staatssamml. Paläont. hist. Geol.*, München, 22: 63-89.

DEMATHIEU G. & OOSTERINK H.W., 1983. Die Wirbeltier - Ichnofauna aus dem unteren Muschelkalk von Winterswijk. *Staringia*, 7: 1-50.

DEMATHIEU G. & WEIDMANN M., 1982. Les empreintes de pas de reptiles dans le Trias du Vieux Emosson (Finahaut, Valais, Suisse). *Eclogae geol. Helv.*, 75 (3): 721-.

DOZY J.J., 1935. Einige Tierfährten aus dem unteren Perm der Bergamasker Alpen. *Paläont. Z.*, Berlin, 17 (1-2): 45-55.

ELLEMBERGER P., 1965. Découvertes de pistes de Vertébrés dans le Permien, le Trias, le Lias inférieur aux abords de Toulon (Var) et d'Anduze (Gard). *C.R. Acad. Sci. Paris*, 269: 5856-5859.

ELLEMBERGER P., 1970. Les niveaux paléontologiques de première apparition des mammifères primordiaux en Afrique du Sud et leur ichnologie. *Proc. Pap. 2nd Gondwana Symp. S. Afr.*, 1970: 343-370.

ELLEMBERGER P., 1972. Contribution à la classification des pistes de vertébrés du Trias: Les types du Stromberg d'Afrique du Sud (I). *Palaeovertebrata,* Mém. extraor., Montpellier: 152 pp.

ELLEMBERGER P., 1974. Contribution à la classification des pistes de vertébrés du Trias: Les types du Stromberg d'Afrique du Sud (II partie: Le Stromberg superieur - I. Le biome de la zone B/1 ou niveau de Moyeni: ses biocenoses). *Palaeovertebrata,* Mém. extraor., Montpellier: 1-142.

ELLEMBERGER P., 1983 a. Sur la zonation ichnologique du Permian moyen (Saxonien) du bassin de Lodève (Hérault). *C.R. Acad. Sci. Paris*, 297 (II): 553-558.

ELLEMBERGER P., 1983 b. Sur la zonation ichnologique du Permian inférieur (Autunien) du bassin de Lodève (Hérault). *C.R. Acad. Sci. Paris*, 297 (II): 631-636.

ELLEMBERGER P., 1984. Données complementaires sur la zonation ichnologique du Permien du Midi de la France (bassin de Lodève, Saint-Affrique et Rodez). *C.R. Acad. Sci. Paris*, 299 (II): 581-586.

GAND G., 1987. Les traces de vertébrés du Permien français (Paléontologie, Stratigraphie, Paléoenvironnements). *Thèse de doctorat III cycle,* Univ. de Bourgogne, Centre des Sciences de la Terre, Dijon: 341 pp.

GAND G. & HAUBOLD H., 1988. Permian tetrapod footprints in Central Europe, stratigraphical and palaeontological aspects. *Z. geol. Wiss.*, Berlin, 16 (9): 885-894.

GAND G., DEMATHIEU G. & BALLESTRA F., 1995. La palichnofaune de vertébrés tétrapodes du Permien supérieur de l'Estérel (Provence, France). *Palaeontographica Abt.*, Stuttgart, A, 235: 97-139.

GEINITZ H.B., 1869. Über fossile Pflanzenreste aus dem Dyas von Val Trompia. *N. Jb. Mineral. Geol. Paläont.*, Stuttgart: 456-461.

GERVAIS P., 1857. Sur les empreintes de pas laisées par plusieurs espèces d'animaux dans le terrain triasique des environs de Lodève. *C. R. Acad. Sc. Paris*, 45: 763.

GIANOLLA P., DE ZANCHE V. & MIETTO P., 1998. Triassic sequence stratigraphy in the Southern Alps (Northern Italy): definition of sequences and basin evolution. In: *Mesozoic and Cenozoic sequence stratigraphy of European basins*. SEPM, Tulsa (Oklahoma), sp. pubbl., 60: 721-747.

GÜMBEL C.W., 1880. Geognostische Mitteilungen aus den Alpen. VI. Ein Geognostischer Streifzug durch die Bergamasker Alpen. *Sitzber. K. Akad. Wiss., Mathem.-naturwiss. Kl.*, München, 1031 (2): 164-240.

HAQ B.U., HARDENBOL J. & VAIL P.R., 1987. Chronology of fluctuating sea levels since the Triassic (250 million years ago to present). *Science*, Washington, 235: 1156-1167.

HAQ B.U., HARDENBOL J. & VAIL P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In: *Sea level changes: an integrated approach*. SEPM, Tulsa (Oklahoma), sp. pubbl., 42: 71-108.

HARLAND W.B., 1992. Stratigraphic regulation and guidance: A critic of current tendencies in stratigraphic codes and guides. *Bull. Geol. Soc. Amer.*, Boulder (Colorado), 104: 1231-1235.

HAUBOLD H., 1966. Therapsiden- und Rhynchocephalen-fährten aus dem Buntsandstein Südthüringens. *Hercynia*, NF, 3 (2):147-183.

HAUBOLD H., 1971 a. Ichnia Amphibiorum et Reptiliorum fossilium. In: Kuhn O. (ed.), *Handbuch der Palaeoherpetologie*. G. Fischer Verlag, Stuttgart, 18: 1-124.

HAUBOLD H., 1971 b. Die Tetrapodenfährten des Buntsandsteins in der deutschen Demokratische Republik und in Westdeutschland und ihre Aequivalente in der gesamten Trias. *Paläont. Abh.*, Berlin, 4 (3): 395-660.

HAUBOLD H., 1984. *Saurierfährten*. Ziemsen Verlag, Wittemberg Lutherstadt: 231 pp.

HAUBOLD H., 1986. Archosaur footprints at the Triassic-Jurassic transition. In: Padian K. (ed.), *The beginning of the age of Dinosaurs*. Cambridge University Press: 189-201.

HAUBOLD H., 1996. Ichnotaxonomie und Klassifikation von Tetrapodenfährten aus dem Perm. *Hallesches Jb. Geowiss.*, Halle, B 18: 23-88.

HAUBOLD H. & SARJEANT W.A.S., 1974. Fossil vertebrate footprints and the stratigraphical correlation of the Keele and Enville Beds of the Birmingham Region. *Proc. Birmingham Nat. Hist. Soc.*, 22 (4): 257-268.

HAUBOLD H., HUNT A.P., LUCAS S.G. & LOCKLEY M.G., 1995 a. Wolfcampian (Early Permian) Vertebrate tracks from Arizona and New Mexico. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 135-166.

HAUBOLD H., LOCKLEY M.G., HUNT A.P. & LUCAS S.G., 1995 b. Lacertoid footprints from Permian dune sandstones, Cornberg and DeChelly Sandstones. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 235-244.

HEDBERG H.D., 1976. *International stratigraphic guide*. A Wiley-Interscience Publication, John Wiley and Sons, New York: 96 pp.

HOLUB V. & KOZUR H., 1981. Revision einiger Tetrapodenfährten des Rotliegenden und biostratigraphische Auswertung der Tetrapodenfährten des obersten Karbon und Perm. *Geol. Paläont. Mitt. Innsbruck*, 11 (4): 149-193.

HUNT A.P. & LUCAS S.G., 1993. Tetrapod footprints from the middle Triassic Moenkopi Formation, west-central New Mexico. In: Lucas S.G. & Morales M. (eds), *The nonmarine Triassic*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 3: 213-218.

