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# FURTHER NOTES ON TERRA ROSSA AND RELATED SOILS NEAR KFAR HAHORESH ARCHAEOLOGICAL SITE, ISRAEL

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## Introduction

In mountainous Mediterranean areas in Israel the two major soil types are recognised on hillslopes are the *terra rossa* (Rhodoxeralfs) on hard lime(dolo)stones and rendzina (or Rendolls) formed either on chalk or calcrete parent materials. In alluvial valleys (wadi) alluvial-colluvial soils and soils with vertic features form (Dan *et al.,* 1972).

Terra rossa and rendzina soils differ in respect to iron oxide mineralogy (Singer *et al.,* 1998) and micromorphologically (Wieder and Yaalon, 1974), albeit both influenced by far-distance transport of wind-blown fine sand (Yaalon and Ganor, 1973).

Presently, there is increasing awareness of polygenetic nature of terra rossas, associated with both climate change (Bronger and Bruhn-Lobin, 1997, Fedoroff, 1997) and prolonged human impact, assumed to take place in Eastern Mediterranean since the beginning of Neolithic farming, ca. 9-10 thousand years ago (Goldberg and Bar-Yosef, 1990; Yaalon 1997).

Evidence of changes in geomorphic processes and soil formation for example, possibly associated with land clearance by Early Neolithic humans, was obtained at the Kfar HaHoresh archaeological site, located in the Nahal Zvi valley in Lower Galilee, Israel (Goring-Morris *et al.,* 1995, Tsatskin *et al.,* 1999). However, thus far, the area tested was restricted to the archaeological site alone. Nor were advanced laboratory methods employed.

This paper presents the results of a new study of soil toposequences near the Kfar Horesh archaeological site. Via integration of soil micromorphology and soil magnetism (Thompson and Oldfield, 1986) we address the question of anthropogenic disturbances in terra rossa and related soils of Lower Galilee in Israel.

## Materials and Methods

Soil pits were dug in major landscape units within the Nahal Zvi catchment. Soil profiles were described by standard soil survey methods defining colour (using Munsell soil colour chart), texture, structure, porosity, secondary neo-formations, and presence of stones and artefacts. Petrographic thin sections were prepared after impregnation of samples by polyester resin under vacuum. Micromorphological descriptions of soil thin sections by a polarising light microscope Olympus BH-2 follow Bullock *et al.* (1985).

The samples were subjected to measurements of low-field magnetic susceptibility ($\chi_{lf}$) at 0.47 kHz and at 4.7 kHz measuring frequency by Bartington MS2 magnetic susceptibility meter. The difference between the measurements ($\chi_{fd}$) is commonly used as estimation of the grain sizes of magnetic minerals (Maher and Taylor, 1988).

Selected samples were analysed at the Institute of Physics of the Earth, Russian Academy of Science, in order to measure saturation magnetisation ($J_s$) at 0.45T magnetic field and temperature-dependent magnetization $J_s(t)$ in temperature interval $20^o$-$700^o$ C, as well as saturation remanence ($J_{rs}$) at 0.85T magnetic field and temperature-dependent remanence $J_{rs}(t)$ in temperature interval $20^o$-$700^o$ C, on vibrating magnetometer and thermomagnetometer (Geophysical observatory, Borok), respectively.

To identify Fe compounds, Mössbauer spectra were taken at room and liquid-nitrogen (ca. 80K) temperature by Mössbauer spectrometer with $^{57}$Co:Rh source in constant acceleration mode. The spectrometer was calibrated with a standard $\alpha$-Fe absorber in a velocity range ±8.5mm/s. The spectra were computed using a least-squares fitting program.

## Results

### Soils and landscape units

Nahal Zvi is an ephemeral stream (wadi) that originates in the Nazareth Hills, ca. 400 m. a.s.l., and enters the Israel Valley to the south. The study area (Figure 1) is located within the mountainous portion of the valley where the stream is influenced by easily eroded rocks of the catchment area.