HUNT A.P., LUCAS S.G., HAUBOLD H. & LOCKLEY M.G., 1995 a. Early Permian (Late Wolfcampian) tetrapod tracks from the Robledo Mountains, South-Central New Mexico. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 167-180.

HUNT A.P., LUCAS S.G. & LOCKLEY M.G., 1995 b. Paleozoic tracksites of the Western United States. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 213-218.

ITALIAN IGCP 203 GROUP, 1986 (ed.). Field Conf. on: *Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys. Field Guide-Book. Brescia, July 1986*. Tipolitogr. Comm. Pavese, Pavia: 180 pp.

KITTL E., 1891. Saurier-Fährte von Bozen. Mitt. Oesterreich. *Tour Klub.*, Wien: 3/7.

LEONARDI G., 2000. I dinosauri d'Italia e delle aree adiacenti. In: Leonardi G. & Mietto P. (eds), *Dinosauri in Italia. Le orme giurassiche dei Lavini di Marco (Trentino) e gli altri resti fossili italiani*. Accademia Editoriale, Pisa: 275-295.

LEONARDI G. & AVANZINI M., 1994. Dinosauri in Italia. In: Ligabue G. (ed.), *Il tempo dei dinosauri*. Le Scienze quaderni, Milano, 76: 69-81.

LEONARDI G. & LOCKLEY M.G., 1995. A proposal to abandone the ichnogenus *Coelurosaurichnus* Huene, 1941 - A junior synonym of Grallator E. Hitchcock, 1858. *J. Vert. Paleont.*, Lawrence, 15 (3): 40 A (Abstract).

LEONARDI G. & NICOSIA U., 1973. Stegocephaloid footprint in the Middle Permian Sandstone ("Grödener Sandsteine") of the Western Dolomites. *Ann. Univ. Ferrara*, 6 (5): 115-124.

LEONARDI P., 1967. *Le Dolomiti. Geologia dei monti tra Isarco e Piave*. 2 vol., Manfrini Ed., Rovereto: 1019 pp.

LEONARDI P., CONTI M.A., LEONARDI G., MARIOTTI N. & NICOSIA U., 1975. *Pachypes dolomiticus* n. gen. n. sp.; Pareiasaur footprint from the "Val Gardena Sandstone" (Middle Permian) in the Western Dolomites (N. Italy). *Acc. Naz. Lincei, Rend. Cl. Sc. mat. fis. nat.*, ser. VIII, Roma, 57 (3-4): 221-232.

LOCKLEY M.G., KING M., HOWE S. & SHARP T., 1996. Dinosaur tracks and other archosaur footprints from the Triassic of south Wales. *Ichnos*, Amsterdam, 5: 23-41.

LUCAS S.G., 1996. Tetrapod biochronology supports three-epoch Permian. *Permophiles*, 28: 39-44.

LUCAS S.G., 1998 a. Global Triassic tetrapod biostratigraphy and biochronology. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, Amsterdam, 143: 345-382.

LUCAS S.G., 1998 b. Permian tetrapod biochronology. *Permophiles*, 32: 17-23.

LUCAS S.G., 1999. A tetrapod-based Triassic timescale. *Albertiana*, 22: 31-40.

LUCAS S.G. & HUNT A.P., 1995. Stratigraphy and paleontology of the Permian Earp Formation, Big Hatchet Mountains, Hildago County, New Mexico. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 287-294.

LUCAS S.G., HUNT A. P. & HECKERT A.B., 1995 a. Preliminary report on paleontology of the Abo Formation, McLeod Hills, Sierra County, New Mexico. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 279-286.

LUCAS S.G., HUNT A.P., HECKERT A.B. & HAUBOLD H., 1995 b. Vertebrate paleontology of the Robledo Mountains Member of the Hueco Formation, Doña Ana Mountains, New Mexico. In: Lucas

S.G. & Heckert A.B. (eds), *Early Permian footprints and facies.* New Mexico Mus. Nat. Hist. Sci. Bull., Albuquerque, 6: 269-278.

LUCAS S.G., LOZOVSKY V.R. & SHISHKIN M.A., 1999. Tetrapod footprints from Early Permian Redbeds of the Northern Caucasus, Russia. *Ichnos*, Amsterdam, 6 (4): 277-281.

LÜTZNER H. (ed.), 1987. Symposium on Rotliegendes in Central Europe. Sedimentary and volcanic Rotliegendes of the Saale depression. *Excursion Guide-book*, 1987, Potsdam: 197 pp.

MASSARI F., CONTI M.A., FONTANA D., HELMOLD K., MARIOTTI N., NERI C., NICOSIA U., ORI G.G., PASINI M. & PITTAU P., 1988. The Val Gardena Sandstone and *Bellerophon* Formation in the Bletterbach Gorge (Alto Adige, Italy): biostratigraphy and sedimentology. *Mem. Sci. Geol.*, Padova, 40: 229-273.

MENNING M., 2000 a. Homogene Stratigraphische Terminologie für die Dyas (Geinitz 1861) und die Germanische Trias (Von Alberti 1834). In: *"An Intern. Symp. in Honour of Hanns Bruno Geinitz"*, 28.1 - 30.1.2000, Dresden, Abstract vol: p. 93.

MENNING M., 2000 b. Global correlation and numerical calibration of the Dyas (Geinitz 1861, Rotligend and Zechstein, Permo-Carboniferous). In: *"An Intern. Symp. in Honour of Hanns Bruno Geinitz"*, 28.1 - 30.1.2000, Dresden, Abstract vol.: 95-97.

MIETTO P., 1975. Orme di tetrapodi nelle arenarie permiche di Recoaro (Vicenza). *Stud. Trent. Sci. Nat.*, Trento, 52 (3a): 57-67.

MIETTO P., 1981. Una grande impronta di pareiasauro nel Permiano di Recoaro (Vicenza). *Rend. Soc. Geol. Ital.*, 4: 363-364.

MIETTO P., 1986. Orme di tetrapodi nella Formazione di Werfen del Recoarese. *Riv. Ital. Paleont. Stratigr.*, 92 (3): 321-326.

MIETTO P., 1987. *Parasynaptichium gracilis* nov. ichnog., nov. sp. (Reptilia: Archosauria Pseudosuchia) nell'Anisico inferiore di Recoaro (Prealpi vicentine - Italia). *Mem. Sci. Geol.*, Padova, 39: 37-47.

MIETTO P., 1988. Piste di dinosauri nella Dolomia Principale (Triassico superiore) del Monte Pelmetto (Cadore). *Mem. Soc. Geol. Ital.*, 30 (1985): 293-299.

MIETTO P., 1990. Le piste di dinosauri sulle rocce triassiche del Pelmetto. *Ass. Cult. "Amici del Museo"*, Selva di Cadore (BI): 11pp.

MIETTO P., 1992. Impronte di dinosauri nel Triassico superiore delle Dolomiti. In: *Dinosaurs. Il mondo dei dinosauri*. Calliano (Trento): 83-87.

MIETTO P., 1995. Museo paleontologico "Dott. Domenico Dal Lago". Guida illustrativa. *Centro Cult. "G. Marzotto"*, Valdagno (Vicenza): 70 pp.

MIETTO P., 2000. La Sezione Geologica del Museo della Val Fiorentina. In: *Museo Selva di Cadore. Storia, Archeologia e Geologia della Val Fiorentina*. Cortina d'Ampezzo (Belluno): 7-29.

MIETTO P. & MANFRIN S., 1995 a. A high resolution Middle Triassic ammonoid standard scale in the Tethys Realm. A preliminary report. *Bull. Soc. Géol. France*, 166 (5): 539-563.

MIETTO P. & MANFRIN S., 1995 b. La successione delle faune ad ammonoidi al limite Ladinico-Carnico (Sudalpino, Italia). *Ann. Sci. Terra Univ. Ferrara*, suppl. 5: 13-35.

MIETTO P. & MUSCIO G., 1987. *Prochirotherium permicum* Leonardi, 1951 (Reptilia: ? Chiroteriidae) nelle Arenarie di Val Gardena della Carnia. *Atti Museo Friul. Storia Nat.*, Udine, 8 (1986): 81-94.

MORALES M. & HAUBOLD H., 1995. Tetrapod tracks from the Lower Permian DeChelly Sandstones of Arizona: systematic description. In: Lucas S.G. & Heckert A.B. (eds), *Early Permian footprints and facies*. New Mexico Mus. Nat Hist. Sci. Bull., Albuquerque, 6: 251-262.

MÜLLER A.H., 1959. Die erste Wirbeltierfährte (*Paradoxichnium problematicum* n. g., n. sp.) aus dem Terrestrischen Zechstein von Thüringen. *Monatsb. Deutsch. Akad. Wiss.*, Berlin, 1 (7-10): 615-623.

NERI C., MASSARI F., CONTI M. A., MARIOTTI N., NICOSIA U. & PITTAU P., 1994. Permian stratigraphy in the Southern Alps (Italy): new contributions. *Permophiles*, 25: 25-33.

NICOSIA U., RONCHI A. & SANTI G., 1999 a. Permian tetrapods from the western Orobic Basin (N Italy), with correlations. *Intern. Field Conf. on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations"*. 15-25 September 1999, Brescia, Abstracts vol.: 28-30.

NICOSIA U., SACCHI E. & SPEZZAMONTE M., 1999 b. New paleontological data on the Val Gardena Sandstone. *Intern. Field Conf. on "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations"*. 15-25 September 1999, Brescia, Abstracts vol.: 33.

NICOSIA U., RONCHI A. & SANTI G., 2000. Permian tetrapod footprints from Orobic Basin (Northern Italy). Biochronological and evolutionary remarks. *Geobios*, 33(6): 753-768.

OLSEN P.E., 1980. A comparison of vertebrate assemblage from the Newark and Hartford Basins (Early Mesozoic, Newark Supergroup) of Eastern North America. In: Jacobs L.L. (ed.), *Aspect of vertebrate history*. Museum of Northern Arizona Press, Flagstaff (Arizona): 35-53.

OLSEN P.E., 1983. Relationships between biostratigraphic subdivision and igneous activity in the Newark Supergroup. *Geol. Soc. Am.*, Abstract Progr., 15: 93.

OLSEN P.E. & GALTON P.M., 1984. A review of the reptile and amphibian assemblages from the Stromberg of Southern Africa, with special emphasis on the footprints and the age of the Stromberg. *Palaeont. Afr*, 25: 87-110.

ORZAG-SPERBERG F., 1966. Stratigraphie et paléogeographie du Trias de Lodève (Hérault). *Bull. Soc. Géol. France*, 7 (VIII): 667-671.

PAJAK A.F.I., SCOTT E. & BELL C. J., 1996. A review of biostratigraphy of Pliocene and Pleistocene sediments in the Elsinore Fault Zone, Riverside County, California. In: Bell C. J. & Sumida S. S. (eds), *The uses of vertebrate fossils in biostratigraphic correlation*. PaleoBios, Berkeley, 17 (2-4): 28-49.

PEABODY F.E., 1948. Reptile and Amphibian trackways from the Lower Triassic Moenkopi Formation of Arizona and Utah. *Bull. Dep. Geol. Sci.*, Berkeley and Los Angeles, 27 (8): 295-468.

PISA G., FARABEGOLI E. & OTT E., 1972. Stratigrafia e paleogeografia dei terreni anisici della Conca di Agordo e dell'alta Val di Zoldo (Dolomiti sudorientali). *Mem. Soc. Geol. Ital.*, 18: 63-92.

REMANE J., BASSET M.G., COWIE J.W., GOHRBANDT K.H., LANE H.R., MICHELESEN O. & NAIWEN W., with the cooperation of members of ICS, 1996. Revised guidelines for the establishment of global chronostratigraphic standards by the International Commission on Stratigraphy (ICS). *Episodes*, 19 (3): 77-81.

ROGHI G. & DALLA VECCHIA F.M., 1997. The palinology and palaeoenvironment of the Upper Triassic Dolomitic/Marly sequence of Dogan Valley (Udine, Friuli Venezia Giulia, NE Italy) with reptile trackways. *Riv. Ital. Paleont. Stratigr.*, 103 (2): 183-192.

ROMER A.S., 1973. Permian reptiles. In: Hallam A. (ed.), *Atlas of palaeobiogeography*. Elsevier, Amsterdam: 159-167.

SALVADOR A., 1987. Unconformity-bounded stratigraphic units. *Geol. Soc. Amer. Bull.*, 98: 232-237.

SALVADOR A. (ed.), 1994. *International stratigraphic guide*. Int. Union Geol. Sci. & Geol. Soc. America, Boulder (Colorado): 214 pp.

SANTI G., 1992. Su alcune impronte d'*Ichniotherium cottae* (Pohlig) 1885 in una lastra depositata nel Museo di Scienze Naturali di Pavia. *Atti Ticin. Sci. Terra*, Pavia, 35:17-29.

SANTI G., in press. Icniti di tetrapodi permiani dell'area bergamasca del Bacino Orobico. Nota preliminare. *Rend. Ist. Lomb. Acc. Sci. Lett.*, Milano.

SANTI G. & KRIEGER C., in press. Lower Permian tetrapod footprints from Brembana Valley – Orobic Basin – (Lombardy, Northern Italy). *Rev. Paléob.*, Genève.

SARJEANT W.A.S., 1971. Vertebrate tracks from the Permian of Castle Peak, Texas. *Texas J. Sci.*, Austin, 22 (4): 343-366.

SCHIMPER W.P., 1850. Palaontologia alsatica. *Mém. Soc. Hist. Nat. Strasbourg*: 6/1.

SIRNA G., DALLA VECCHIA F.M., MUSCIO G. & PICCOLI G., 1994. Catalogue of Paleozoic and Mesozoic vertebrates and vertebrate localities of Tre Venezie area (North Eastern Italy). *Mem. Sci. Geol.*, Padova, 46: 255-281.

SUMIDA S.S., BERMAN D.S. & MARTENS T., 1996. Biostratigraphic correlations between the Lower Permian of North America and Central Europe using the first record of an assemblage of terrestrial tetrapods from Germany. *PaleoBios*, Berkeley, 17 (2-4): 1-12.

WALSH S.L., 1998. Fossil datum and paleobiological event terms, paleontostratigraphy, chronostratigraphy, and the definition of land mammal "Age" boundaries. *J. Vert. Paleont.*, Lawrence, 18 (1): 150-179.

WOPFNER H., 1999. Über Tetrapoden fährten, Kohlen und versteinerte Hölzer aus dem Grödner Sandstein (Perm) bei Deutschnofen. *Derschler*, Bozen, 73 (1): 23-32.

WYSS A.R., CHARRIER R. & FLYNN J.J., 1996. Fossil mammals as a tool in Andean stratigraphy: dwindling evidence of Late Cretaceous volcanism in the South Central Main Range. In: Bell C. J. & Sumida S. S. (eds), *The uses of vertebrate fossils in biostratigraphic correlation*. PaleoBios, Berkeley, 17 (2-4): 13-27.