The Nahal Zvi catchment is developed on tectonically faulted Senonian/Eocene chalk alternating with limestone and occasionally capped by petrocalcic horizon, or calcrete, locally termed *nari*. The complex lithology results in combination of rather steep erosion slopes with shallow soil cover and gentle step-like slopes with deep reddish soils.

The air photograph (Figure 1), taken in the 1940s, clearly demonstrates the sparse vegetation on hillslopes and pine plantations on both sides of the valley, as well as the existence of farming plots, primarily along the wadi floor and on alluvial fans of its tributaries. At present, the catchment area is afforested with pines, albeit remnants of Tabor Oak maquis (Figure 2) are still present.

Both the wadi floor with adjacent small-scale colluvial aprons and step-like gentle footslopes are still used as a pasture ground. Remains of several Byzantine structures within the study area, including water reservoir and building foundations, indicate the existence of agricultural farms producing grain, olives and grapes in antiquity (Safrai, 1994). In the headwaters of the wadi, the Early Neolithic settlement of Kfar HaHoresh is located on a north-facing slope (Figure 1) and ca. 1 km upstream we found the remains of agricultural terraces, related to traditional farming.

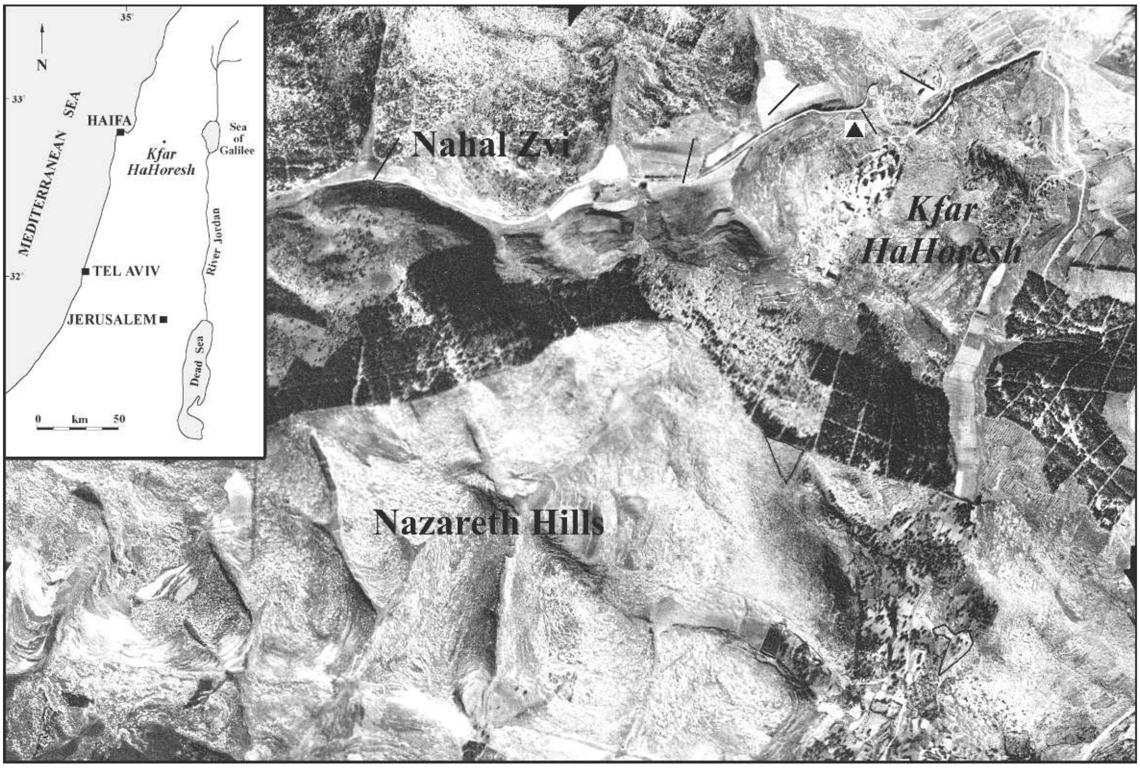


Figure 1. Location map of Nahal Zvi catchment in Nazareth Hills of Lower Galilee near Kfar HaHoresh archaeological site (marked with triangle).