«NATURA BRESCIANA» Ann. Mus. Civ. Sc. Nat., Brescia, MONOGRAFIA N. 25, 2001: 109-116

CORRELATION OF THE UPPER PERMIAN SPOROMORPH COMPLEXES OF THE SOUTHERN ITALIAN ALPS WITH THE TATARIAN COMPLEXES OF THE STRATOTYPE REGION

PAOLA PITTAU [1]

Key words – Palynology; Upper Permian; correlation; Southern Alps.

Abstract – The microfloras of the sub-Angarian province of the Tatarian stage of Late Permian age, in the type region, have been discussed and compared with Dzhulfian and Changxingian microfloras of the Southern Alps. A moderate taxonomic similarity, as well as different vegetation composition in the two regions, is indicated for the Urzhumsky Horizon (lower Tatarian). The occurrence of *Lunatisporites* and *Klausipollenites schaubergeri* pollen grains, and the smaller number of Costati, enhance the similarity between the Severodvinsky Horizon and the Val Gardena Sandstone 1st cycle microfloras. Based on the presence of *Protohaploxypinus microcorpus* in the Vjatsky Horizon and the very high degree of taxonomic similarity between the assemblages, a correlation is proposed between the microfloras of this late Tatarian horizon and those of the Val Gardena Sandstone and Bellerophon Formation 2nd and 3rd cycles. The appearance of *Lunatisporites noviaulensis*, contained in the topmost levels of the Vjatsky Horizon, and the absence of *Lueckisporites parvus* and *Tympanicysta* from the Tatarian type section, which are observed stratigraphically later in the Southern Alps, might suggest a very limited extent for the stratigraphic gap between the Tatarian and the Triassic, probably coinciding with only part of the Dorashamian (or Changxingian). The strong taxonomic similarity also indicates the rapid dispersion of the plants brought about by territorial continuity and by the similar paleoenvironmental and paleoclimatic conditions in the two regions. The two vegetations formed part of a single Euro-Cisuralian paleobotanical province.

Parole chiave – Palinologia; Permiano superiore; correlazione; Alpi Meridionali.

Riassunto –Vengono discusse e comparate le microflore di età Tatariana della regione tipo, con quelle della regione sudalpina di età Dzhulfiano e Changsingiano.
Si evidenzia una discreta similarità tassonomica tra le microflore delle due regioni in corrispondenza dell' orizzonte di Urzhumsky (Tatariano inferiore); la comparsa di granuli pollinici di *Lunatisporites* e la riduzione dei Costati aumenta la similarità tra le microflore dell'orizzonte di Severodvinsky e quelle di una parte del I ciclo delle Arenarie di Val Gardena; con la comparsa di *Protohaploxypinus microcorpus* nell'orizzonte di Vjatsky, e la alta similarità tassonomica che si instaura tra le associazioni si propone la correlazione tra le microflore di questo orizzonte (Tatariano superiore) con le microflore del I, II e III ciclo delle Arenarie di Val Gardena e della Formazione a Bellerophon. La assenza di *Lueckisporites parvus* e la non documentata presenza dell'evento a funghi (*Tympanicysta*), che nell'area sudalpina seguono stratigraficamente la comparsa di *Lunatisporites noviaulensis*, presente nel Tatariano terminale, potrebbero suggerire che l'entità della lacuna stratigrafica tra il Tatariano e il Trias sarebbe molto ridotta e verosimilmente corrispondente solo a parte del Dorashamiano (o Changsingiano).
La elevata similarità tassonomica evidenzia inoltre la rapida dispersione dei vegetali favorita dalla continuità territoriale e dalle simili condizioni paleoambientali e paleoclimatiche delle due regioni. Le due vegetazioni erano parte di una unica Provincia paleobotanica euro-cisuraliana.

INTRODUCTION

This study intends to contribute to the fervid debate within the Permian Working Group and the Subcommission of Permian Stratigraphy concerning the biostratigraphical and chronostratigraphical correlations of the Upper Permian.

Although understandably it is difficult to establish a correlation between the Upper Permian timescales of Europe and North America, because of the significant differences in sedimentary environments of their respective successions, ranging from continental to paralic in Western and Eastern Europe to deep marine in North America, we believe an attempt can be made to correlate the sporomorph assemblages of the Tatarian in the Volga–Urals type area, to those observed in the Val Gardena Sandstone (VGS) and the Bellerophon Formation in the Italian Alps, through the recognition of paleobotanical events such as the appearance of characteristic components.

The discussion that evolves herein takes into consideration a number of assumptions, namely:

• similar sedimentary environments in the two regions,

[1] Dipartimento di Scienze della Terra, via Trentino 51, 09127 Cagliari, Italy.

from continental to paralic and shallow marine;
• position of the two regions roughly within the same latitude band (Ziegler, 1990) and the same paleoclimatic conditions;
• territorial continuity between Late Hercynian Europe and the East European Platform, ensuring rapid dispersion of the plants.

The Tatarian stage crops out extensively in the type area following the Kazanian, after a stratigraphic gap. Lithologically it is represented by sandstones, variegated clays, marls, dolostones and limestones, frequently crossed by lens-shaped bodies of fluvial sand, indicating prevalently continental, lagoonal and shallow-marine sedimentation. The fossils also belong to continental and lagoonal fauna such as pelecypods, conchostracans, ostracods and vertebrates.

In the type area the Tatarian stage is divided into three horizons: Urzhumsky, Severodvinsky and Vyatska. The most completely exposed portions of the latter horizon are to be found in the River Vetluga basin, where it has been further subdivided into three members (Borozdina & Olferiev, 1970; Olferiev, 1974).

The Tatarian begins with a geomagnetic polarity reversal (Illawarra-Khama Reversal) that continues from the Lower Permian (Burov & Esaulova, 1996). In the stratotype Cisuralian area, the Illawarra event distinguishes the Lower Tatarian (Urzhumskian) from the Upper Tatarian (Severodvinskian and Vjatskian) (Burov & Esaulova, 1996), and in Asiatic Russia the event can be traced up to the Tungusska and Pechora Basin, where it is possible to correlate Upper Permian sediments belonging to different paleobotanical environments.

SPOROMORPH ASSOCIATIONS OF THE TATARIAN IN THE TYPE AREA

Tatarian macro- and microfloras contained in the marine, transitional and continental sediments of the type region have been well identified by Kuntzel (1965), Gomankov & Meyen (1986), Esaulova (1995) and Koloda & Kanev (1996). Thus microfloral associations can be carefully compared on the basis of the widely published data. Biostratigraphical investigations conducted in the Volga–Urals region (Gusev *et al.*, 1993) based on brachiopods, foraminifers, ostracods, pelecypods, radiolarians, corals, bryozoans, macroflora, microflora and continental vertebrates have shown that the most significant changes within the major faunistic groups, along with flora renewal, took place between the Lower and Upper Tatarian. During this interval there was a transition from the floristic *Phylladoderma* complex to the *Tatarina* complex. This passage is believed to be a potentially correlative event between the different paleobotanical provinces of the Russian Federation because it is also marked by a paleomagnetic event.

The Urzhumsky Horizon (lower Tatarian) is characterised by miospore associations in which the striate and costate morphogroups are dominant and the disacciatriletes subdominant. Koloda & Kanev (1996) distinguish three taxa groups (important, common and rare) which, for greater clarity, are shown in table 1.