Figure. 2. Photograph of Nahal Zvi. North-facing footslopes covered by natural Tabor Oak maquis (left of the photo), channel floor used as grazing ground.

In the Nahal Zvi catchment, three soil taxons related to terra rossas and dark rendzina (Table 1) are dominated by argillic horizon that varies in thickness, colour, and stoniness. Shallow terra rossa soils, in pockets between karren on karstic limestone, and dark rendzina on hard nari both have a darker hue than elsewhere and are not readily distinguished in the field, probably because of similar physical properties of their parent materials (Wieder *et al.,* 1994).

Terra rossa with thick argillic horizon and slickensides covers gently sloping surface in the vicinity of the Early Neolithic site (Figure 1). Singer *et al* (1998) found that terra rossa and rendzina soils of Lower Galilee are smectite rich and both have similar hematite/goethite ratio, which may account for the absence of colour differences. However, pale rendzina on chalky eroded slopes is conspicuously different, which is manifested by strong calcareousness and stoniness, and occasional pottery sherds.

The signs of early farming, as suggested by the presence of Byzantine artefacts (Table 1), are ubiquitous on gentle slopes around the Neolithic and Byzantine sites, and within the remains of agricultural terraces in the headwaters of the Nahal Zvi. In these soils, tentatively termed anthropic, abundant carbonate pseudomicelium and high stoniness in the subsoil are characteristic. In the upper Nahal Zvi, soils in the wadi floor that is no more than 20 m wide show strongly compacted brown-gray, calcareous clay, with scatted stones and ceramic sherds, developed on a soil/sedimentary sequence in which reddish gravely lenses at 1.1 m depth and dark-brown clay overlie grayish hydromorphic clay at ca. 4.0 m depth.

Table 1. Major soils types in the Nahal Zvi catchment

| **Conditions** | **Soils** | **Diagnostic Horizon** | **Munsell colour** | **Stoniness** | **Structure** | **$CaCO_3$ Neofor-mations** | **Artefacts** |
|---|---|---|---|---|---|---|---|
| Gentle slopes | Terra rossa | Thick argillic B horizon | 10YR 3/2 grading to 5YR 3/2 | Less than 5-10% | Prismatic, abundant slickensides | None | None |
| Steep slopes/ divides | Terra rossa | Shallow argillic B horizon | 5YR 3/2 | 20-30% | Prismatic, subtle slickensides | Few nodules | Few potsherds |
| Hard calcrete | Dark rendzina | Shallow argillic B horizon | 7.5YR 3/2 to 10YR 3/2 | Ca. 30% | Subtle prismatic | Nodules | Few potsherds |
| Soft chalk/ Erosion slopes | Pale rendzina | Shallow Mollic horizon | 2.5Y 4/2 | 30-50% | Crumbly | Massive | None |
| Footslopes | Alluvial-colluvial | Undiffe-rentiated | 2.5Y 4/2 | More than 50% | Massive | Massive | Byzantine potsherds |
| Channel floor | Alluvial-colluvial | Complex Stratig-rafy | 2.5Y 4/2 to 5YR 3/2 | More than 50% | Massive compacted | Massive | Byzantine potsherds |
| Colluvium | Anthropic | Agric (?) | 10YR 4/4 | More than 50% | Massive with crumbles | Pseudom ycelia | Potsherds |
| Old agricultural terraces | Anthropic | Agric | 10YR 5/2 | More than 50% | Crumbly | Pseudom ycelia | Byzantine potsherds |

## Soil micromorphology

Soils of the Nahal Zvi catchment show different suites of micromorphological features (Table 2), which allow us to identify the key soil-forming processes and their possible anthropogenic modifications.

Table 2. Micromorphological characteristics of soils in the Nahal Zvi catchment.

| | Stress cutans | Coatings | Needle-like Calcite | Micritic Calcite | Calcitic hypocoatings | Microstructures | Clasts |
|---|---|---|---|---|---|---|---|
| Terra rossa | ++ | + | - | + | + | Blocky | - |
| Anthropic on colluvium | - | ++ | ++ | + | - | Spongy with moderate pedality | +++ |
| Anthropic of agricultural terraces | - | ++ | +++ | + | - | Spongy with fluffy and perfect pedality; breakup of aggregates | ++ |
| Colluvial/ alluvial | - | - | - | - | + | Massive with zones of vughs and channels | +++ |

Codes used: - absent; + rare; ++ common; +++ abundant.

*Textural concentration features*. Terra rossa soils with deep argillic horizons show strial b-fabric (Fig. 3a; Table 2), similar to smectite-rich vertisols, where it originates from shrinlking/swelling of clays in wet-dry cycles (Nettleton *et al.,* 1969). Alongside redoximorphic features, such as ferric and manganese segregations, and carbonate leaching, stress cutans indicate intermittent waterlogged conditions. This supports soil identification as vertic terra rossa.

However, alternative interpretation of these cutans resulting from the aging and disintegration of clay illuviation features, seems plausible. As recently shown by Fedoroff (1997), clay coatings, as indication of illuviation, are not preserved in terra rossa because of churning and swell-shrink process. We found degraded clay coatings, stained by organic matter or ferric compounds, in the dissolution channels of rock clasts (Fig. 3b).

Clay coatings peak in anthropic soils, post-dating the Neolithic occupation horizon, and in soils of old agricultural terraces (Table 2). It is tentatively suggested that they formed due to turbulent vertical flow of clay-rich solutes through the soil when its surface was plowed, as in both modern and ancient agricultural soils (Macphail *et al.,* 1990).

*Calcitic features*. We found needle-like calcite in vughs and interconnecting channels (Fig. 3c) in both types of anthropic soils (Table 2). Needles of calcite are documented in soils from various environments and are assumed to originate either from pseudomorphic replacement of root mats or from microbial induced precipitation (Monger *et al.,* 1991).