Roughly 50% of the Urzhumskian xerophytic flora species is present in the sporomorph associations of the Val Gardena Sandstone in the Italian Alps (Pittau, in Massari *et al.*, 1988, 1994; Pittau, in Cassinis, Cortesogno *et al.*,

Main taxa	Common taxa	Rare taxa
Alisporites splendens	*Scheuringipollenites ovatus*	*Limitisporites moersensis*
A. nuthallensis	*Protohaploxypinus jacobii*	*Gardenasporites heisseli*
Vesicaspora schemeli	*P. samoilovitchii*	*Vitreisporites signatus*
Protohaploxypinus amplus	*Ventralvittatina rotunda*	*Falcisporites zapfei*
P. perfectus		*Platysaccus papilionis*
Striatolebachiites spp.		*Gigantosporites* sp.
Vittatina costabilis		*Protohaploxypinus minor*
Vittatina subsaccata		*Striatopodocarpites antiquus*
Weylandites striatus		*Striatoabieites wilsonii*
		S. jansonii
		S. multistriatus
		S. richteri
		Lueckisporites virkkiae
		Representatives of *Weylandites*, *Vittatina* and *Fusacolpites*

Table 1

1999), with the exception of the representatives of *Fusacolpites*, *Striatolebachiites*, *Weylandites*, certain species of *Vittatina* and of *Protohaploxypinus*, specifically *P. amplus* and *P. perfectus*. The latter is a key taxon of the Kazanian microflora (Utting *et al.*, 1997) in the type region and extends up to the lower Tatarian. *P. amplus* has perhaps a broader stratigraphic range, Kungurian–lower Tatarian (Samoilovich, 1953; Varjuchina, 1971; Molin & Koloda, 1972; Foster, 1979; Koloda & Kanev, 1996), and its geographical distribution is also very wide. The two species have never been reported in the Val Gardena Sandstone or in the Bellerophon Formation. On the other hand, they have recently been recorded in the Tregiovo Formation (Pittau in Cassinis, Cortesogno *et al.*, 1999) of the southern Alpine basin, but are still not accurately dated – they may be Kazanian (Pittau in Cassinis, Cortesogno *et al.*, 1999) or Kungurian-Ufimian (Cassinis & Doubinger, 1991), but certainly older than the VGS (Cassinis *et al.*, 1999 and in press). Moreover, in the Urzhumsky microflora, significant characterising components of the younger flora of the southern Alpine and European Permian are missing.

The overlying Severodvinsky horizon is again characterised by xerophytic flora. Compared with the sporomorph associations in the Urzhumsky horizon, the following can be identified:

• a significant decrease in Costati and increase in Disaccites;
• a larger number of *Leuckisporites virkkiae* and, locally, of *Gigantosporites*;
• the appearance of species of *Lunatisporites* (= *Taeniaesporites*), *Scutasporites* and *Klausipollenites shaubergeri*.

The appearance of these pollen grains, especially *Lunatisporites* and *K. schaubergeri*, which are characteristic constituents of the Zechstein and southern Alpine Upper Permian sporomorph associations, is important because it enhances the similarity of the Cisuralian flora with the European flora for this stratigraphic interval.

The change in flora "from *Phylladoderma* to *Tatarina*" reported by the Russian authors appears therefore to translate, from a palynological point of view, into the points outlined above.

The palynological associations in the Vjatsky horizon testify once again to a xerophytic flora with dominant disaccates. *Vitreisporites*, represented by various species, is an abundant component in the associations together with *Leuckisporites virkkiae* and different species of *Lunatisporites* (*Taeniasporites labdacus*, *Taeniaesporites* sp.). *Protohaploxypinus microcorpus* appears along with another, albeit rare, element (*incertae sedis*) reported in the Southern Alps, *Inaperturopollenites nebulosus*. The presence of *Lunatisporites noviaulensis* (*noviaulensis/pellucidus* complex) has been reported by Foster & Jones (1994) in the upper Tatarian strata.

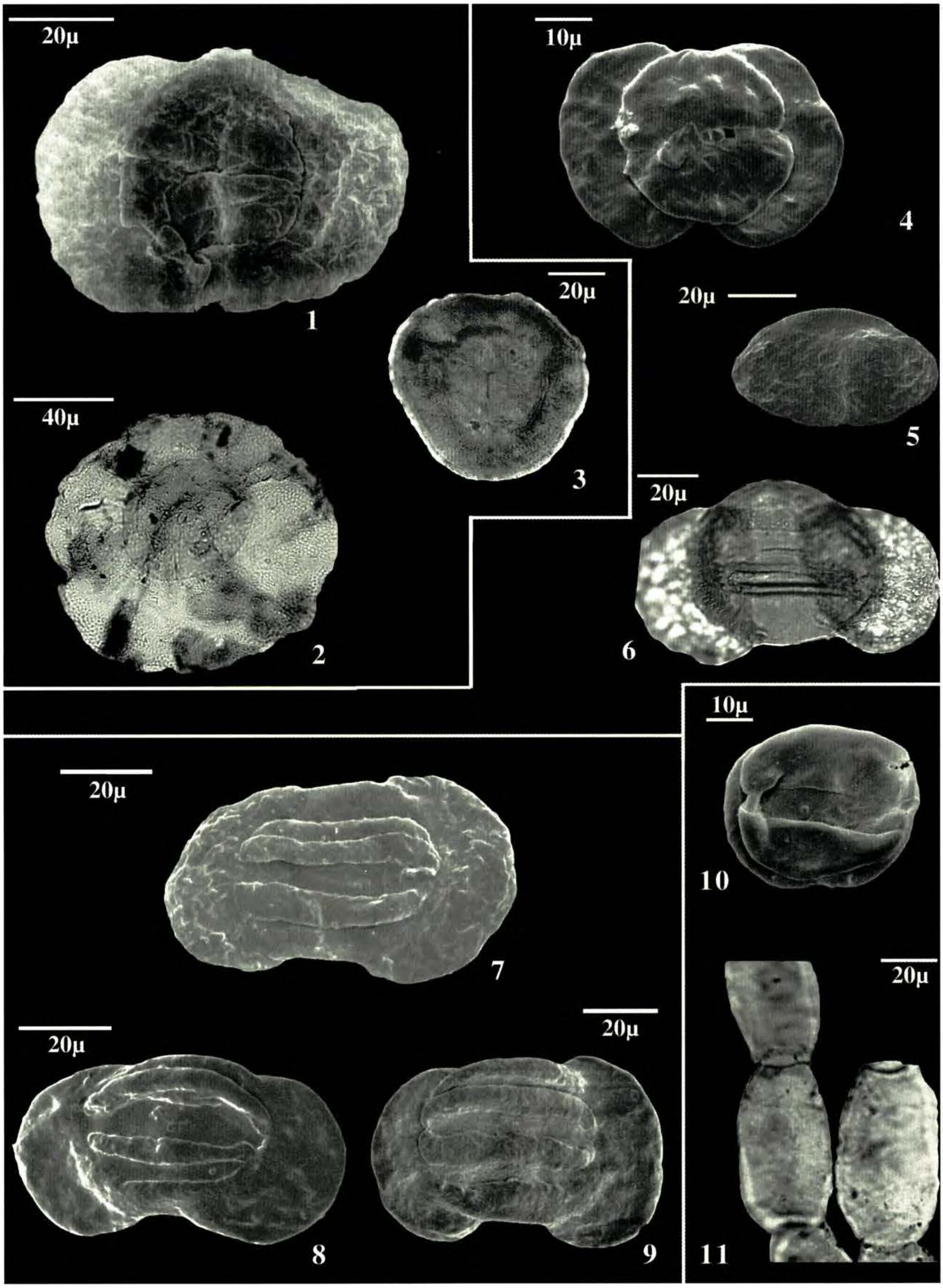
Contextually neither *Tympanicysta* nor *Leuckisporites parvus* have been reported in this stratigraphic interval in the Tatarian type section.