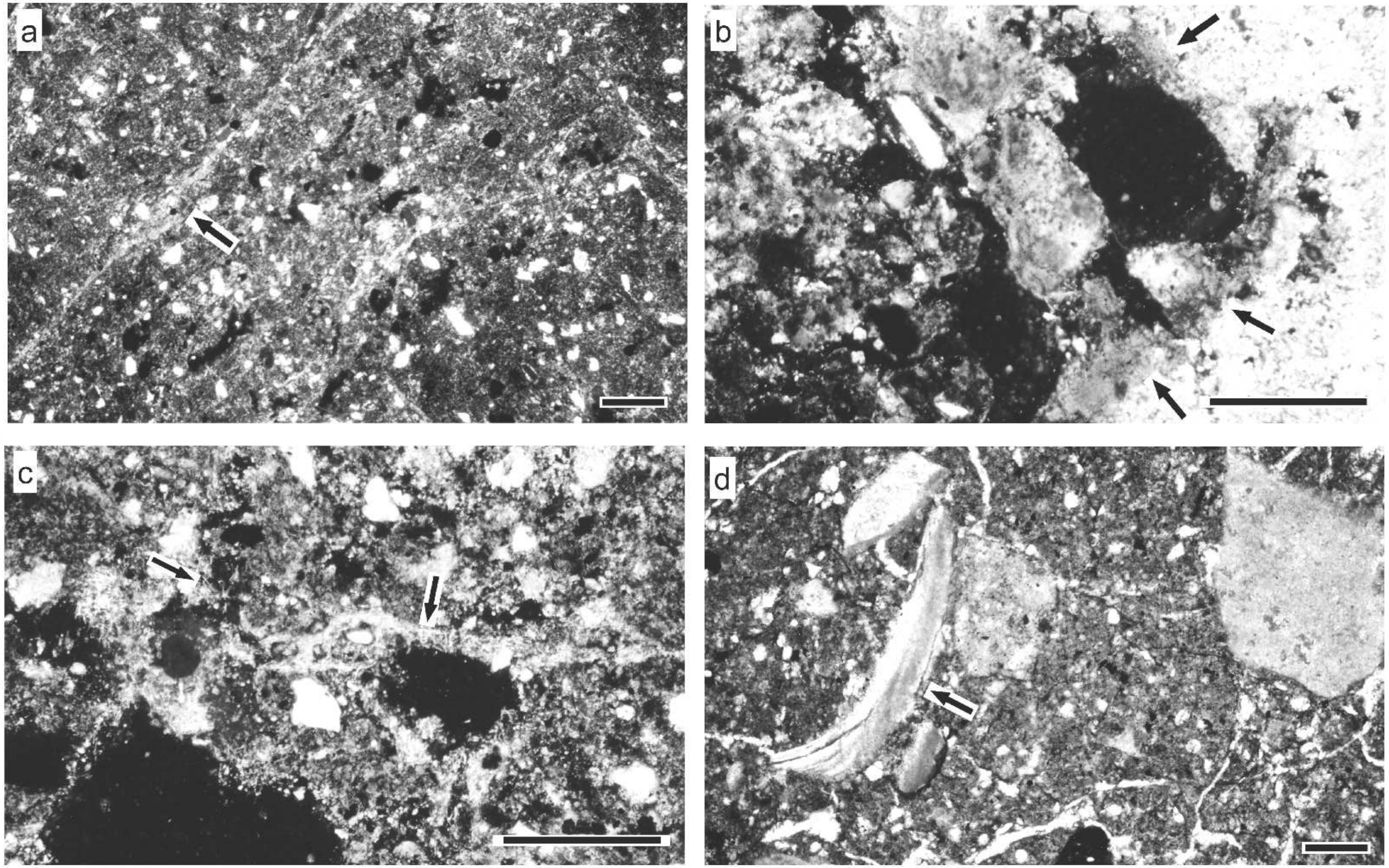


Figure 3. Photomicrograph of micromorphological features from soils in the Nahal Zvi catchment; plane polarised light (PPL); cross-polarised light (XPL); scale bar=200µm. (a) Stress cutan (arrow) in a strial b-fabric in vertic terra rossa, predating ca. 9ka occupation level (XPL); (b) Remnants of degraded dusty clay coatings (arrows) around vesicles of rock clast (XPL); (c) Needle-like calcite (arrows) on walls of pores in porous anthropic soil (XPL); (d) Land snail shell (arrows) and various rock clasts in dense groundmass of anthropic soil (PPL).

Wieder and Yaalon (1974) suggest that acicular forms of carbonate in Israeli soils are the first stage of their development, and eventually re-crystallise. In mature terra rossa soils in the Nahal Zvi area, indeed, only micritic calcite, sometimes iron/clay-stained (Wieder and Yaalon, 1982), is found. Depletion hypocoatings, due to local moisture re-distribution, are occasionally preserved in hillslope soils and, albeit in incipient form, in alluvial settings as well.

Biologically derived calcite is represented also by sparite infillings, *i.e*. equant, ca. 100 μm thick, crystals along channels, probably originating from decayed roots in anthropic soils. The final stage of their evolution is calcitic infillings in channels, compacted to such a degree that, if removed by erosion, they act as rock clasts and are still recognisable in the soil matrix of alluvial/colluvial soils in the wadi channel.

*Microstructure*. In the study area, biotic effects on soil microstructures are much more common than swell-shrink restructuring leading to blocky peds (Table 2). The increase in pedality in anthropic soils is remarkable alongside breakup of aggregates and increase in porosity. Loose fabric of anthropic soils is due to intersecting set of agro- and pedotubules and abundance of fecal pellets of soil biota.