In the subsurface successions of the Moscow syneclise, European Russian Platform, the sporomorph assemblages (Lozovsky & Yaroshenko, 1994) attributed to the Vjatsky horizon are strongly hygrophytic. In the upper member of the horizon (Molomsky), in addition to about 30% of spores and a significant amount of *Ephedripites* (20%), the sporadic presence of *Tympanicysta stoschiana* is also reported. The presence of *Tympanicysta* has also been recorded from the latest Permian to lowermost Triassic basal Vetlugian deposits of Nedubrovo in the Vologda region of the Russian Platform (Krassilov *et al.*, 1999). Through these findings it is possible to define better the upper limit of the Tatarian and the consequent stratigraphic gap, which seems to be very small. Outside this geological district, in the Pechora Basin, *Tympanicysta* has been observed in the Induan (Foster & Yaroshenko, in Foster & Jones, 1994).

COMPARISON WITH THE VAL GARDENA SANDSTONE AND THE BELLEROPHON FORMATION IN THE ITALIAN ALPS

The quantitative and compositional evolution of the microflora in the southern Alpine basin has been addressed by the author in several papers (Conti *et al.*, 1986; Massari *et al.*, 1988, 1994; Conti *et al.*, 1997; Cassinis *et al.*, 1999), in an endeavour to recognise microfloristic events useful for establishing interbasin correlations, as distinguished from useful events for establishing international correlations (Plate 1).

The restricted stratigraphical range of *Protohaploxypinus microcorpus* together with its wide geographical distribution (see Pittau in Massari *et al.*, 1988) make this a very important taxon for correlation. Furthermore, if its FAD is accurately determined in a continuous succession and possibly in the stratotype of a chronostratigraphic unit, its correlating potential and reliability is enhanced considerably. Pittau (Conti *et al.*, 1986; in Massari *et al.*, 1988) attempted to correlate the Val Gardena Sandstone and Bellerophon Formations with the marine stages using key taxa such as *Endosporites hexareticulatus* (= *Playfordiaspora crenulata*, *sensu* Foster, 1979), *Protohaploxypinus microcorpus* and *Densoisporites playfordi*, to correlate the Val Gardena Sandstone (VGS) with the *P. microcorpus* palynozone (including *E. reticulatus* and *P. microcorpus*) in Australia (Foster, 1982) with unit 4 of the Chhidru Formation. At the time a poorly defined Dzhulfian age was assigned. Now that there appears to be general consensus (Foster & Jones, 1994) in attributing unit 4 of the Chhir-


20µ
1
40µ
2
20µ
3
10µ
4
20µ
5
20µ
6
20µ
7
20µ
8
20µ
9
10µ
10
20µ
11

dru Formation to the late Dzhulfian and part of the Dorashamian, this assignment can be extended to the VGS and to part of the Bellerophon Formation.

P. microcorpus appears in the lower portion of the VGS and its FO can be observed in the section with the longest stratigraphical interval relative to the fossil record, namely 20 m above the base of the formation in the Blätterback section (Massari *et al.*, 1988, 1994); it has never been observed in older successions in the Southern Alps, such as the Tregiovo Formation (Pittau in Cassinis *et al.*, 1999; Cassinis & Doubinger, 1991; Barth & Mohr, 1994).

Bearing in mind that this species occurs within the continuous sedimentary succession deposited in continental–paralic environments in the Tatarian type section, and that it has not yet been reported in older strata, the base of the Vjatsky horizon could be taken as the spike (?FAD) for this first appearance, or alternatively, level 2 of the Blätterback Formation, situated 20 m above the base of the VGS Formation, in the first sedimentary cycle.

CORRELATIONS BETWEEN TATARIAN AND SOUTHERN ITALIAN ALPINE SPOROMORPH ASSEMBLAGES

In the light of the above observations, the sporomorph assemblages observed in the Urzhumsky horizon are believed to be older than those of the VGS because they precede the appearance of *Lunatisporites* and *Klausipollenites schaubergeri*. On the other hand, the presence of characterising Kazanian flora species like *Protohaploxypinus amplus* and *P. perfectus*, combined with abundant costates pollen grains, indicate that they are again older than the southern Alpine and Zechstein floras. In conclusion it may be assumed that the Urzhumsky microfloras are older than the VGS and perhaps younger than the Tregiovo microfloras, although this hypothesis needs to be corroborated by further observations.

In the Severodvinsky horizon the palynoflora and plant communities exhibit similarities in the two regions: the floras concerned are meso-xerophytic containing few hygrophytic species, reflecting the extremely low occurrence of spores. The similarity in this stratigraphic interval is accentuated by the presence of *Lunatisporites* (=*Taeniaesporites*), *Klausipollenites schaubergeri* and *Scutasporites*, which, with the increased number of *Luekisporites virkkiae*, make the vegetational composition of the Cisuralian flora more similar to the VGS.

Taking the appearance of *P. microcorpus* as a basis for the correlation, the Severodvinsky microfloras can be correlated with the lower part of the Val Gardena Sandstone, coinciding with part of the first sedimentary cycle (Massari *et al.*, 1994).

The occurrence of *Protohaploxypinus microcorpus* in the Vjatska horizon of the Tatarian type section allows correlation with this portion with the Val Gardena Sandstone, and with part of the Bellerophon Fm.

In fact, the absence of *Lueckisporites parvus* and secondly of *Tympanicysta* can be considered an element of correlation between the two areas, indicating that the Vjatska horizon in the type section does not comprise the entire VGS and the Bellerophon period of deposition, but only a portion of the first cycle, all of the second and part of the third: that is, up to the appearance of *L. parvus* and the fungal event.

The presence of *Lunatisporites noviaulensis*, another important species because of its vast geographical distribution and the fact that its occurrence is stratigraphically confined to the uppermost Permian, is reported by Foster & Jones (1994) in the upper layers of the Vjatska horizon. In the Southern Alps this species occurs prior to the appearance of *L. parvus* and *Tympanicysta*, so again its presence does not contradict the existence of a stratigraphic gap between the Tatarian in the type section and the Triassic.

The comparison suggests a small stratigraphic gap, corresponding to the IV and V sedimentary cycles of the Southern Alpine basin (Massari *et al.*, 1994), which in chronostratigraphical terms should coincide with part of the Changxingian and may be even shorter in other parts of the Moscow syneclise.

Thus, on the basis of the assumptions discussed above and the criteria outlined here, a correlation is suggested between the upper Tatarian and the Val Gardena Sandstone and Bellerophon Formations of the Southern Alps, schematically represented in Fig. 1, and updated in the chronostratigraphical references to the marine stages.

A final consideration concerns the position in temporal terms of the two southern Alpine formations with respect to the paleomagnetic reversal event which was long sought in the Dolomitic basin. According to this correlation hypothesis, the Illawarra Event could be assigned to between the VGS and the Tregiovo Formation.

Plate 1

1. *Protohaploxypinus microcorpus* (Schaarschmidt) Clarke
2. *Endosporites hexareticulatus* Klaus
3. *Densoisporites playfordii* (Balme) Dettman
4. *Lueckisporites virkkiae* Potonié & Klaus
5. *Klausipollenites schaubergeri* Klaus
6. *Lunatisporites labdacus* (Klaus) Pittau
7. *Lunatisporites pellucidus* (Gobin) Helby
8. *Lunatisporites noviaulensis* (Leschik) Scheuring
9. *Lunatisporites noviaulensis* (Leschik) Scheuring
10. *Lueckisporites parvus* Klaus
11. *Tympanicysta stoschiana* Balme

CONCLUSIONS

Comparison of the sporomorph assemblages in the Val Gardena Sandstones and Bellerophon Formations, described in detail by Klaus (1963), Pittau in Conti *et al.* (1986, 1997), Massari *et al.* (1988, 1994), and Cassinis *et al.* (1999), with those of the Tatarian type section described by Koloda & Kanev (1996), has allowed us to advance correlation hypotheses that will certainly have to be substantiated by other data, but that can represent a starting point for further investigations and discussion.

The starting assumption is the territorial contiguity between the two regions and the similar paleoenvironmental and climatic conditions established at the end of the Paleozoic, in addition to the similarity of the microfloras, more so in the Severodvinsky and Vjatsky horizons.

The key features of the correlation are the appearance of *Lunatisporites* and *Klausipollenites schaubergeri* of *Protohaploxypinus microcorpus* and *Lunatisporites noviaulensis*. The absence of *Lueckisporites parvus* and the fungal event are considered correlational elements that rule out the presence of part of the Changxingian in the Tatarian type section, although these two points warrant further investigation.

The correlation proposed here suggests a correspondence of microfloras of the Severodvinsky and Vjatsky horizons with those of the VGS and Bellerophon Formation of the I, II and III cycles (Massari, 1994). The gap claimed to exist between the Tartarian of the type section and the Triassic is believed to coincide with the IV and V sedimentary cycles of the southern Alpine succession, specifically to part of the Changxingian, but there are elements in favour of the existence of a smaller gap in other parts of the Moscow basin (Lozovsky & Yaroshenko, 1994; Krassilov *et al.*, 1999).

Correspondence with the marine stages (Late Dzhulfian and Changxingian) is based on correlation with unit 4 of the Chhidru Formation and on the occurrence of foraminifers in the upper part of the Bellerophon Fm., as pointed out previously (Massari *et al.*, 1988; Conti *et al.*, 1995).

As the scientific debate on correlations of marine and continental scales is always lively and topical in the Working Groups, it is hoped that the subject dealt with in this paper will stimulate further investigation and speculation.

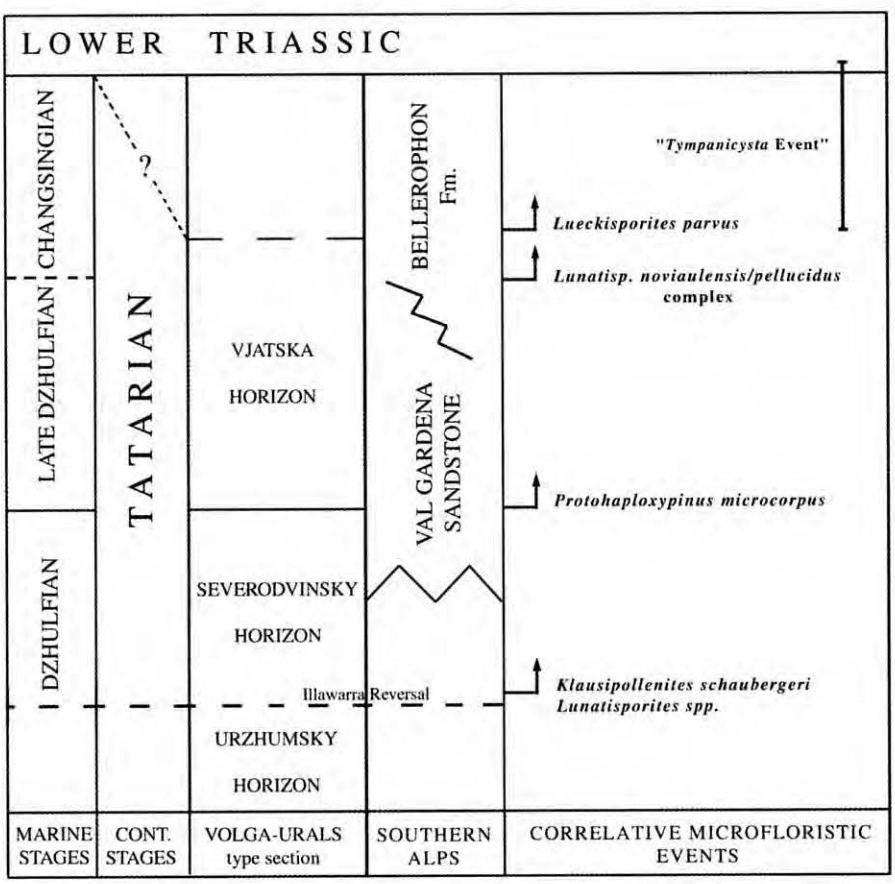


Fig. 1 – Correlation of the Tatarian with Southern Alps continental to shallow marine successions and the marine stages.

List of the sporomorphs cited in the text

Alisporites nuthallensis (Clarke) Balme, 1970
Alisporites splendens (Leschik) Foster, 1979
Densoisporites playfordi (Balme) Dettmann, 1963
Endosporites hexareticulatus Klaus, 1963
Ephedripites sp.
Falcisporites zapfei Klaus, 1963
Fusacolpites sp.
Gardenasporites heisseli Klaus, 1963
Gigantosporites sp.
Inaperturopollenites nebulosus Balme, 1970
Klausipollenites schaubergeri (Potonié et Klaus) Jansonius, 1962
Limitisporites moersensis (Grebe) Klaus, 1963
Lueckisporites parvus Klaus, 1963
Lueckisporites virkkiae Potonié et Klaus, 1954
Lunatisporites (Taeniaesporites)
Lunatisporites labdacus (Klaus) Pittau, 1988
Lunatisporites noviaulensis (Leschik) Scheuring, 1970
Platysaccus papilionis Potonié et Klaus, 1954
Protohaploxypinus amplus (Balme et Hennelly) Hart, 1964
Protohaploxypinus jacobii (Balme et Hennelly) Hart, 1964
Protohaploxypinus microcorpus (Schaarschmidt) Clarke, 1965
Protohaploxypinus minor (Klaus) Pittau, 1988
Protohaploxypinus perfectus (Naumova) Samoilovich, 1953
Protohaploxypinus samoilovitchii (Jansonius) Hart, 1964
Scheuringipollenites ovatus (Balme et Hennelly) Foster, 1975
Scutasporites sp.
Striatoabieites jansonii (Klaus) Hart, 1964
Striatoabieites multistriatus (Balme et Hennelly) Hart, 1964
Striatoabieites richteri (Klaus) Hart, 1964
Striatoabieites wilsonii (Klaus) Hart, 1964
Striatolebachiites spp.
Striatopodocarpites antiquus (Leschik) Potonié, 1958
Tympanicysta stoschiana Balme, 1979
Ventralvittatina sp.
Vitreisporites signatus Leschik, 1957
Vittatina costabilis Wilson, 1962
Vittatina sp.
Vittatina subsaccata Samoilovich ex Wilson, 1962
Weylandites sp.
Weylandites striatus (Luber) Utting, 1994

Acknowledgements – The Author thanks the anonimous revisors for the critical reading of the manuscript and the suggestions given to the discussion. This research has been financed by the Cagliari University research grant (60%) and the RAS Institution.