Faunal activity is also indicated by the existence of land snail shells (Fig. 3d). However, biotic microstructures in anthropic soils are not confined to a single horizon but, instead, alternate with colluvially reworked layers. It implies that anthropic soil formation in the study area included several stages of man-induced pedogenic reworking punctuated with natural soils colluviation.

Interestingly, soil fauna reworking occurs also in alluvial soils despite their high compactness and abundant rock clasts. In deeper horizons of alluvial sequences, ca. at 1.1 m depth, faunal effects wane while mélange of original terra rossa from catastrophic slopewash dominate.

*Rock clasts*. In colluvial and alluvial settings, the presence of rounded limestone clasts 0.3-0.5 mm is micromorphological manifestation of colluviation (Fig. 3d), which is absent in deep argillic horizons in terra rossa (Table 2). In anthropic soils, chips of flint, basalt, and bones are present in big amounts, along with wood charcoal, aggregates of manure, and man-made clay materials.

Carbonate rock clasts, primarily of chalk, show dissolution cavities in hillslope soils. In alluvial settings, abundance and type of rock clasts change within the soil/sedimentary sequence. For example, in the uppermost horizon only rounded chalk fragments ranging from 100 μm to 3-5 mm occur, while at 1.1m depth, mélange of terra rossa aggregates are mixed with various rock clasts.

Summarising, micromorphology allows us to support the taxonomic nomenclature of major soils in the area: vertic (hydromorphic) terra rossa on gentle slopes; anthropic colluvial soils, post-dating the Neolithic occupation level; alluvial/ colluvial soil sequence, resulting from intermittent superimposition of soil-forming processes on various colluvial materials, transported from adjacent slopes.

## Soil magnetism

The terra rossa demonstrates 250-280 x $10^{-8}$ $m^3$ $kg^{-1}$ low-frequency magnetic susceptibility ($\chi_{lf}$), which is about 7 times higher than in pale rendzina (Table 3). The high $\chi_{fd}$ value (9.7%) may indicate the pedogenic enhancement of soil by fine-grained magnetic signature carrier (Maher and Taylor, 1988). Magnetic parameters of anthropic colluvial soil on a gentle slope, albeit fluctuating, are quite similar to vertic terra rossa, which indicates that the former formed from terra rossa derived colluvium.

Although affected by waterlogging, as deduced from micromorphology, vertic terra rossa remains strongly magnetic, in contrast to mid-latitude soils (Tompson and Oldfield 1986). Lower $\chi_{lf}$ and $\chi_{fd}$ values in anthropic soils on old terraces are likely to be explained by mixing of both rendzina and terra rossa materials.

Table 3. Magnetic properties of of soils in the Nahal Zvi catchment.

| | **Vertic terra rossa** | **Pale Rendzina** | **An-thropic Colluvial** | **Alluvial/colluvial Soil Sequence** | | | **Anthropic on old terraces** |
|---|---|---|---|---|---|---|---|
| | | | | **0.2 m** | **1.1 m** | **4.0 m** | |
| $\chi_{lf}$, $10^{-8}m^3kg^{-1}$ | 250-280 | 30-40 | 250-300 | 140 | 200 | 70 | 160-80 |
| $\chi_{fd}$, % | 9.7 | 6-9 | 9.7 | 8.6 | 9.9 | 8 | 8-10 |
| $J_s$, $10^{-1}$ $Am^2$ $kg^{-1}$ | 18.3 | No data | 23.1-43.6 | 12.2 | No data | 2.8 | No data |
| $J_{rs}$, $10^{-2}$ $Am^2$ $kg^{-1}$ | 2.3 | --“-- | 2.2-2.3 | 1.2 | --“-- | 0.5 | --“-- |
| $S_{total}$, arbitrary units | 7.5 | --“-- | No data | 1.96 | --“-- | 4.27 | --“-- |
| M3/ΣMs | 1.14 | --“-- | --“-- | 0.1 | --“-- | 0.23 | --“-- |
| M2/ ΣMs | 0.12 | --“-- | --“-- | 0.07 | --“-- | 0.11 | --“-- |