REFERENCES

BARTH S.& MOHR B.A.R., 1994. Palynostratigraphically determined age of the Tregiovo sedimentary complex in relation to radiometric emplacement ages of the Atesina volcanic complex (Permian, Southern Alps, N Italy). *N. Jb. Geol. Paläont. Abh.*, 192: 273-292.

BOROZDINA Z.I. & OLFERIEV A.G., 1970. About the principles of the division of Vjatskian horizon in the sections of SE part of Moscow syneclise. *Izvestia Ak. Nauk. SSSR*, ser. Geol., 1: 114-120. (In Russian).

BUROV B.V. & ESAULOVA N.K., 1996. On the problems of the study of the Upper Permian stratotypes. *Permophiles* (a Newsletter of SPS), 30-34.

CASSINIS G. & DOUBINGER J., 1991. On the geological time of the typical Collio and Tregiovo continental beds in the Southalpine Permian (Italy), and some additional observations. *Atti Ticin. Sci. Terra*, Pavia, 34: 1-20.

CASSINIS G., CORTESOGNO L., GAGGERO L., MASSARI F., NERI C., NICOSIA U. & PITTAU P. (coordinators), 1999. *Stratigraphy and facies of the Permian deposits between eastern Lombardy and the western Dolimites. Field Trip Guidebook.* Intern. Field Conf. on "The Continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations", Brescia. Dip. Sci. Terra, Univ. Pavia., 157 pp.

CASSINIS G., NICOSIA U., PITTAU P. & RONCHI A., (in press). Paleontological and radiometric data from the Permian deposits of the Southern Alps (Italy), and their stratigraphic implications. *Ass. Géol. du Permien*, Paris, Mém. 2.

CONTI M.A., FONTANA D., MARIOTTI N., MASSARI F., NERI C., NICOSIA U., PASINI M. & PITTAU P., 1986. The Blätterbach-Butterloch section (VGS and Bellerophon Formation). In: Italian IGCP 203 Group (ed.), *Permian and Permian-Triassic boundary in the South-Alpine segment of the western Tethys.* Tipolit. Comm. Pavese, Pavia: 91-110.

CONTI M.A., MARIOTTI N., NICOSIA U. & PITTAU P., 1997. Succession of selected bioevents in the continental Permian of the Southern Alps (Italy): improvements in intrabasinal and interregional correlations. In Dickins J.M., Yang Zunyi, Yin Hongfu, Lucas S.G. & Acharyya S.J. (eds), *Late Paleozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation*, Cambridge Univ. Press, Cambridge: 51-65.

ESAULOVA N.K., 1995. Correlation of the Upper Permian floristic complexes of the Volga-Urals region of Russia with Dalongkou section of China. *Permophiles* (a Newsletter of SPS), 27: 34-38.

FOSTER C.B., 1979. Permian plant microfossils of the Blair Athol coal measures, Baralaba coal measures and basal Rewan Formation of Queensland. *Geol. Surv. of Queensland*, publ.372, paleont. paper 45, Brisbane: 244 pp.

FOSTER C.B., 1982. Spore-pollen assemblages of the Bowen basin Queensland (Australia): their relationship to the Permian-Triassic boundary. *Rev. Paleobot. Palynol.*, 36: 165-183.

FOSTER C.B. & JONES P.J., 1994. Correlation between Australia and the type Tatarian, Russian platform, evidence from palynology and conchostraca: a discussion. *Permophiles* (a Newsletter of SPS), 24: 36-43.

GOMANKOV A.V. & MEYEN S.V., 1986. *The Tatarina flora (composition and distribution in the Late Tatarian of Eurasia).* Ed. Nauka, 194 pp. (In Russian).

GUSEV A.K., BUROV B.V., ESAULOVA N.K., BOGOV A.V.,IGONIN V.M., LUKIN V.A., SOLODUKHO M.G. & SILANTIEV V.P., 1993. Biostratigraphic characteristics of the Upper Permian deposits of the Volga and Kama regions. *Bulletin of the Regional Stratigraphic Com-*

mission on the Centre and South of the Russian Platform, Moscow, CSP, Rosgeolfonda: 75-80.

KLAUS W., 1963. Sporen aus dem südalpinen Perm. Jb. Geol. Bundesanst., 106: 229-363.

KOLODA N. & KANEV G., 1996. Analogue of the Ufimian, Kazanian and TatarianStages of Russia in north-western China based on miospores and bivalves. *Permophiles* (a newsletter of SPS), 28: 17-24.

KRASSILOV V., AFONIN S.& BALINOVA S., 1999. *Tympanicysta* and the Terminal Permian Events. *Permophiles* (a Newsletter of SPS), 35: 16-17.

KUNTZEL M.K., 1965. The palynological characteristic of Upper Permian and Lower Triassic deposits in the Vetluga River basin and Volga-Unza watershed in Kostroma district. *Sbornik statei po geol. I gidrogeol.*, Ed. Nedra, 4: 75-80. (In Russian).

LOZOVSKY V.R. & YAROSHENKO D.P., 1994. The Permian/Triassic boundary in the continental series of the Moscow syneclise: recent achievements. *Permophiles* (a Newsletter of SPS), 24: 54-59.

MASSARI F., CONTI M.A., FONTANA D., HELMOLD K., MARIOTTI N., NERI C., NICOSIA U., ORI G.G., PASINI M. & PITTAU P., 1988. The Val Gardena Sandstone and the *Bellerophon* Formation in the Blätterbach gorge (Alto Adige, Italy): biostratigraphy and sedimentology. *Mem. Sci. Geol.*, Padova, 60: 229-273.

MASSARI F., NERI C., PITTAU P., FONTANA D. & STEFANI C., 1994. Sedimentology, palynostratigraphy and sequence stratigraphy of a continental to shallow-marine rift-related succession: Upper Permian of the eastern Southern Alps. *Mem. Sci. Geol.*, Padova, 46: 119-243.

MOLIN V.A. & KOLODA N.A., 1972. *Upper Permian sporomorph associations of the northern part of Russian platform*. Ed. Nauka, 76 pp. (In Russian).

OLFERIEV A.G., 1974. About the correlation of the stratotype section of the Upper Tatarian. *Izvestia Ak. Nauk SSSR*, ser. Geol., 10: 123-132. (In Russian).

SAMOILOVICH S.R., 1953. Pollen and spores from the Permian of the Cis-Urals. *Oklahoma Geol. Surv.*, circular 56: 1-103. (Translation).

UTTING J., ESAULOVA N.K., SILANTIEV V.V. & MAKAROVA O.V., 1997. Late Permian palynomorph assemblages from Ufimian and Kazanian type sequences in Russia, and comparison with Roadian and Wordian assemblages from the Canadian Arctic. *Canad. J. Earth Sci.*, 34: 1-16.

VARJUCHINA L.M., 1971. *Spores and pollen from the redbeds and coal-bearing beds of Permian and Triassic in the north-east of European part of USSR*. Ed. Nauka, Leningrad: 158 pp. (In Russian).

ZIEGLER A.M., 1990. Phytogeographic patterns and continental configurations during the Permian Period. In McKerrow W.S.L. & Scotese C.R. (eds), *Paleozoic Paleogeography and Biogeography*, The Geol. Soc. Mem. No. 12, London: 363-379.