Codes: $S_{total}$ = total area of Mössbauer spectra; M2 and M3 = doublets related to Fe in smectite lattice and superparamagnetic Fe oxyhydroxides, respectively; ΣMs=sum of structural doublets

In the alluvial/colluvial sequence (Table 3), depth functions of magnetic properties show enhanced $\chi_{lf}$ and $\chi_{fd}$ values at 1.1 m depth, in agreement with micromorphological identification of terra-rossa colluvium mélange here. In contrast, samples at 0.2 m depth and at 4.0 m depth show a drop of $\chi_{lf}$, $\chi_{fd}$, $J_s$ and $J_{rs}$ values, all indicating significantly lower concentration and probably smaller grain sizes of magnetic signal carrier. The similarity of $J_{rs}$(t) curves (Figure 4) and close value of blocking temperature (about 600°C) indicate that in both soils on hillslope and in wadi floor, the main magnetic signal mineral is single- or multidomain magnetite.

Mössbauer spectra clarified more about the iron oxide mineralogy in the soils. In vertic terra rossa the spectrum at room temperature shows doublets due to $Fe^{3+}$-smectite and superparamagnetic (SP) Fe hydroxides. At 80 K the spectrum, instead, shows broadened sextet of magnetically ordered Fe minerals with mean $B_{hf}$ of about 51.6T, which is interpreted as related to magnetite/hematite grains of 7-12 nm in size. In alluvial/colluvial sequence magnetic ordering is not revealed even at low temperatures, which indicates ultrafine grain sizes (less than 5 nm) of SP hematite and/or Fe oxyhydroxides.

It is important that all Fe is in the oxidised $Fe^{3+}$ form, despite the evidence of waterlogging conditions in both soils. Compared to terra rossa, surface horizon of alluvial soil at 0.2 m depth shows decrease in total iron content seen by drop in $S_{total}$ value, in amount of SP Fe oxyhydroxides, estimated by M3/ΣMs ratio, and in amount of Fe in the lattice of smectite, evaluated by M2/ΣMs ratio (Table 3). However, at 4.0 m depth the above parameters increase (Table 3), suggesting stronger ferruginization in the lowermost more hydromorphic (!) horizon.

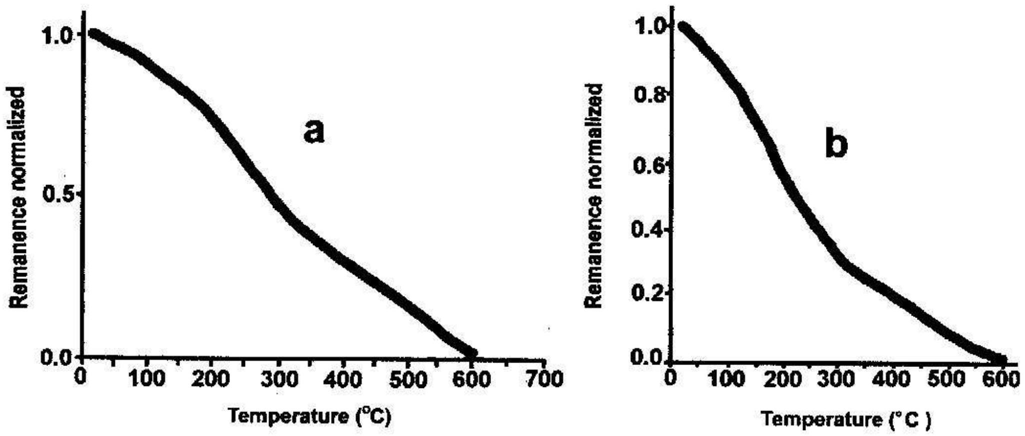


Figure 4. Temperature-dependent saturation remanence curves for terra rossa (a) and for upper horizon of alluvial sequence (b). Note similar shapes and different values for two soil types, indicating that magnetite is the main magnetic signal carrier.

## Discussions

In the Nahal Zvi catchment there is a strong component of soils disturbed by colluviation and early agriculture, which makes field identification of natural soils on the basis of existing taxonomies somewhat dubious. Our survey shows that distinction between shallow terra rossa and dark rendzina soils on relatively steep hillslopes is subtle.

Because in the study area, terra rossas with thick argillic horizons predate the Neolithic occupation of ca.9 thousands years ago, we infer that their formation has already completed by Early Holocene. Hence ubiquitous shallowness of their profiles in the catchment area may result from prolonged erosion, apparently due to first land clearance and then farming and herding, presumably since Late Neolithic and well through Roman-Byzantine time and on.

As a result, the headwaters of the wadi were filled with colluvium from the slopes and complex soil/colluvium sequences formed, in which the upper 1.5m contain abundant Byzantine ceramic sherds, like elsewhere (Vita-Finzi, 1969, van Andel *et al.,* 1990). At present, we are still unable to devide the major erosive episodes alternating with periods of stability and soil formation in the wadi. This is partly because of the absence of typical paleosols with A, B, C horizons in the sequence, and partly because of overwhelming calcification of the profile. However, magnetic stratigraphy and micromorphology seems to provide a means for unraveling the Holocene history of sediment supply dynamic.

Anthropic soils developed on terra rossa-derived colluvium contain features of early agricultural activities, which are similar to the soils of abandoned agricultural terraces. Micromorphologically anthropic soils are characterised primarily by structural changes, i.e. aggregate breakup, increase in porosity, formation of perfectly rounded, occasionally fluffy, peds, which may potentially increase soil erodibility.

Early and traditional cultivation also leads to microbial needle-like calcite accretion, large sparite accumulation in decayed root channels, and increase in illuviation of clayey slurries through vughs and channels. Intensification of these processes is not necessarily detrimental for soil fertility, although surplus of active carbonates may be a problem. The upper part of alluvial/colluvial soil shows enhanced calcification due to seasonal waterlogging, which seems to enhance crusting and soils compaction.

Terra rossa in the study area are magnetically enhanced both from detrital and finer=grained presumably pedogenic magnetite, as seen by high $\chi_{lf}$, $\chi_{fd}$, $J_s$ and $J_{rs}$ values. Magnetically depleted are pale rendzinas and soils in alluvial settings, formed on rendzina colluvial material. Although magnetic parameters vary in alluvial sequence primarily because of changes in source materials, eroded from slopes into the wadi, the role of pedogenic transformations under reduced conditions, e.g. eventual magnetite destruction (Thompson and Oldfield, 1986), has to be also taken into account. However, Eh probably never dropped too strong, since only $Fe^{3+}$ is present in clays, and in dominating SP hematite and Fe hydroxides here.

## Conclusions

1) Anthropic features in terra rossa and related soils are widely spread in the Nahal Zvi catchment of Lower Galilee. The earliest disturbances in soils seem to be related to the Early Neolithic and peak at Roman-Byzantine times. In this way, terra rossas of the area are to be considered relict surface soils, whose formation was completed at least by the Early Holocene.

2) Agricultural activities in the past caused restructuring and porosity changes in upper soil horizons, strongly intensified calcification, clay illuviation, and probably magnetic susceptibility depletion. Erosion from hillslopes during Holocene resulted in the accumulation of slopewash in the wadi floor, where upper 1.5-2 m of the alluvial/colluvial sequences are comprised of post-Byzantine calcareous colluvium.

3) Terra rossa soils, in contrast to pale rendzinas, are strongly magnetically enhanced both from detrital and fine-grained pedogenic magnetite, which accumulates here along with hematite/goethite and Fe oxyhydroxides. In alluvial/colluvial sequences rock magnetic properties variations reflect both the origin of source material and pedogenic destruction of magnetite under reduced conditions.

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